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Is Energy Efficiency Capitalized into Home Prices?

Evidence from Three US Cities

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Xian Bak

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Abstract

We test for evidence that energy efficiency features are capitalized in home prices in three US metropolitan areas. Using a careful matching procedure and hedonic regressions, we find that Energy Star certification is associated with higher sales prices in two of the markets: the Research Triangle region of North Carolina and Portland, Oregon. We find that local “green” certifications in Portland and in Austin, Texas, are also associated with higher prices and the estimated impacts are larger than Energy Star. Matching on observables proves to be important—estimated impacts are reduced by roughly half compared with models without matching. We calculate the implied energy savings from the estimated premiums and find that, in the Triangle and Portland markets, the Energy Star premiums roughly match the savings that program is designed to achieve. In contrast, the local certifications appear to capitalize more than just energy savings.

Key Words: energy efficiency, Energy Star, green certifications, housing markets, propensity score matching, hedonic model

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Introduction

One oft-cited explanation for underinvestment in residential energy efficiency is that homeowners do not expect to occupy their homes long enough to realize energy savings benefits that offset up-front investment costs. If energy efficiency features of a home are capitalized in the selling price, then homeowners could recoup their costs when they sell their homes, but asymmetric information is likely to be a barrier (Bardhan et al. 2014). Home buyers may be unable to accurately observe a home's energy efficiency because features such as wall and attic insulation, air ducts, and even heating and cooling equipment efficiencies are difficult to see or fully understand. Moreover, sellers may not be able to credibly signal that they are selling an energy-efficient home.

The federal government's Energy Star program was designed, in part, to overcome some of these information problems. Homes certified under the program are designed and built to be 15 percent more efficient than homes that meet most current building codes. In earlier days of the program, certified homes were to be 30 percent more efficient. To obtain the Energy Star label, a home must go through a process of inspections, testing, and verification set up by the US Environmental Protection Agency (EPA). The number of Energy Star certified homes has grown over the years; the EPA estimates that 26 percent of all housing starts in 2011 were Energy Star certified (US EPA 2012a). In addition to Energy Star, the US Green Building Council administers the Leadership in Energy & Environmental Design (LEED) certification program and many localities have their own certification schemes.¹

In this study, we analyze the effect of Energy Star and two local "green" certifications on sales prices of homes in three urban areas: Austin, Texas; Portland, Oregon; and the Research Triangle area (Durham-Raleigh-Chapel Hill) of North Carolina. These localities are chosen because realtors participating in the multiple listing services (MLS) in these regions have agreed to report a set of green characteristics on home listing sheets. These data include information on green and energy efficiency certifications that could reduce the extent of imperfect information

¹ LEED stands for Leadership in Energy and Environmental Design. See <http://www.usgbc.org/leed> for more information on the program.

in the market for residential real estate.² We examine over 170,000 sales transactions for single-family homes over the 2005–2011 time period. We employ a combination of spatial matching, propensity score matching, and regression analysis to mitigate potential bias in our estimates of the relationship between certification and house prices in each of the three cities.

Our results show that Energy Star certification is associated with an increase in the sales prices of single-family homes in the Research Triangle and Portland markets of approximately 2 percent, but we find no statistically significant effect in Austin. The local certifications in Austin and Portland appear to have larger effects on sales prices than Energy Star. In Austin, locally certified homes sell for 7 to 8 percent more than noncertified homes, after matching and conditioning on a set of house characteristics. In Portland, locally certified homes sell for approximately 3 percent more. These local certifications go beyond energy efficiency to encompass other environmental attributes such as water efficiency, landscaping choices, and building materials, which could account for some of the price premium. Individuals at the certification agencies and builders in the two cities with local certifications believe that the certifications are a symbol of overall quality in materials and construction, which could also explain the difference. These anecdotes highlight the relatively coarse information signal provided by certifications, particularly green certification schemes that cover environmental attributes beyond energy.

To put the findings in perspective, we compute implied annual energy cost savings from our estimated sales price premiums from the regressions under the restrictive assumption that price differences reflect only expected energy savings. Although the capitalization effect of about 2 percent for Energy Star homes in Portland and Triangle is modest, the implied savings are 21 to 23 percent of the estimated average annual energy costs of a home in Portland, depending on year, and 16 to 19 percent in the Research Triangle housing market.³ These implied savings are similar in magnitude to the Energy Star requirement that homes be 15 to 30 percent more energy efficient than noncertified homes (depending on the year of construction). Thus housing markets in these two cities seem to be appropriately capitalizing energy savings

² A “greening the MLS” movement by some energy efficiency advocates is pushing to have green certifications and a host of energy-related and other green features of homes included on sales listing sheets. See <http://www.usgbc.org/advocacy/campaigns/greening-mls> for more information (accessed August 7, 2015). Although the listing sheets can include more information than just certifications, such as the efficiency levels of heating and cooling equipment, we found that other information was generally absent in the three MLS programs we analyzed.

³ These figures assume a 5 percent annual discount rate over 30 years. We also compute the annual estimates for alternative discount rates and time periods.

from Energy Star certification. These results suggest that Energy Star labels for homes may be helping to close the energy efficiency gap.

The implied energy savings are significantly higher for the local certification programs in Austin and Portland, however, exceeding 30 percent of energy costs for an average home in Portland and 60 percent in Austin. These results suggest that homeowners are either overpaying for energy efficiency in these locally certified homes or that they greatly value the non-energy environmental attributes of the homes.

Most recent studies of Energy Star and other certifications have focused on commercial buildings. Eichholtz et al. (2010), using data on US office buildings from the 2004–2007 time period, find that buildings with LEED or Energy Star certification have contract rents that are 3 percent higher than noncertified buildings and effective rents (contract rent multiplied by occupancy) that are 6 percent higher; sales prices are 16 percent higher for certified properties. Subsequent analysis using additional data confirmed these findings (Eichholtz et al. 2013). Related research on commercial buildings in Europe has reached similar conclusions (Kok and Jennen 2012; Fuerst et al. 2012).

Early studies of energy efficiency in residential buildings found a positive correlation between home sales prices and various measures of energy efficiency (Dinan and Miranowski 1986; Laquatra 1986; Johnson and Kaserman 1983). However, these early studies were limited by small sample sizes. In recent work, Brounen and Kok (2011) find houses in the Netherlands with “green” labels under the EU Energy Performance Certificates transact at a premium of roughly 3.5 percent relative to comparable houses with lower efficiency ratings. Hyland et al. (2013) analyze a rating scheme in Ireland in which homes are given a score on a 15-point scale based on the measured efficiency of the heating and water heating equipment, insulation, and lighting. They find that each 1-point decline on the scale reduces sale prices by 1.3 percent and rents by 0.5 percent. Deng and Wu (2014) study the Green Mark certification scheme in Singapore. They estimate a 4.1 percent sales price premium for apartments in Green Mark-rated apartment complexes that are sold by developers in so-called “presales” and a nearly 10 percent premium for resale of those same properties.⁴ Kahn and Kok (2014) conduct a statewide analysis of California, where homes with a green certification are associated with a 2–5 percent average sales price premium based on real estate transactions between 2005 and 2012. The authors group

⁴ The authors argue that the presale results suggest developers are unable to cover costs associated with certification. They attribute the differential effects in the two markets to information failures, which are attenuated over time with energy use experience in the property.

three certification schemes – Energy Star, LEED and California’s own Green Point Rating -- together into a single certification dummy variable. In a robustness check in which the three schemes are considered separately, only Energy Star has a statistically significant effect on house price.

Our study makes four main contributions to this literature. First, we assess the impacts of certifications in three independent residential real estate markets in the US, which allows a comparison across markets that are very different in climate, home characteristics and prices, and, arguably, household preferences.⁵ Moreover, use of MLS data from markets where the certifications are explicitly incorporated on house sales listing sheets provides more assurance that prospective homebuyers know whether homes are certified.⁶ Second, separately identifying the impacts of local green certifications from the national Energy Star program provides an interesting comparison of local versus national programs and of energy-focused certification versus a broader “green” standard. Previous US studies have tended to focus only on Energy Star or grouped certifications together or have not detected effects from alternative certifications (e.g., Kahn and Kok (2014)). Third, we employ several matching procedures to minimize the bias from unobserved house characteristics that confounds causal identification (i.e., the fact that “treated” (certified) houses are likely to differ from “control” (noncertified) houses in ways other than certification status). Finally, we use the estimated capitalization effect of certification to calculate an implied annual energy savings and compare it with an estimate of actual energy expenditures for the homes in our sample. This exercise allows us to investigate whether housing consumers are valuing certifications consistently with the energy savings those schemes are intended to bring about and provides context for our results.

Our work also contributes to the broader literature on energy and green certification schemes, as well as studies that have looked at the role of information provision in closing the energy efficiency gap. Houde (2014) finds that consumers are heterogeneous in their understanding of the Energy Star label on refrigerators—some consumers appear to overvalue the energy savings from certification while others undervalue. Datta and Gulati (2014) find that utility rebate programs increase the market share of some types of Energy Star-certified appliances but not others. Jacobsen (2015) finds no statistical relation between electricity prices

⁵ It has long been recognized that hedonic models need to be estimated on data from a single housing market and not aggregated across multiple markets (Straszheim 1974), which calls into question studies that analyze a single model on statewide data or other similarly aggregated data. The findings for our three cities do not necessarily have external validity to other real estate markets but are suggestive for similar cities. The issue of external validity is a common one in hedonic studies.

⁶ In other studies, independent information on which homes are certified is merged with sales data.

and the market share of Energy Star appliances, which calls into question, in the author's view, whether consumers actually value the energy savings embodied in the certification. Rapson (2014), on the other hand, in a dynamic model of the timing of new, more efficient air conditioner purchases finds support for a rational expectations model over myopia or naïve expectations, suggesting consumers do understand and value energy savings. Newell and Siikamaki (2014) reach a similar conclusion about the Energy Guide label, which provides energy cost information for all appliances, not just those that are Energy Star certified. The findings in these two studies seem consistent with our finding for Energy Star homes—the price premiums we measure in two of the housing markets we analyze are roughly in line with the savings Energy Star is supposed to achieve.

