The “green premium” for environmentally certified homes: a meta-analysis and exploration

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Abstract

Housing has a large environmental impact. Certification programs such as LEED and Energy Star endeavor to reduce this impact with homes that, among other things, perform above code requirements. However, the voluntary nature of certification implies the need for a price premium, where certified homes sell for more than similar uncertified homes. Does this premium exist? And if so, what are buyers paying for?

We conducted a systematic review and meta-analysis of existing studies of the premium for certified homes. Over 20 studies worldwide, the mean weighted premium was 4.3% ± 0.6% SD. This finding was robust, changing little over numerous variations in the analysis, and was considerably less than the 9% figure used in some certification marketing.

Next, we explored several possible sources of value behind the premium, in a sample of 43 certified homes in Portland, Oregon USA. We compared the financed yearly cost of the premium to the market values of the utility savings and carbon mitigation associated with those homes. On average per year, the premium cost the owner $891, while the home provided utility savings of $327, and carbon mitigation with a market value of $24. Many other purchases and lifestyle options available to consumers deliver bigger carbon benefits at lower prices per ton.

These results suggest that while certified homes do provide environmental and financial benefits, those benefits are often limited in scope. Nonetheless, surveys indicate buyers of certified homes are satisfied with their purchases, in part due to tangible but hard-to-quantify characteristics such as comfort and quality. In our Portland sample, 60% of the premium's value came from such sources, while 3% came from carbon mitigation and 37% from utility savings.

The premium for certified homes seems to represent a collection of benefits for the buyer. Currently the values of individual benefits are not well quantified, and open to question. As real estate markets and green building techniques continue to evolve, home certification programs may need to evolve as well, to continue to prove their homes are distinctive enough to merit a higher price. # # #

Introduction

Housing has a substantial impact on the global environment. In the United States, residences represent 17% of national greenhouse gas emissions, when associated electrical generation is included (US Environmental Protection Agency 2015, page ES-23). Moreover, housing decisions made today have effects far into the future, with the average lifespan of an American home 70 years (Oregon Department of Environmental Quality 2010, page 9).

There are many approaches to reducing the environmental impact of newly constructed housing. Governments can create mandates that require all builders and developers (hereafter, simply called "builders") to build in a "greener" way. For example, planning and zoning could require smaller units in denser arrangements (Ewing and Rong 2008); or energy codes could be introduced into areas that lack them (Aroonruengsawat et al. 2012).

Another set of approaches avoids mandating green construction, but instead tries to inform consumer choice. In Europe, homes for sale may be required to post "Energy Performance Certificates," or EPCs (Fuerst et al. 2015; Brounen and Kok 2011), similar to the energy labels attached to refrigerators in the USA. The hope is that buyers will prefer the greener choice.

There are also voluntary whole-home certification programs, for example LEED for Homes (US Green Building Council 2014b), Environments for Living (Environments for Living 2015), and dozens of lesser-known or regional brands. Such a certification promises the buyer the home meets a defined collection of features and/or performance standards.

In the United States, whole-home certification programs have become nearly synonymous with "green" housing. Unlike the field of commercial building, where there is a substantial debate about the efficacy of building certifications (Malin 2008; Newsham, Mancini, and Birt 2009; Scofield 2009; Carassus 2011; USA Today 2012), residential certifications have not yet been examined with a dispassionate eye.

Can voluntary whole home certifications lead to a substantial, rather than symbolic, reduction in the environmental impact of housing? If so, we presume that three criteria must be met.

First, as with any approach to greener housing, mandated or voluntary, the premises behind the program must be correct. For example, certified homes must reduce resource use in practice as well as intention. In terms of energy, this is not completely clear, because nearly all home certifications are based on modeled energy use instead of actual, observed energy use. Attempts to calibrate such models (Rubado 2015; Ingle et al. 2014) and confirm the expectation that certified homes reduce actual use (Hassel, Blasnick, and Hannas 2009; P. Jones and Vyas 2008) have produced mixed results.