The next section of the paper provides a brief description of the Energy Star program and the two local certification programs in Austin and Portland. We describe our data in Section III, including some summary statistics for house sales in the three cities, followed in Section IV by description of our empirical methodology, including the matching procedures. Section V presents results from the hedonic model and finally in Section VI, we present our calculations of implied energy savings and a discussion of those findings. The final section of the paper provides some concluding remarks.

Housing Certification Schemes

Energy Star

The Energy Star certification program for new homes has been in existence since 1995 and has evolved over time as state and local building codes, appliance standards, and building practices have evolved.⁷ Version 1 of the program, in existence from 1995 through part of 2006, specified that new homes had to be 30 percent more efficient than a home built to the 1992 Model Energy Code, but no inspection checklists existed for this first version. Version 2.0 strengthened the guidelines and incorporated a variety of inspections, added specific efficiency requirements for heating, ventilation, and air conditioning (HVAC) systems, and promoted efficient lighting and appliances. Homes certified under version 2.0 are at least 15 percent more efficient than homes built to the 2004 International Residential Code. Version 3.0 was phased in

⁷ It is possible for an existing home to be certified as an Energy Star Home, but it is generally not cost effective to do so. See <http://energystar.supportportal.com/link/portal/23002/23018/Article/14677/Can-I-upgrade-my-existing-home-to-become-ENERGY-STAR-certified> (accessed August 7, 2015). Thus the certification almost always applies to new homes.

starting in April 2011 and is the most recent version of Energy Star applicable in most parts of the country.⁸ It requires home to be at least 15 percent more efficient than the 2009 International Energy Conservation Code in order to be certified.

There are two paths to Energy Star certification: a “performance path” and a “prescriptive path” (US EPA 2012b). The performance path is based on results from a computer model, which provides an Energy Star score. The second involves a long checklist of specific requirements. Energy Star certification is completely voluntary, but utilities and state and local governments offer incentives in some regions of the country.

Local Green Certifications

A handful of local, regional, and statewide certifications for homes exist across the country. Some examples include the Salt River Project’s SRP Power Wise Homes program in Phoenix and the surrounding area, which focuses on energy efficiency, and broader “green” certification schemes such as the Vermont Builds Greener program, Florida’s FGBC Green Home Standard, and the GreenPoint rating program in California.⁹ In this study, we focus on two local certifications: Earth Advantage in greater Portland, Oregon and the Austin Energy Green Building Program (AEGB) in Austin, Texas.

Earth Advantage

The Earth Advantage New Homes certification is a green certification scheme in Oregon and parts of Washington operated by Earth Advantage Institute, a nonprofit organization that promotes building energy efficiency.¹⁰ The Earth Advantage New Homes standard requires homes to achieve a minimum number of points on a scoring sheet covering five categories—energy efficiency, indoor air quality, resource efficiency, environmental responsibility and water conservation. Depending on the number of points earned, the projects may qualify for different

⁸ EPA has developed a version 3.1 Energy Star certification that applies to new homes constructed in states that have adopted stricter building codes based on 2012 International Energy Conservation Code. Texas is among these states but the new requirements will not take effect for new homes constructed in Texas until October 1, 2017. See http://www.energystar.gov/index.cfm?c=bldrs_lenders_raters.nh_v3_1 (accessed August 2, 2015).

⁹ Information on these programs can be found at <http://www.srpnet.com/energy/powerwise/business/homebuilders.aspx>, <http://www.bsr-vt.org/VermontBuildsGreenerProgram>, <http://www.floridagreenbuilding.org/homes>, and <https://www.builditgreen.org/greenpoint-rated>.

¹⁰ The program began in 2000 and was originally operated by the local utility, Oregon General Electric. Earth Advantage Institute was spun off into a separate entity in 2005 and runs the certification program, along with other programs and initiatives.

levels of certification: Silver, Gold, or Platinum. Verification that the requirements have been met is conducted over the course of two inspection visits. The program was established in 2000 and its requirements in the program were tightened in 2008.¹¹

Earth Advantage certified homes must be 15 percent more energy efficient than homes built to code. This means that all homes that are Energy Star certified automatically meet the energy efficiency requirement for Earth Advantage. This does not mean, however, that all Earth Advantage certified homes are Energy Star certified. Some builders choose not to incur the additional costs required for Energy Star certification (Brown 2012).

Austin Energy Green Building Program

The AEGB program was started by the city of Austin in 1991 and thus predates Energy Star. In 1998, the program became part of Austin Energy, the municipal utility that operates in Austin. The program has changed over the years and the efficiency requirements have tightened; in 2010, AEGB required builders to demonstrate energy savings above code by submitting a Texas Climate Vision score for each home (AEGB 2011).¹² The single-family home rating system for AEGB has five levels indicated by stars; one star is the entry level and five stars is the highest, or “greenest,” level.¹³ Like the Earth Advantage program, AEGB focuses not just on energy efficiency but also material use, water efficiency, and other factors. Points are assigned for several green characteristics, including various site selection criteria, home design features, material efficiency (which includes house size), construction waste management, a variety of factors related to the thermal envelope, energy efficiency of equipment and appliances, water efficiency, lighting and other electrical efficiency factors, interior materials and paint, and landscaping.

Data and Summary Statistics

We employ real estate data from multiple listing services in the Research Triangle (Raleigh-Durham-Chapel Hill) region of North Carolina, Austin, Texas and Portland, Oregon. An MLS provides a centralized location for real estate agents to advertise and select homes for their clients, and MLS data represent the primary information sources for market participants

¹¹ Earth Advantage requirements were further tightened in 2012, which is after the end of our data period.

¹² The score is obtained using a software program developed by Texas A&M researchers (AEGB 2011).

¹³ Because the one and two star ratings require no percentage of energy efficiency above code, we do not assume those homes are “certified” in our econometric analysis; almost all of the AEGB rated homes in our sample have three or more stars.

(i.e., real estate brokers and potential homebuyers), including highly detailed house characteristics useful for hedonic analysis. In our three cities, the MLSs have also agreed to include information on green and energy certifications. In the case of Portland and Austin, this includes the local schemes.

We have home sales over the 2005–2011 time period in Portland, 2008–2011 in Austin, and the last quarter of 2009 through 2011 in the Research Triangle market. Although this provides useful temporal variation that we exploit in our analysis, we treat the data as repeated cross-sections because there are very few instances of multiple transactions for a single property. We use only data on single-family detached homes to focus on a more consistent set of house types and because these form the majority of certified residential properties. In each of the markets, certified home sales are a small percentage of total home sales. The largest percentage is in the Research Triangle market, where nearly 8 percent of the sample is Energy Star certified. Certified homes are approximately 1 percent of home sales in the Portland and Austin housing markets over this time period. Figure 1 shows the distribution of certified home sales as a percentage of all home sales by zip code in each market. Certified homes are geographically dispersed in each city, but certification is more common in some zip codes than others.

To address likely data entry errors, we eliminated observations from our data set with unrealistic or missing values for particular house characteristics employed in our analysis.¹⁴ We also eliminated very high-priced (above the 99th percentile) and low-priced (below the 1st percentile) homes in an effort to remove the effect of outliers on our econometric results as well as any sales that were not arms-length transactions. To assemble an appropriate set of control (noncertified) houses to match with our treated (certified) houses, we eliminate geographic outliers by restricting our sample to those noncertified houses that lie within a 1-mile buffer of certified houses.¹⁵ After these changes, the sizes of the original data sets for these markets were reduced from 91,857 to 42,600 in Austin, from 41,861 to 16,041 in Triangle, and from 291,967 to 117,828 in Portland. Summary statistics for this restricted set of sales in each of the three markets are shown in Tables 1, 2, and 3.

¹⁴ Examples include negative square footage, unrealistically high number of stories, bedrooms, or baths, and zip codes that do not exist.

¹⁵ Limiting the noncertified homes to those within the buffer leads to between 117 and 1,019 noncertified homes for each certified home in Austin, 21 to 252 noncertified for each certified in Triangle, and 152 to 1,984 for each certified home in Portland; the averages in each market are 396, 111, and 800, respectively. We also tried a 0.5-mile radius and the corresponding regression results were not substantially different from those with a 1-mile radius.

Figure 1. Certified Home Sales as a Percentage of All Home Sales, by Zip Code

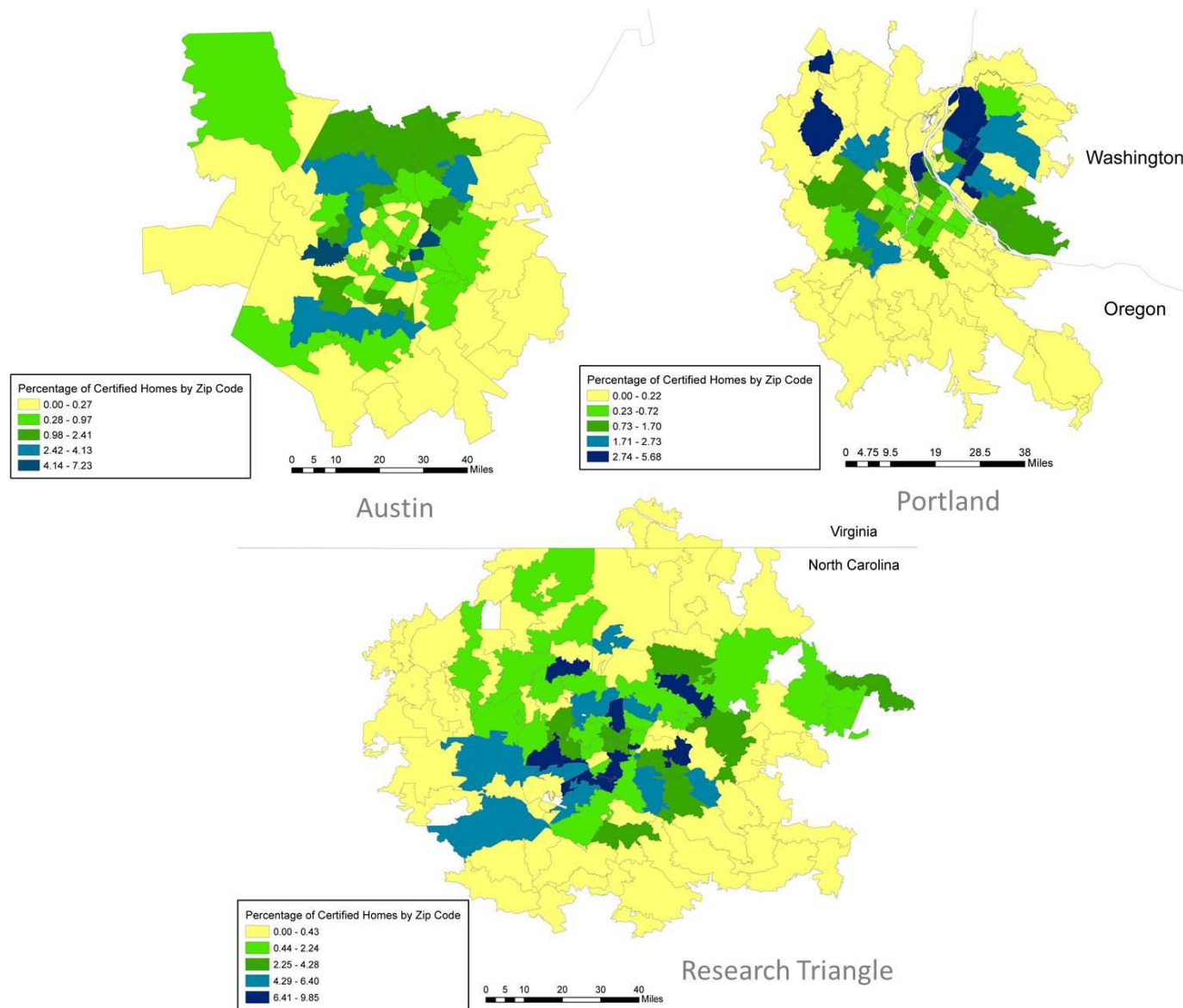


Table 1. House Characteristics by Certification Type—Austin, Texas

	<i>No certification</i>		<i>ENERGY STAR</i>		<i>LOCAL</i>	
	<i>Mean</i>	<i>Sd</i>	<i>Mean</i>	<i>Sd</i>	<i>Mean</i>	<i>Sd</i>
Sales Price (in infl. adjusted 2011\$)	255,592	182,429	302,525	135,489	369,482	238,821
No. of Bedrooms	3.46	0.76	3.86	0.66	3.28	0.62
No. of Full Baths	2.23	0.66	2.69	0.67	2.28	0.54
No. of Half Baths	0.40	0.51	0.54	0.52	0.52	0.56
House size (in sq. ft)	2,227	882	2,849	790	2,154	749
No. of Stories	1.45	0.51	1.57	0.50	1.59	0.51
Age	16.57	19.53	0.84	1.36	7.08	18.27
Fireplace (Y/N)	0.68	0.47	0.74	0.44	0.45	0.50
Garage (Y/N)	0.91	0.29	0.99	0.11	0.84	0.37
Waterfront (Y/N)	0.01	0.11	0.00	0.05	0.02	0.14
Private Pool (Y/N)	0.06	0.23	0.01	0.08	0.02	0.14
Quality	4.14	1.01	4.94	0.29	4.80	0.57
Observations	41,684		750		202	

Note: Data from Austin Central Texas Realty Information Services (ACTRIS), based on information from the Austin Board of REALTORS® for the period 1/1/2008 through 9/23/2011.

Table 2. House Characteristics by Certification Type—Research Triangle, North Carolina

	<i>No certification</i>		<i>ENERGY STAR</i>	
	<i>Mean</i>	<i>Sd</i>	<i>Mean</i>	<i>Sd</i>
Sales Price (in infl. adjusted 2011\$)	267,685	162,848	326,940	157,993
No. of Bedrooms	3.57	0.79	3.86	0.77
No. of Full Baths	2.35	0.77	2.69	0.76
No. of Half Baths	0.60	0.52	0.66	0.51
House size (in sq. ft.)	2,363	983	2,701	808
No. of Stories	1.70	0.49	1.91	0.37
Lot size (in acres)	0.39	0.37	0.27	0.24
Age	17.38	21.09	0.44	0.81
Fireplace (Y/N)	0.88	0.32	0.92	0.27
Garage (Y/N)	0.74	0.44	0.98	0.14
Private Pool (Y/N)	0.01	0.10	0.01	0.08
HOA Pool (Private) (Y/N)	0.16	0.37	0.32	0.47
Observations	14,068		1,970	

Note: Based on information from the Triangle MLS, Inc. for the period 10/1/2009 through 9/30/2011.

Table 3. House Characteristics by Certification Type—Portland, Oregon

	<i>No certification</i>		<i>ENERGY STAR</i>		<i>LOCAL</i>	
	<i>Mean</i>	<i>Sd</i>	<i>Mean</i>	<i>Sd</i>	<i>Mean</i>	<i>Sd</i>
Sales Price in infl. adjusted 2011\$)	333,923	183,683	322,829	130,322	389,124	162,857
No. of Bedrooms	3.3	0.8	3.6	0.7	3.5	0.7
No. of Full Baths	1.9	0.7	2.2	0.5	2.3	0.5
No. of Half Baths	0.5	0.6	0.8	0.6	0.8	0.4
House size (in sq ft)	2,078	875	2,250	674	2,400	728
No. of Stories	1.85	0.69	1.95	0.47	2.04	0.41
Age	35.95	31.79	0.54	0.86	0.68	1.06
Fireplace (Y/N)	0.77	0.42	0.80	0.40	0.88	0.32
Garage (Y/N)	0.90	0.31	0.99	0.07	0.98	0.14
Waterfront (Y/N)	0.01	0.12	0.01	0.09	0.00	0.07
Private Pool (Y/N)	0.01	0.11	0.00	0.00	0.00	0.00
HOA Pool (Private) (Y/N)	0.02	0.14	0.01	0.09	0.07	0.26
Observations	115,949		905		1,303	

Note: Based on information provided by Regional Multiple Listing Services Inc.TM Portland, Oregon, for the period 1/1/2005 through 11/28/2011.

Energy Star homes have a higher average price than noncertified homes in the Austin and Research Triangle markets. In contrast, the average sales price for Energy Star homes is slightly lower than that of noncertified homes in Portland. Homes in Austin and Portland that have local certifications (AEGB and Earth Advantage) have higher average prices. These raw comparisons are confounded by systematic differences in the property characteristics of certified and noncertified homes. Certified homes are substantially newer than noncertified homes. Certified homes are larger, with more bedrooms, full baths, half baths and stories, on average. Certified homes are less likely to have a private pool in Austin (private pools are rare across the other two samples) and more likely to have access to a homeowners' association pool in Triangle and Portland. These differences illustrate the importance of using matching and regression to disentangle the effects of certification on home prices from other factors. In the next section, we describe the matching procedures we use to ensure we are comparing treated homes to an appropriate set of controls.

Empirical Methodology

To analyze the effect that certification has on house prices, we estimate a hedonic price model applied to the MLS data from each of the three housing markets (Rosen 1974). The non-

experimental nature of our data creates challenges to identifying the causal effect of certifications on house prices. In an ideal experiment, we would randomly assign certification (and the characteristics certification requires) to otherwise comparable new homes and estimate the average treatment effect attributable to certification. Our empirical methodology attempts to approximate this experiment through the use of matching and regression using rich information on house characteristics in order to develop a reasonable counterfactual for certified homes.

First, we construct a matched sample by obtaining propensity scores from logit regressions of certification status on various house characteristics and property location and use the propensity scores to implement three alternative matching algorithms. This mitigates concern over the extrapolation bias problem highlighted by Dehejia and Wahba (2002) and Ho *et al.* (2007). We then estimate hedonic regressions using these matched samples. This method of using propensity score matching as a means of trimming and/or weighting the data to reduce sample selection bias has been recommended by Rosenbaum and Rubin (1983), Ho *et al.* (2007), and Imbens (2014).

Matching

We estimate logit models of the likelihood of certification (either Energy Star or the local certifications) on the set of property characteristics included in the hedonic model, as well as longitude and latitude.¹⁶ The results are shown in Appendix A. We then use the predicted propensity scores to implement three different matching algorithms: k -nearest neighbor matching, radius matching, and kernel matching. For nearest neighbor matching, we select k noncertified homes for each certified home (sampling with replacement) based on the smallest propensity score distance. This leads to a matched sample for each city that is no larger than $k*n$, where n is the sample size for the certified homes in that city. Radius matching uses a caliper to filter out controls that do not have propensity scores sufficiently close to the treated homes, ensuring certified homes will not be matched to dissimilar noncertified homes. In contrast to these two approaches, kernel matching does not necessarily drop any controls, but rather uses the difference in propensity scores to weight noncertified properties.¹⁷

¹⁶ Studies have shown that matching performance is improved when treatment and control groups are located in the same geographic area (Todd, 2008). McMillen (2012) also includes latitude and longitude in a propensity score logit model.

¹⁷ A general kernel weight is defined by:

The differences in the propensity score distributions prior to matching are large. This indicates a degree of non-randomness in certification, at least based on the observables. All three matching algorithms that we employ greatly reduce the differences. Figures A1, A2, and A3 in Appendix A show the distributions before and after matching. The nearest neighbor and radius matching approaches yield a closer match than the kernel weighting techniques as they keep only the closest or close enough matches in terms of estimated propensity scores and drop all other observations. However, efficiency gains from using more data through kernel matching, which relies on weighting rather than eliminating observations, could justify the introduction of some bias (Heckman *et al.*, 1998).

To assess match quality, we employ the concept of standardized bias (Rosenbaum and Rubin 1985; Imbens 2014).¹⁸ Standardized bias (SB) provides a measure of the similarity of the means of house characteristics of our certified and matched samples. Tables 4, 5, and 6 show the means for the treated and control groups after nearest neighbor matching, along with the SB statistic and the percent reduction in the SB due to matching; we also show the test for a difference in means between treated and matched controls.¹⁹ The tables show that, with the exception of a few variables, the matching procedures reduce the SB by about 80-90 percent compared to the original unmatched samples.

$$w(ps_i, ps_j) = \frac{K\left(\frac{|ps_j - ps_i|}{h}\right)}{\sum_{c \in C} K\left(\frac{|ps_c - ps_i|}{h}\right)}$$

where w is a function deriving the weight for control j with respect to treatment i ; h is the window size within which a kernel weight will be given; ps_i and ps_j are respectively the propensity score of a certified home (treatment) and an uncertified home (control); $K(\cdot)$ is a kernel function that is decreasing (or non-increasing); and C denotes the entire set of controls. As $|ps_j - ps_i|$ diminishes, the propensity score for the noncertified home is closer to the certified, and thus the noncertified home will receive a higher weight. If the difference between ps_j and ps_i is greater than h , then the weight will be zero. We discuss results below of robustness checks using alternative values of k for the number of nearest neighbors and alternative parameter values for the kernel bandwidth and radius caliper.