Second, any greener housing program must influence a broad part of the market. The highest standards will have little global effect if only a few improved dwellings are created. Certification's influence does appear to be growing. McGraw-Hill Construction (2014) estimates that by 2016, "green" construction will be about 30% of the US residential market by dollar value.

Finally, for a program driven by consumer choice, such as certified housing, there is an additional challenge: the greener choice must have demonstrated value. Buyers must show they want such housing, and builders must have some reason to choose to create it. The clearest sign that both these conditions are being met is a premium in the price for certified housing — that is, a surplus that buyers are willing to pay, above and beyond the market price for a similar but uncertified dwelling.

This "certification premium" is the subject of this paper. We take a practical, non-theoretical approach to the topic, focusing on the questions most relevant to those working in real estate and sustainability: how big is the premium, if it exists, and what are people paying for?

In recent years there have been numerous studies of the sales price premium for certified homes, as well as similar work on commercial real estate, for example Reichardt et al. (2012). Most of the residential studies are not widely known, perhaps because their geographic focus varies (Europe, the US, the Pacific Rim) and many were published outside the formal peer-reviewed literature.

Only one study has garnered much attention, and unfortunately it has become a source of confusion. Kok and Kahn (2012) initially reported a 9% premium for certified homes across California. However, the authors revised this analysis (Matthew Kahn, personal communication) and in a journal publication of the results (Kahn and Kok 2014 p. 30) reduced the finding to 5%. In the meantime the 9% figure made its way into major newspapers (e.g. Harney 2012) and, as of this writing, was still in use in the marketing materials of at least one certification program (US Green Building Council 2014a; US Green Building Council 2014c).

As a result, there is a strong need for a credible summary of all the research on the certification premium.

Assuming that some premium exists, there is also a need to move on to the question of *why* it exists. What are buyers paying for?

This is an essential topic, because the source of value behind the premium influences the prospects for voluntary certification as a movement. We presume that if certification represents a mere label or provides few tangible benefits to the buyer, the premium will decay in size, and the builder's incentive to voluntarily create this type of housing will decline. We also presume that if certification represents meaningful benefits to the buyer, its value will stabilize, and the prospects that voluntary certification can influence the broader housing market, and thereby the global environment, will improve.

Only one possible basis for the certification premium has been discussed in any detail in the literature: savings in utility costs (electricity, gas, etc.). For example, Amado (2007) found a sales price premium and associated it with energy savings, writing "consumers appear to recognize and pay for this form of expected future energy savings." Walls, Palmer, and Gerarden (2013) have calculated the value of utility savings for several sets of certified homes.

While these works do not rule out other sources of value, the focus on utility savings implies these savings are, or should be, the central reasons for the premium. However, from a consumer perspective, there is no evidence for this. Surveys of buyers of certified homes (e.g. Guild Quality 2013), clearly suggest a wide range of reasons buyers might pay a premium. It could be that buyers value something else entirely, and utility savings are a side effect.

A less restricted survey of the sources of value in the premium would be welcome, one that considers all the possible benefits of the certified home, from a buyer's or resident's point of view.

In this paper we look at the sales price premium for certified homes with two lines of research, one very formal and the next much more exploratory. First, we objectively quantify the size and significance of the premium with a systematic review and meta-analysis of all relevant studies worldwide. The result is a weighted mean average for the certification premium, with confidence limits.

Next, we explore the practical scale of the premium, and the possible sources of its value, in an actual real estate marketplace. Using a sample of well-characterized certified homes in Portland, Oregon, we compare the financed cost of the premium to the market values of utility savings and carbon benefits associated with those homes. To interpret these results, we turn to consumer surveys and a model of "green" lifestyle choices available to consumers. The result is a draft breakdown of the premium into three sources of value.

This combination should be useful to readers of several types. The formal meta-analysis of the premium will be a valuable reference for appraisers, lenders, builders, and anyone involved in housing. Meanwhile, we hope our exploratory breakdown of the premium will inspire a more exacting discussion of what gives green homes value, in both the financial sense and the environmental one.