¹⁸ Standardized bias is defined as the difference in the sample means between two groups as a percentage of the square root of the average sample variance. It is given by:

$$SB = \frac{100 \cdot (\bar{X}_1 - \bar{X}_0)}{\sqrt{(V_1(X) + V_0(X))/2}}$$

where $\bar{X}_i(V_i)$ is the weighted mean (variance) of the treatment group if $i=1$ and the control group if $i=0$. While there is not a specific criterion for the matching quality, empirical studies usually consider a value of 3% or 5% for SB as sufficient (Caliendo, 2008).

¹⁹ We present only one set of covariate balance tests to save space but the results for other matching schemes are qualitatively similar.

Table 4. Balancing Tests for Nearest Neighbor Matching—Austin, Texas

	<i>Mean</i>		<i>SB</i>	<i>% SB </i>	<i>t-test</i>
	<i>Certified</i>	<i>Matched Control</i>			
			<i>Reduction</i>		<i>(p-values)</i>
No. of Bedrooms	3.76	3.76	-0.2	99.6	0.972
No. of Full Baths	2.61	2.61	-0.3	99.4	0.946
No. of Half Baths	0.53	0.52	2.3	90.1	0.626
log (House size)	7.86	7.86	0.9	98.5	0.833
Fireplace (Y/N)	0.69	0.69	-0.8	-3791.8*	0.863
Garage (Y/N)	0.96	0.96	-1	94.5	0.788
Waterfront (Y/N)	0.01	0.01	-0.9	82.7	0.83
No. of Stories	1.57	1.56	1.8	91.8	0.695
Age	2.23	2.04	1.3	98.6	0.598
Age ²	87.79	45.83	3.8	92	0.143
Quality (Fair)	0.00	0.00	0.2	99.3	0.866
Quality (Average)	0.02	0.02	2	95.2	0.43
Quality (Good)	0.04	0.03	2.1	97.5	0.405
Quality (Excellent)	0.93	0.95	-3.3	97.2	0.247
Private Pool (Y/N)	0.01	0.00	2.4	91.3	0.275
Latitude	30.39	30.39	1.2	88.3	0.8
Longitude	-97.77	-97.77	1.1	71.9	0.828
Year Built	2007.5	2007.7	-1.6	98.3	0.521

*Before matching, the mean of the fireplace dummy in the treated group in Austin (0.68778) is almost the same as the mean in the unmatched control group (0.68768). Because the matching procedure induced a larger difference in the means the %|SB| reduction is large. We keep the variable in the logit propensity score regression, however, because the t-test and SB in the matched sample indicate to keep it in.

Note: %|SB| reduction is $|SB_0 - SB|/SB_0$, where SB_0 is the standardized bias derived using the full sample.

The SB is less than 3 percent for almost all variables indicating that the means of the distributions of characteristics in the treated and control groups are similar. The mean SB across the markets ranges from 0.8 to 1.5. We fail to reject the two-sample t-test for each variable, indicating that the means are not statistically significantly different between the two groups. Hotelling's *T*-square test, which tests the joint null hypothesis that the means of two sets of variables are equal, fails to reject the null hypothesis of equal means at the 1 percent level for Triangle, but rejects the null of equal means for Austin and Portland. This result for Austin and Portland lends support to including these house characteristics in the subsequent hedonic regression to control for the remaining imbalances.

Table 5. Balancing Tests for Nearest Neighbor Matching—Research Triangle, NC

	<i>Mean</i>		<i>SB</i>	<i>% SB </i>	<i>t-test</i>
	<i>Certified</i>	<i>Matched Control</i>			
			<i>Reduction</i>		<i>(p-values)</i>
No. of Bedrooms	3.86	3.86	-0.6	98.4	0.861
No. of Full Baths	2.69	2.69	-0.1	99.9	0.985
No. of Half Baths	0.66	0.66	-0.6	94.2	0.842
log (House size)	7.86	7.86	-0.8	98.4	0.781
Fireplace (Y/N)	0.92	0.93	-1.6	88.7	0.579
Garage (Y/N)	0.98	0.98	0.1	99.9	0.945
No. of Stories	1.91	1.91	-0.1	99.7	0.964
Age	0.44	0.41	0.2	99.8	0.201
Age ²	0.85	0.81	0.0	100	0.762
Log(Acres)	-1.53	-1.54	0.4	99.2	0.916
Private Pool (Y/N)	0.01	0.00	1.5	61.2	0.573
HOA Pool (Y/N)	0.32	0.30	5.6	85.2	0.112
Latitude	35.83	35.83	0.0	98.3	0.994
Longitude	-78.78	-78.77	-4.2	67.4	0.213
Year Built	2009.9	2010	-0.2	99.8	0.264

Note: % |SB| reduction is $|SB_0 - SB|/SB_0$, where SB_0 is the standardized bias derived using the full sample.

Table 6. Balancing Tests for 5 Nearest Neighbor Matching—Portland, Oregon

	<i>Mean</i>		<i>SB</i>	<i>% SB </i>	<i>t-test</i>
	<i>Certified</i>	<i>Matched Control</i>			
			<i>Reduction</i>		<i>(p-values)</i>
No. of Bedrooms	3.53	3.53	0.2	99.5	0.957
No. of Full Baths	2.23	2.22	1.7	96.8	0.542
No. of Half Baths	0.83	0.84	-1.2	98.1	0.706
log (House size)	7.72	7.72	-0.2	99.5	0.93
Fireplace (Y/N)	0.87	0.87	0.1	99.5	0.967
Garage (Y/N)	0.98	0.99	-0.4	98.9	0.81
Waterfront (Y/N)	0.01	0.00	1.5	80.2	0.517
No. of Stories	2.02	2.01	1.6	94.5	0.517
Age	0.63	0.65	-0.1	100	0.614
Age ²	1.37	1.25	0.0	100	0.3
Private Pool (Y/N)	0.00	0.00	0.0	-	-
HOA Pool (Y/N)	0.05	0.06	-2.1	88.7	0.592
Latitude	45.51	45.51	1.2	-14.1	0.726
Longitude	-122.68	-122.68	1.1	91.7	0.737
Year Built	2008.5	2008.5	0.1	99.9	0.638

Note: % |SB| reduction is $|SB_0 - SB|/SB_0$, where SB_0 is the standardized bias derived using the full sample.

Hedonic Regressions

Using the matched samples, we estimate a log-linear hedonic price model of the following form:

$$\ln P_{ijqt} = c + \alpha ES_{ijqt} + \beta AEGB_{ijqt} + \gamma EA_{ijqt} + \delta X_{ijt} + \eta_j \tau_t + \theta_q + \varepsilon_{ijqt} \quad (1)$$

where P_{ijqt} is the price of house i in zip code j sold in quarter q and year t . The primary variables of interest are ES_{ijqt} , a dummy variable identifying homes that are in the Energy Star treatment group, and $AEGB_{ijqt}$ and EA_{ijqt} , dummy variables that identify homes that are in the AEGB and Earth Advantage certification treatment groups, respectively. The coefficients α , β , and γ capture the marginal effects of the certifications on house prices, all else equal. The regression includes a vector of house characteristics, X_{ijt} ; an interaction between zip code, η_j , and sale year, τ_t , fixed effects to control for unobserved neighborhood characteristics that vary over time; sale quarter fixed effects, θ_q , to control for seasonal effects on home prices; and an idiosyncratic error term, ε_{ijqt} . We estimate the equation separately for each of the three real estate markets.

Results

In Table 7, the hedonic regression results are presented for each market. Column 1 shows the results using the full unmatched sample, while columns 2-4 show the results from the propensity score k -nearest neighbor matching ($k=5$), Radius matching, and Epanechnikov kernel matching. All models include zip code-by-year fixed effects and quarter fixed effects (to control for seasonal effects on house prices). Standard errors reported are clustered at the zip code-by-year level to control for intragroup correlation.²⁰ We suppress the reporting of the house characteristics coefficients, though all of them have the expected signs and most are statistically significant (see Appendix B for full estimation results).²¹

²⁰ We follow Ho *et al.* (2007) who argue standard errors from the regression model do not need to be adjusted for uncertainty in the matching procedure.

²¹ The estimated coefficients of the continuous variables in the hedonic regression maintained the same significance level in the matched model as the unmatched model, while estimated coefficients of several dummy variables became insignificant after matching.

Table 7. Hedonic Regression Results

	(1)	(2)	(3)	(4)
	<i>Unmatched sample</i>	<i>Nearest-neighbor matching (5 neighbors with replacement)</i>	<i>Radius Matching (Caliper=0.0001)</i>	<i>Kernel-weighted matching (Type: Epanechnikov; bandwidth=0.05)</i>
Austin				
Energy Star	0.038*** (0.014)	0.004 (0.011)	0.001 (0.011)	0.008 (0.010)
Local green certification ¹	0.143*** (0.028)	0.081*** (0.017)	0.083*** (0.016)	0.073*** (0.016)
Observations	42,582	4,238	25,214	41,653
R-squared	0.878	0.909	0.906	0.905
N. Treatment	900	900	855	900
Research Triangle				
Energy Star	0.024** (0.012)	0.022** (0.010)	0.023*** (0.008)	0.024** (0.011)
Observations	16,038	4,837	10,733	16,026
R-squared	0.832	0.891	0.899	0.887
N. Treatment	1970	1958	1210	1958
Portland				
Energy Star	0.036*** (0.013)	0.019** (0.008)	0.020** (0.009)	0.020** (0.008)
Local green certification ¹	0.080*** (0.010)	0.030*** (0.007)	0.033*** (0.007)	0.032*** (0.007)
Observations	117,825	6,467	11,621	116,303
R-squared	0.785	0.907	0.901	0.897
N. Treatment	1876	1876	1567	1876
Zip*year FE	Yes	Yes	Yes	Yes
Quarter FE	Yes	Yes	Yes	Yes

¹Local green certification in Austin is Austin Energy Green Building program and in Portland is Earth Advantage.

Note: In all models, the following house characteristics are included as repressors: age, age squared, number of bedrooms, number of full bathrooms, number of half bathrooms, natural log of square footage of the home, number of stories, and dummy variables for a fireplace, garage, waterfront location, and private pool. Additional variables included in markets where they are available: index of house quality (Austin), natural log of lot size (Triangle) and dummy for existence of a homeowner association pool (Triangle and Portland). Robust standard errors clustered at zip code-by-year level are in parentheses.

*** p<0.01, ** p<0.05, * p<0.1

Results from the unmatched sample suggest all certifications are associated with a statistically significant price premium in each market. Matching attenuates these estimates, however, suggesting that extrapolation bias is important in our setting. In the Portland and Triangle markets, Energy Star certification is associated with a 2 percent price premium within

the matched sample; in Austin, Energy Star no longer has a statistically significant premium. The percentage of certified homes out of all home sales is much smaller in Austin and Portland than in Triangle, thus it is not unreasonable to see the matching procedures induce a greater change in the results in these two markets than in Triangle. When the potential number of controls is large, matched sampling can reduce the nonrandom sample selection bias otherwise brought about by an indiscriminant selection of the control group (Rosenbaum & Rubin, 1985).

The local certification schemes, which encompass more factors than just energy efficiency, appear to be more valuable than Energy Star. This is particularly true in Austin, where the AEGB certification is associated with a 7 to 8 percent price premium compared to a noncertified home. The effect is smaller in Portland—Earth Advantage certification is associated with about a 3 percent premium over no certification, which is relatively close to the 2 percent premium for Energy Star in that market.²²

The results are fairly robust to alternative choices of parameters used in each matching procedure. We estimated the model using nearest neighbor matching with $k=1$ to $k=10$ at step of 3, radius matching with a caliper ranging from 0.00005 to 0.0002 at a step of 0.0005, and kernel matching with bandwidth between 0.01 and 0.09 at a step of 0.02. In all cases, Energy Star certification remains insignificant in Austin; in Triangle and Portland, the estimated coefficient on Energy Star ranges from 0.015 to 0.025 and from 0.018 to 0.023, respectively. The range of the estimated coefficients for AEGB is 0.066 to 0.085 and for Earth Advantage is 0.026 to 0.036.

Putting the Price Premiums in Context: Comparison to Energy Expenditures

The econometric results suggest that local certifications in Austin and Portland have significant value for homes of all vintages and Energy Star certification has value for homes in the Portland and Triangle markets. But are the magnitudes of the estimated premiums reasonable? In this section, we shed light on this question. We use the econometric results to infer a discounted present value of implied energy savings from each of the certifications, annualize these numbers, and divide them by an estimate of annual energy expenditures for single-family homes in each market. This ratio should be roughly equivalent to the energy savings percentage expected from certification *if* housing markets are appropriately capitalizing the energy savings.

²² In comparison to these results, Kahn and Kok (2014) find that only Energy Star, and not the local certification they consider in a robustness check (their baseline model does not separately identify the certification schemes), has a statistically significant effect on house prices in California.

Table 8 shows the results of annualizing the point estimates of house price premiums estimated in the regressions that use the nearest neighbor matching technique. We use a 5 percent discount rate and three alternative time horizons to solve for the stream of constant annual payments that yields a present discounted value equivalent to the average estimated home price premium. We use 7, 15, and 30 years for the time horizons because 7 years is a typical length of time that a household lives in a home before moving, and 15 and 30 reflect common mortgage periods. We perform this calculation for each certification program in each city that we found to have a statistically significant and positive effect on home prices.

Table 8. Certification Price Premiums and Implied Annual Energy Savings for Average Home

<i>Program</i>	<i>Sales price premium (\$)</i>	<i>Implied Energy Savings (\$)</i> <i>(5% discount rate)</i>		
		<i>7-year horizon</i>	<i>15- year horizon</i>	<i>30- year horizon</i>
Energy Star				
Austin	-	-	-	-
Triangle	5,892	970	541	365
Portland	6,160	1,014	565	382
Local certifications				
Austin	19,920	3,279	1,828	1,234
Portland	9,727	1,601	892	603

The implied annual energy cost savings from Energy Star certification are approximately the same in Portland and Triangle, \$365-382 per year based on a 30-year time horizon. The implied savings from the estimated premium on the local certification in Austin is the largest and is approximately twice the magnitude of the local scheme in Portland—\$1,234 versus \$603 per year based on a 30-year lifetime.

We do not observe energy expenditures for homes in our data. Instead, we predict them using electricity and natural gas demand modeling results from Alberini et al. (2011) combined with retail price data for electricity and natural gas from the US Energy Information Administration (EIA). The Alberini et al. equations predict monthly electricity and natural gas consumption based on energy prices, house characteristics, appliance stock, occupant characteristics, and heating and cooling degree days. The regression results from Alberini et al. are reproduced in Appendix C. We use city-specific average electricity and natural gas prices and heating and cooling degree days, average demographic factors, including income, for each of

our cities, and the individual house characteristics in our data set to predict average monthly electricity and gas consumption for each house. We convert these monthly averages to annual expenditures using the average annual retail price for each type of energy and then sum the two categories of energy expenditures. We calculate baseline annual energy expenditures for two years, 2007 and 2010, for all of the certified homes in our data set for each city. We use only certified homes rather than the full sample to ensure an “all else equal” comparison when looking at the relative benefits of certification, and we consider two different years to provide a range of estimates. The year 2007 is the last year of data used in the Alberini et al. study; we include 2010 to have a more recent year covered by our sample of home sales data and to include a year with lower natural gas prices and consequentially lower average household energy costs.

The results of these energy expenditure calculations are displayed in Table 9 alongside the ratio of implied energy savings under a 30-year time horizon (from Table 8) relative to these baseline energy expenditures. In the Triangle market, Energy Star certified homes sell for a premium that implies average annual energy savings of about 16 to 19 percent of baseline expenditures, depending on the year. In Portland, the implied average savings from Energy Star are higher at 21 to 23 percent. As a point of comparison, energy savings from Energy Star are expected to be 15 to 30 percent relative to other new houses depending on the year. While these calculations require several assumptions and are only meant to be illustrative, they are consistent with homebuyers rationally trading off home prices and future energy expenditures.

The implied savings from local certifications in Austin and Portland are higher than those from Energy Star.²³ In Portland, the figures suggest that buyers of Earth Advantage certified homes may expect a 31 to 34 percent savings on their energy bills over a 30-year lifetime. The price premium may be capturing other home characteristics we do not observe, as Earth Advantage certification covers several additional features beyond energy efficiency such as water efficiency and “green” materials used in construction. The implied savings for the Austin AEBG program are even higher, at 60 to 66 percent of energy expenditures for an average home. This suggests that Austin homebuyers greatly value other aspects of AEBG certification, that they may be overpaying for the benefits of certification, or that our hedonic analysis fails to capture other differences between certified and noncertified homes. Interviews with the representatives of the certification agencies and local builders in both Austin and Portland reveal there is a strong sense that these green certifications are more a symbol of overall quality than

²³ Some houses that have Earth Advantage or AEBG certifications are also Energy Star certified. The numbers in the table represent the effects of the individual certifications, holding all else constant.

any single green feature of the homes, including energy efficiency. This could explain why we find that house premiums in Austin and Portland are larger than a naïve calculation of expected energy savings would suggest.

Table 9. Estimated Average Annual Energy Expenditures per Household and Implied Energy Savings as a Percentage of Energy Expenditures

Year=2007						
Program	Austin		Triangle		Portland	
	Energy Expenditures	Implied Energy Savings as a Percentage of Expenditures	Energy Expenditures	Implied Energy Savings as a Percentage of Expenditures	Energy Expenditures	Implied Energy Savings as a Percentage of Expenditures
Energy Star	2,289	-	2,250	16.2	1,814	21.0
AEGB	2,054	60.1				
EA					1,955	30.8
Year=2010						
Program	Austin		Triangle		Portland	
	Energy Expenditures	Implied Energy Savings as a Percentage of Expenditures	Energy Expenditures	Implied Energy Savings as a Percentage of Expenditures	Energy Expenditures	Implied Energy Savings as a Percentage of Expenditures
Energy Star	2,068	-	1,935	18.9	1,684	22.7
AEGB	1,860	66.3				
EA					1,750	34.4

Conclusion

Energy efficiency and other environmental characteristics of a home may be difficult to observe and can lead to information asymmetries in the marketplace. Energy and green certification programs are one way to signal to the real estate market that a house is more energy efficient or more “green” than other comparable homes. In some housing markets, real estate multiple listing services include these certifications to make these signals more salient and provide additional information about homes to potential buyers.

In this paper, we analyze data on housing transactions in three urban areas where MLS listing sheets are incorporating information on Energy Star and local green certifications: Portland, Oregon, Austin, Texas, and the Research Triangle region of North Carolina. We use matching techniques to control for sample selection bias and a hedonic approach to compare prices of certified homes to an appropriate set of noncertified homes. We find that matching is important: the effects of certification are much smaller from the matched sample regressions than the unmatched sample. Energy Star certification is associated with higher home prices in two of

the markets, Portland and Triangle, and the size of the effect is similar across the markets—homes sell for about a 2 percent higher price, on average. In Austin, we find no statistically significant relationship between Energy Star and home prices after matching on observables. The local green certifications in Austin and Portland appear to be more valuable than Energy Star. In Austin, the premium for certified homes is 7 to 8 percent while in Portland it is about 3 percent.

When we annualize the estimated price premiums, we conclude that housing markets in Portland and Triangle are likely accurately capitalizing the annual energy savings implied by Energy Star certification. The implied energy savings from Energy Star (as reflected in the hedonic regression results) are approximately 16 to 22 percent of average energy expenditures, which is similar in magnitude to the current 15 percent savings that homes are required to achieve to be Energy Star certified. These results suggest that the Energy Star program may be helping narrow the energy efficiency gap in these two markets by providing salient information to potential homebuyers. Our findings call into question some earlier studies that find larger estimated effects of certification on home prices—when compared to energy expenditures, these previously estimated effects may be unreasonably large. One reason may be that these studies tend to group multiple certification schemes together. We find that the two local certification schemes we analyze have larger estimated price premiums than Energy Star, suggesting that consumers place additional value on the other environmental features of these homes.