Systematic review & meta-analysis

Our goal was to find and credibly summarize all the existing studies of the price premium for environmentally certified homes, given a reasonable amount of labor.

Search strategy and syntax

We performed our literature search in June 2015, looking through six search indexes, both academic (Google Scholar, Academic Search Premier, Academic OneFile, and JSTOR) and general interest (Google.com, Business Source Premier). Because we wanted a diversity of perspectives, we followed the advice of Borenstein et al. (2009), and did not limit our search to peer-reviewed journals. We found that there was relevant data in consulting reports and other "gray" literature, and that the venue of publication was not a reliable indicator of the quality of the work.

Our search was on the full text (when available) and not simply keywords. It looked for combinations of the ideas of environment, home, certification, price, and surplus. The syntax, which changed slightly depending on the interface, was: "(environment OR environmental OR green) AND (home OR house OR residence OR residential OR dwelling) AND (certified OR certification OR accredited) AND (value OR price) AND (premium OR surplus OR capitalize OR capitalization)".

When possible, we set the publication year to 2005 or after. This was a practical measure more than it was a date limitation. We did not want our full-text search to be overwhelmed by spurious results from before certification influenced the market. Green housing represented only 2% of the US residential construction market in 2005 (McGraw-Hill Construction 2014).

Applying this syntax in a full-text search yielded thousands of results, nearly all of them documents that matched some but not all of our conditions. Within each search index, we sorted by "relevance" if possible, then reviewed the first 100 entries presented, reading the abstract or other summary presented by the indexer. Any source (that is, a publication or other document) that looked like it might fit our criteria (described below) was put into a list of candidates. There were 62 candidate sources after all six search indexes were reviewed.

Inclusion criteria

We attempted to obtain the full text of all 62 candidate sources, though in a few cases only the abstract was available. Looking through all available text, we evaluated each source against the following criteria for inclusion in our meta-analysis. Sources contributing data to our meta-analysis were required to:

- Contain an estimate of the sales price premium (not a rental premium) for a whole-home environmental certification, such as LEED or Energy Star for Homes (in contrast to premiums associated with individual features such as photovoltaic cells or appliances). A few papers looked at Energy Performance Certificates, or EPCs, which also apply to whole homes; we counted higher levels of EPC (A, B, or C) as "certified" for the purpose of our analysis *if* these homes were explicitly compared to other levels of EPC.
- Use data from individual homes, such as houses or condominiums, not large developments sold as a whole;
- Be based on actual real estate transaction prices (in contrast to surveys based on intent or recollection);
- Include sufficient methodological detail that the statistical design was clear (e.g. paired samples with t-test; multiple “hedonic” regression on log-linear dependent, etc.);
- Be independent of each other. (When the same set of market data was analyzed or reported on more than once, only the single most detailed or credible source would be used);
- Contain sufficient statistical detail to express the certification premium in terms of a proportional price above or below comparable uncertified homes (for example +0.062 or +6.2%);
- Make credible attempts to separate the effect of certification from other likely influences on sales price, such as location. (A simple summary of average sales prices for certified vs. uncertified homes, as is commonly available in regional real estate sales reports, would be insufficient, because certified homes might be located in more expensive neighborhoods.)

During this process, we also examined the citation list of each candidate source publication for any additional sources which might be useful. We added such sources to the list of candidates, and reviewed them as well. Also added to the list of candidates were several unpublished reports we, the authors, have conducted for institutional clients.

After this review, 17 sources met the criteria specified above. They are the basis of the meta-analysis, and are listed in the Appendix. Readers familiar with the field may note the absence of several papers from the Appendix. To demonstrate they have not been omitted from consideration, here are a few examples: Kok and Kahn (2012) and Bradshaw (2006) each used data which was later re-analyzed and republished, so only the later sources were used. Bloom, Nobe, and Nobe (2011) did not present statistical results in sufficient detail to characterize the premium as a proportion. Heinzle, Yip, and Xing (2013)'s work was based on a survey, not transaction prices.

In general, we feel we have covered the field.