Appendix A

Table A1 shows the results of the propensity score model—i.e., the logistic regression of the likelihood of certification, either local certification or Energy Star, as a function of property characteristics and location (latitude and longitude).

Table A1. Logistic Regression Results: Probability of Certification

	(1) <i>Austin</i>	(2) <i>Triangle</i>	(3) <i>Portland</i>
Age	0.097*** (0.035)	-0.053 (0.077)	0.216*** (0.059)
Age Squared	0.002*** (0.000)	-0.050*** (0.019)	-0.084*** (0.015)
No. of Bedrooms	-0.064 (0.069)	-0.101* (0.055)	-0.453*** (0.050)
No. of Full Baths	0.099 (0.079)	0.332*** (0.066)	-0.027 (0.071)
No. of Half Baths	0.001 (0.088)	0.093 (0.077)	0.064 (0.054)
House size (log sq ft)	1.190*** (0.221)	-0.254 (0.184)	0.275** (0.112)
Fireplace (Y/N)	0.099 (0.099)	-0.142 (0.127)	0.197** (0.081)
Garage (Y/N)	-1.274*** (0.202)	0.255 (0.212)	-0.365 (0.230)
Waterfront (Y/N)	-0.050 (0.433)		-0.146 (0.334)
No. of Stories	-0.337*** (0.094)	0.061 (0.100)	0.249*** (0.070)
Private Pool (Y/N)	-1.557*** (0.367)	0.778** (0.385)	
Latitude	-0.479** (0.216)	1.343*** (0.195)	0.162 (0.143)
Longitude	1.265*** (0.295)	-0.998*** (0.147)	-0.453*** (0.114)
Year Built	0.384*** (0.033)	0.606*** (0.046)	0.582*** (0.015)
Lot size (log acres)		-0.227*** (0.043)	
HOA Pool (Y/N)		0.624*** (0.067)	0.258** (0.123)
Constant	-643.318*** (71.511)	-1,343.720*** (93.822)	-1,233.760*** (32.449)
Observations	41,666	16,038	116,303
N. Treatment	900	1970	1876
Quality FE	Yes	-	-

Note: Model estimated on properties within 1-mile buffer of certified homes. Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Figures A1, A2, and A3 show the estimated propensity score distributions for the unmatched and matched samples for each of four matching approaches in each of the three housing markets. The differences in the propensity score distributions for the certified (treated) and noncertified (control) properties prior to matching are large as can be seen in the left-hand graphs in each figure; the right-hand side graphs illustrate how matching reduces the difference.

Figure A1. Estimated Propensity Score Distribution, Austin

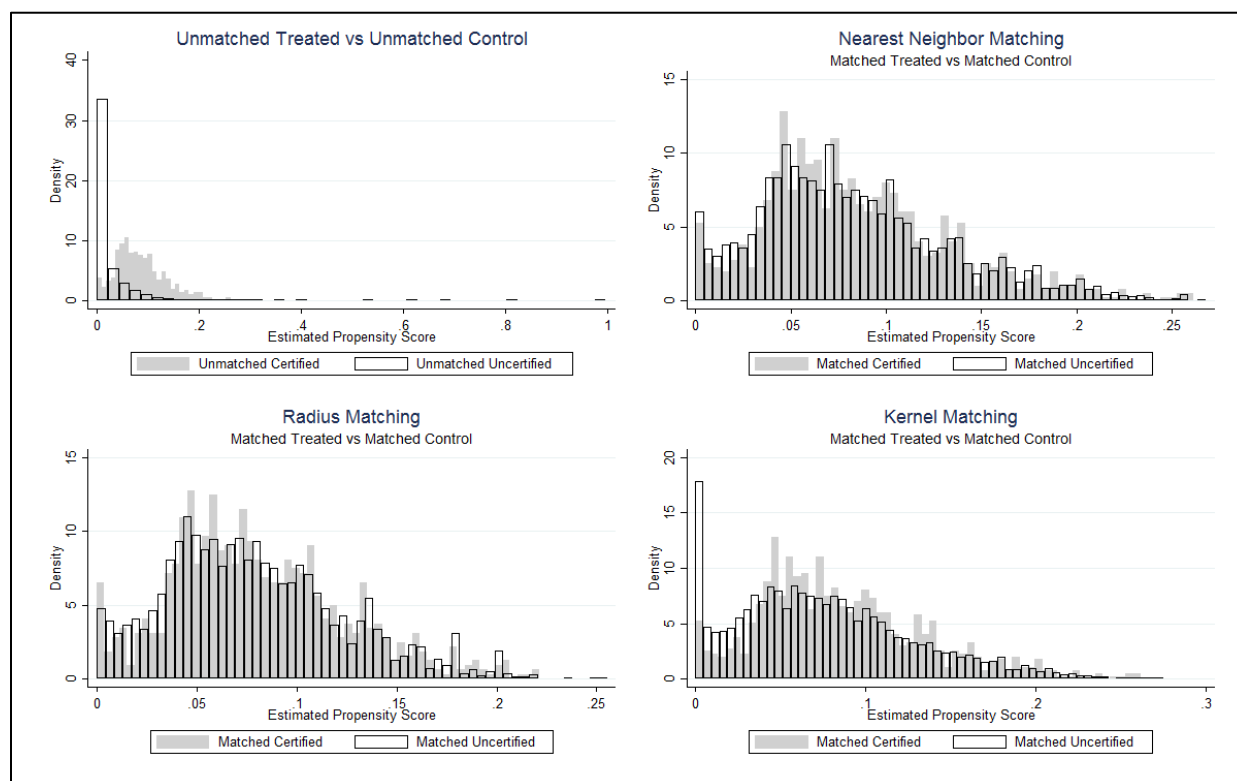
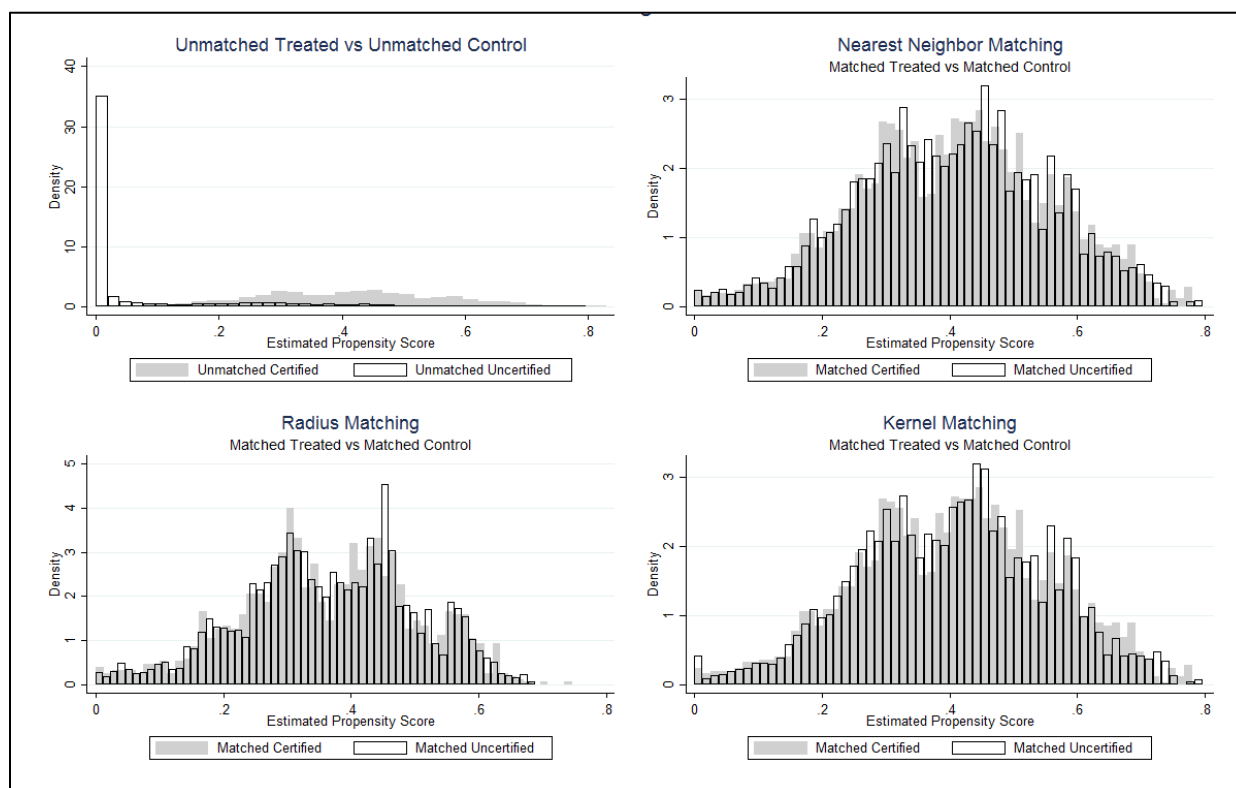
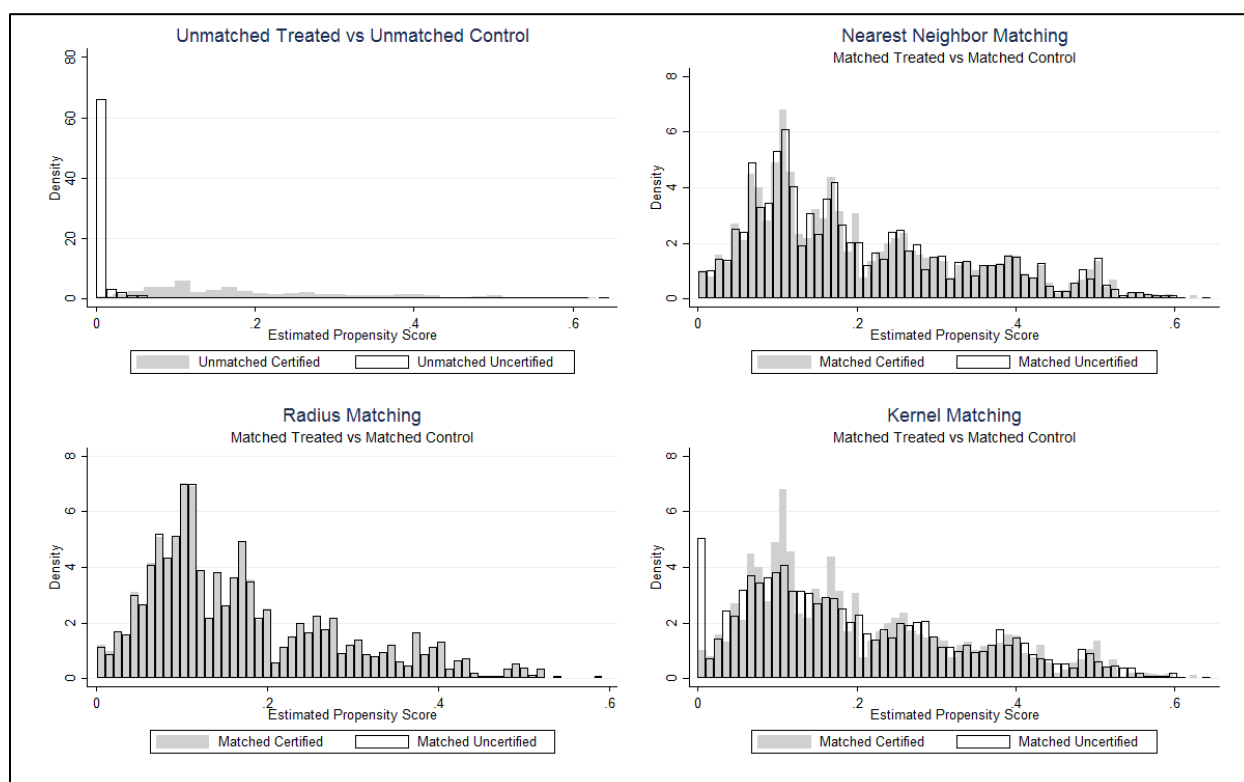


Figure A2. Estimated Propensity Score Distribution, Triangle**Figure A3. Estimated Propensity Score Distribution, Portland**

Appendix B

Tables in this appendix present the full hedonic regression results table corresponding to Table 7 in the main text.

Table B1. Full Hedonic Regression Results-Austin

	(1)	(2)	(3)	(4)
	<i>Unmatched sample</i>	<i>Nearest-neighbor matching (5 neighbors with replacement)</i>	<i>Radius Matching (Caliper=0.0001)</i>	<i>Kernel-weighted matching (Type: Epanechnikov; bandwidth=0.05)</i>
Energy Star	0.038*** (0.014)	0.004 (0.011)	0.001 (0.011)	0.007 (0.010)
Local green certification	0.143*** (0.028)	0.081*** (0.017)	0.083*** (0.016)	0.073*** (0.016)
Age	-0.005*** (0.001)	-0.005*** (0.002)	-0.006*** (0.002)	-0.006*** (0.001)
Age Squared	0.00009*** (0.000008)	0.00006*** (0.000022)	0.00006*** (0.000021)	0.00008*** (0.000020)
No. of Bedrooms	-0.044*** (0.003)	-0.060*** (0.007)	-0.060*** (0.007)	-0.063*** (0.006)
No. of Full Baths	0.110*** (0.006)	0.085*** (0.008)	0.082*** (0.007)	0.081*** (0.007)
No. of Half Baths	0.042*** (0.004)	0.037*** (0.008)	0.035*** (0.008)	0.032*** (0.006)
House size (log sq ft)	0.751*** (0.013)	0.919*** (0.029)	0.931*** (0.025)	0.925*** (0.022)
Fireplace (Y/N)	0.045*** (0.006)	0.055*** (0.010)	0.049*** (0.010)	0.047*** (0.009)
Garage (Y/N)	0.007 (0.009)	0.004 (0.043)	-0.014 (0.040)	-0.016 (0.029)
Waterfront (Y/N)	0.313*** (0.036)	0.224*** (0.082)	0.254*** (0.085)	0.224*** (0.063)
No. of Stories	-0.114*** (0.006)	-0.139*** (0.011)	-0.140*** (0.010)	-0.132*** (0.009)
Private Pool (Y/N)	0.176*** (0.008)	0.281*** (0.086)	0.275*** (0.059)	0.244*** (0.045)
Constant	6.313*** (0.096)	4.984*** (0.218)	5.050*** (0.192)	5.188*** (0.169)
Observations	42,582	4,238	25,214	41,653
R-squared	0.878	0.909	0.906	0.905
N. Treatment	900	900	855	900
Zip-year FE	Yes	Yes	Yes	Yes
Quarter FE	Yes	Yes	Yes	Yes
Quality FE	Yes	-	-	-

Note: Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table B2. Full Hedonic Regression Results-Triangle

	(1)	(2)	(3)	(4)
	<i>Unmatched sample</i>	<i>Nearest-neighbor matching (5 neighbors with replacement)</i>	<i>Radius Matching (Caliper=0.0001)</i>	<i>Kernel-weighted matching (Type: Epanechnikov; bandwidth=0.05)</i>
Energy Star	0.024** (0.012)	0.022** (0.010)	0.023*** (0.008)	0.024** (0.011)
Age	-0.008*** (0.001)	-0.008 (0.008)	-0.007* (0.004)	-0.008*** (0.002)
Age Squared	0.00007*** (0.00001)	0.00035 (0.00140)	0.00004 (0.00006)	0.00007*** (0.00003)
No. of Bedrooms	-0.066*** (0.007)	-0.080*** (0.009)	-0.087*** (0.009)	-0.081*** (0.008)
No. of Full Baths	0.100*** (0.006)	0.118*** (0.008)	0.112*** (0.011)	0.113*** (0.008)
No. of Half Baths	0.056*** (0.008)	0.062*** (0.011)	0.040*** (0.015)	0.056*** (0.011)
House size (log sq ft)	0.820*** (0.018)	0.898*** (0.031)	0.896*** (0.034)	0.902*** (0.029)
Fireplace (Y/N)	0.141*** (0.018)	0.027** (0.013)	0.028* (0.016)	0.024* (0.013)
Garage (Y/N)	0.115*** (0.011)	0.016 (0.021)	0.018 (0.026)	0.028 (0.018)
No. of Stories	-0.092*** (0.009)	-0.144*** (0.014)	-0.135*** (0.018)	-0.139*** (0.013)
Lot size (log acres)	0.046*** (0.009)	0.040*** (0.013)	0.066*** (0.016)	0.041*** (0.012)
Private Pool (Y/N)	0.047*** (0.015)	-0.003 (0.030)	0.020 (0.048)	-0.011 (0.028)
HOA Pool (Y/N)	0.030*** (0.009)	0.011 (0.014)	0.018 (0.013)	0.009 (0.014)
Constant	6.089*** (0.135)	5.771*** (0.218)	5.844*** (0.239)	5.735*** (0.203)
Observations	16,038	4,837	10,733	16,026
R-squared	0.832	0.891	0.899	0.887
N. Treatment	1970	1958	1210	1958
Zip-year FE	Yes	Yes	Yes	Yes
Quarter FE	Yes	Yes	Yes	Yes

Note: Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Table B3. Full Hedonic Regression Results-Portland

	(1)	(2)	(3)	(4)
	<i>Unmatched sample</i>	<i>Nearest-neighbor matching (5 neighbors with replacement)</i>	<i>Radius Matching (Caliper=0.0001)</i>	<i>Kernel-weighted matching (Type: Epanechnikov; bandwidth=0.05)</i>
Energy Star	0.036*** (0.013)	0.019** (0.008)	0.020** (0.009)	0.020** (0.008)
Local green certification	0.080*** (0.010)	0.030*** (0.007)	0.033*** (0.007)	0.033*** (0.007)
Age	-0.003*** (0.000)	-0.023*** (0.007)	-0.026*** (0.007)	-0.005*** (0.000)
Age Squared	0.00002*** (0.000003)	0.00185 (0.00169)	0.00251 (0.00176)	0.00005*** (0.00001)
No. of Bedrooms	0.007 (0.009)	-0.031*** (0.005)	-0.026*** (0.007)	-0.027*** (0.004)
No. of Full Baths	0.099*** (0.013)	0.073*** (0.009)	0.080*** (0.011)	0.074*** (0.008)
No. of Half Baths	0.039*** (0.005)	0.013* (0.007)	0.014* (0.007)	0.008 (0.006)
House size (log sq ft)	0.491*** (0.067)	0.863*** (0.018)	0.817*** (0.040)	0.819*** (0.017)
Fireplace (Y/N)	0.040*** (0.006)	0.003 (0.007)	0.002 (0.008)	0.006 (0.006)
Garage (Y/N)	0.064*** (0.003)	0.015 (0.029)	0.011 (0.034)	0.028 (0.021)
Waterfront (Y/N)	0.179*** (0.018)	0.111* (0.063)	0.091 (0.057)	0.086* (0.047)
No. of Stories	-0.023* (0.014)	-0.126*** (0.009)	-0.107*** (0.011)	-0.114*** (0.008)
Private Pool (Y/N)	0.064*** (0.010)			
HOA Pool (Y/N)	0.070*** (0.018)	0.059*** (0.020)	0.070*** (0.020)	0.066*** (0.019)
Constant	8.662*** (0.425)	6.263*** (0.123)	6.564*** (0.264)	6.534*** (0.117)
Observations	117,825	6,467	11,621	116,303
R-squared	0.785	0.907	0.901	0.896
N. Treatment	1876	1876	1567	1876
Zip-year FE	Yes	Yes	Yes	Yes
Quarter FE	Yes	Yes	Yes	Yes

Note: Robust standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

Appendix C

The model that we use to estimate electricity and natural gas demand by city comes from equations 9 and 10, respectively, in Alberini et al. (2011). Alberini et al. use data from multiple years of the American Housing Survey between 2000 and 2007 to estimate monthly household level demand for electricity and natural gas in several cities, two of which overlap with the cities in our study and one of which is a close proxy. The estimated coefficients are reported in Table C1.

Table C1. Alberini et al (2011) Energy Consumption Equations

Variables	<i>Electricity consumption</i>		<i>Natural gas consumption</i>	
	Coefficient	T-statistic	Coefficient	T-statistic
Log electricity price	-0.860***	(-9.374)	0.150*	(2.152)
Log gas price	0.117*	(2.024)	-0.693***	(-6.567)
Log square feet	0.216***	(11.045)	0.189***	(9.882)
Age of home	0.00553***	(8.377)	0.00383***	(5.869)
Age of home squared	-0.0000540***	(-7.555)	-0.00000911	(-1.305)
Owns the home	0.0696***	(4.857)	0.0322*	(2.558)
Number of rooms	0.0659***	(14.743)	0.0549***	(18.606)
Number of floors	-0.0171*	(-2.069)	0.00974	(1.177)
Log household income	0.0225***	(8.826)	0.00357	(1.610)
Young child	0.0963***	(15.060)	0.0711***	(12.006)
Elderly	-0.0390***	(-4.200)	0.0640***	(7.228)
Log CDD	0.0727***	(3.582)	-0.00384	(-0.132)
Log HDD	0.00350	(0.069)	0.0991	(1.665)
Dishwasher	0.0849***	(6.553)	-0.0166	(-1.257)
Gas heat	-0.0990**	(-2.786)	0.215***	(4.204)
Electric heat	0.154***	(4.722)	0.0211	(0.470)
Heating oil heat	-0.0971*	(-2.282)	-0.938***	(-11.467)
Any A/C	0.161***	(7.998)	-0.0147	(-0.941)
Gas A/C	0.00624	(0.497)	0.0441**	(2.758)
Dryer	-0.0137	(-1.139)	0.0409***	(6.650)
Electric stove	0.0719***	(7.912)	-0.0291**	(-3.428)
2007 dummy	0.0891*	(2.509)	0.196***	(3.667)
Austin	0.157	(1.227)	0.184	(1.341)
Portland	0.0708	(0.417)	0.446*	(2.479)
Raleigh-Durham	-0.102	(-0.654)	0.538**	(3.172)
Constant	1.422**	(2.716)	0.214	(0.350)

We solve each of the equations for all of the certified houses in our data set from the perspective of 2007 and 2010 to predict energy consumption in the absence of certification. The data for the house characteristic variables in the equation come from the MLS data and thus are specific to each home. The energy price data come from EIA. For electricity, the retail price is average revenue per residential kilowatt-hours (kWh) and is calculated at the utility level, or, if the region covered by the MLS data is served by multiple utilities, the price is averaged across those utilities. Prices of natural gas are calculated similarly using data from EIA. Data on heating and cooling degree days comes from the National Oceanic and Atmospheric Administration and is calculated at the regional level so does not vary by house but does vary over time. Sociodemographic information on the presence of an elderly person or child in the home is based on averages at the city level from Census information, and data on average household income is from the Internal Revenue Service.

We solve these equations for houses in each of our three cities in 2007 and 2010 to obtain monthly consumption of electricity and natural gas (adjusting from natural logs using the regression mean square error). In Table C2, we compare the estimated annual average consumption of natural gas and electricity to state level averages from the US EIA.

Table C2. Comparison of Annual Energy Expenditures per Household City-Level Estimates and State-Level Data from EIA

2007				
	<i>City-specific estimate*</i>		<i>EIA State-level average</i>	
	<i>Electricity (kWh)</i>	<i>Natural gas (Mcf)</i>	<i>Electricity (kWh)</i>	<i>Natural gas (Mcf)</i>
Austin	14,610	46	13,627	48
Triangle	12,273	51	13,713	55
Portland	12,791	51	12,109	64
2010				
Austin	14,301	54	14,382	53
Triangle	11,885	65	14,851	67
Portland	11,850	59	11,564	60

*Expenditure estimates are averaged for homes built after 1994.

Sources: US Energy Information Administration, *Electricity Data Browser*

<http://www.eia.gov/electricity/data/browser/#/topic/5?agg=1.0&geo=000000040202&endsec=8&freq=A&start=2001&end=2010&ctype=linechart<ype=pin&pin=&rse=0&maptype=0>; US Energy Information Administration, *1990–2011 Number of Retail Customers by State by Sector (EIA-861)* <http://www.eia.gov/electricity/data/state/>; and US Energy Information Administration, *Natural Gas* <http://www.eia.gov/naturalgas/data.cfm#consumption>.

References

- Alberini, Anna, Will Gans and Daniel Velez-Lopez. 2011. Residential Consumption of Gas and Electricity in the US: The Role of Prices and Income. *Energy Economics* 33: 870-881.
- Bardhan, Ashok, Dwight Jaffee, Cynthia Kroll and Nancy Wallace. 2014. Energy Efficiency Retrofits for US Housing: Removing the Bottlenecks. *Regional Science and Urban Economics* 47: 45-60.
- Brounen, Dirk and Nils Kok. 2011. On the Economics of Energy Labels in the Housing Market. *Journal of Environmental Economics and Management* 62: 166–179.
- Brown, Peter. 2012. Director of Residential Services, Earth Advantage Institute. Personal communication with the authors, May 15.
- Dastrup, Samuel R., Joshua Graff Zivin, Dora L. Costa and Matthew E. Kahn. 2012. Understanding the Solar Home Price Premium: Electricity Generation and “Green” Social Status, *European Economic Review* 56 (5): 961–973.
- Datta, Souvik and Sumeet Gulati. 2014. Utility Rebates for ENERGY STAR Appliances: Are They Effective? *Journal of Environmental Economics and Management* 68: 480-506.
- Caliendo, M., & Kopeinig, S. (2008). Some practical guidance for the implementation of propensity score matching. *Journal of economic surveys*, 22(1), 31-72.
- Dehejia, R. H., & Wahba, S. (2002). Propensity score-matching methods for nonexperimental causal studies. *Review of Economics and statistics*, 84(1), 151-161.
- Deng, Yongheng and Jing Wu. 2014. Economic Returns to Residential Green Building Investment: The Developers' Perspective. *Regional Science and Urban Economics* 47: 35-44.
- Dinan, Terry and Miranowski. 1986. Estimating the Implicit Price of Energy Efficiency Improvements in the Residential Housing Market: A Hedonic Approach. *Journal of Urban Economics* 25: 52-67.
- Eichholtz, Piet, Nils Kok, and John M. Quigley. 2010. Doing Well by Doing Good? Green Office Buildings. *American Economic Review* 100(5): 2492–2509.
- Eichholtz, P., Kok, N., & Quigley, J. M. (2013). The economics of green building. *Review of Economics and Statistics*, 95(1), 50-63.
- Fuerst, F., J van de Wetering and P. Wyatt. 2012. Is Intrinsic Energy Efficiency Reflected in the Price of UK Office Leases? working paper, October.

- Heckman, J. J., Ichimura, H., & Todd, P. (1998). Matching as an econometric evaluation estimator. *The Review of Economic Studies*, 65(2), 261-294.
- Ho, D. E., Imai, K., King, G., & Stuart, E. A. (2007). Matching as nonparametric preprocessing for reducing model dependence in parametric causal inference. *Political analysis*, 15(3), 199-236.
- Hoen, Ben, Ryan Wiser, Peter Cappers and Mark Thayer. 2011. An Analysis of the Effects of Residential Photovoltaic Energy Systems on Home Sales Prices in California, Lawrence Berkeley Laboratories, Environmental Energy Technologies Division Report LBNL-4476E, April.
- Houde, Sébastien. 2014. *How Consumers Respond to Environmental Certification and the Value of Energy Information*. Working Paper 20019. National Bureau of Economic Research.
- Hyland, Marie, Ronan C. Lyons, and Seán Lyons. 2013. The Value of Domestic Building Energy Efficiency—Evidence from Ireland. *Energy Economics* 40: 943-952.
- Imbens, G. (2014). *Matching methods in practice: Three examples* (No. w19959). National Bureau of Economic Research.
- Jacobsen, Grant. 2015. Do Energy Prices Influence Investment in Energy Efficiency? Evidence from Energy Star Appliances. *Journal of Environmental Economics and Management* 74: 94-106.
- Johnson, R. C., and D. L. Kaserman. 1983. Housing Market Capitalization of Energy Saving Durable Good Investments, *Economic Inquiry* 21: 374-386.
- Kahn, M. E., & Kok, N. (2014). The capitalization of green labels in the California housing market. *Regional Science and Urban Economics*, 47, 25-34.
- Kok, N., and M. Jennen. 2012. The Impact of Energy Labels and Accessibility on Office Rents. *Energy Policy* 46 (1): 489-97.
- Laquatra, Joseph. 1986. Housing Market Capitalization of Thermal Integrity, *Energy Economics* 8(3): 134-138.
- McMillen, D. P. (2012). Repeat sales as a matching estimator. *Real Estate Economics*, 40(4), 745-773.
- Newell, Richard G., and Juha V. Siikamaki. 2014. Nudging Energy Efficiency Behavior: The Role of Information Labels. *Journal of the Association of Environmental and Natural Resource Economists* 1(4): 555–598.

- Rapson, David. 2014. Durable Goods and Long-run Electricity Demand: Evidence from Air Conditioner Purchase Behavior. *Journal of Environmental Economics and Management* 68: 141-160.
- Rosenbaum, P. R., & Rubin, D. B. (1983). The central role of the propensity score in observational studies for causal effects. *Biometrika*, 70(1), 41-55.
- Rosenbaum, P. R., & Rubin, D. B. (1985). Constructing a control group using multivariate matched sampling methods that incorporate the propensity score. *The American Statistician*, 39(1), 33-38.
- Straszheim, Mahlon. 1974. Hedonic Estimation of Housing Market Prices: A Further Comment. *Review of Economics and Statistics* 56(3): 404-406.
- Todd, P. (2008). Matching estimators. *The New Palgrave Dictionary of Economics*, 2.
- US EPA. 2012a. ENERGY STAR® and Other Climate Protection Partnerships: 2011 Annual Report. Washington, DC: US EPA (December). Available at http://www.energystar.gov/ia/partners/publications/pubdocs/2011_AnnualReport_Final_low-res_12-13-12.pdf?ca38-facc (accessed March 5, 2013).
- US EPA. 2012b. ENERGY STAR Qualified Homes, Version 3 (Rev. 06) National Program Requirements. Washington, DC: US EPA (September). Available at http://www.energystar.gov/ia/partners/bldrs_lenders_raters/ES_Combined_Path_v_65_clean_508.pdf (accessed March 5, 2013).