Validity of the certification assignments

An essential premise of each of the 17 sources is that homes have been correctly assigned to "certified" and "uncertified" groups. The Appendix lists the supplier of information for this assignment: a government or nonprofit organization ("agency"), the certifying organization themselves ("certifier"), a "private" supplier of data, a combination of the previous suppliers ("mixed"), and finally, for 4 of the 17 sources, "MLS."

This last source of information is potentially problematic. MLS means "multiple listing service" and refers to a database where individual properties are characterized via entries by real estate sales agents. Such records can be inaccurate (Amado 2007; Shewmake and Viscusi 2015; Stephenson 2012), perhaps because real estate sales agents may not know the difference between whole-home certifications and labels on individual features, such as refrigerators. While it seems excessive to discard MLS-based sources entirely, they deserve detailed examination later.

Distinguishing sources and "studies", primary and secondary results

Though 17 source publications met our criteria, some of these sources examined more than one real estate market. For example, Griffin, Kaufman, and Hamilton (2009) provided results for two different real estate markets, Seattle, WA, and Portland, OR. In the language of Borenstein et al. (2009), this one source contained two different "studies" — independent estimates of the same quantity.

In addition, many sources presented several variant estimates of the certification premium. For example, Shewmake and Viscusi (2015) presented four variants: one general model for any certification, and three for individual certification brands such as Energy Star.

This variety of related results was a danger to the objectivity of the meta-analysis. To throw all such variants into a single data pool could weight the final meta-analytical summary by a meaningless factor, the number of variant results the authors chose to publish.

We needed to choose a single “primary” result for each source and geographic market. Our overriding interest was the effect of certification on home prices *in general*, without regard to individual certification brands or other subgroups. Therefore, for each market in each source, we chose a “primary” variant that came closest to representing the general effect of certification.

To identify this primary result, we first looked to the author's text and abstract, to see if the authors presented any of their variants as a single simple summary of the effect of certification. We also looked at the size and breadth of each variant and chose the most general. For example, if the authors presented separate variants for houses, for condominiums, and for all kinds of housing combined, we chose the combined variant. When no combined results were available, we chose the variant that represented the biggest group in terms of the number of certified homes studied. For example, if there were variants for LEED, based on 100 homes, and for Energy Star, based on 1000 homes, we chose the Energy Star variant as the primary result.

Applying this examination to the 17 sources yielded 20 variants we considered primary results. These are identified in the Appendix in the column “role in meta-analysis”. Any variants remaining we labeled “supplemental,” and saved for detailed analyses, focused on particular types of housing or brands of certification.

Expectations, hypothesis, and meta-analytical model

Our meta-analysis generally follows the guidelines, vocabulary, and math of Borenstein et al. (2009). The "effect size" our meta-analysis aims to summarize is the certification premium, which we will notate b_c, and define as the proportional surplus in sales price for a certified home above a similar uncertified one. For example, when an uncertified home costs \$100,000, and a similar certified one costs \$104,000, the premium b_c is 0.04, or 4%.

Our hypothesis is that the weighted mean effect size, $\overline{b_c}$, as figured by the meta-analysis procedure, will be significantly more than zero.

Simple meta-analyses come in two forms, the "fixed effect" and the "random-effects" (perhaps better called the multiple effects) models. The fixed effect model assumes the true effect size is the same across all studies, and that the only reason for variation among studies is sampling error. The random-effects model allows that other factors may alter the effect size from study to study, and variation among studies comes not only from sampling error but the influence of those other factors (Borenstein et al. 2009, chapter 10).

We chose the random-effects model, because it seems highly plausible that other considerations, for example market conditions and certification brand, could influence the size of the certification premium. Accordingly, we expect heterogeneity to be high, and view the weighted mean produced by the meta-analysis as the best summary of the available and compatible studies, not a universal prediction of the certification premium in every circumstance.

Statistical details

The 20 primary studies all computed the same quantity, the certification premium, and in the same terms: a proportional difference in price. This makes the certification premium a good candidate for meta-analysis. However, the studies did not always use the same method or express the result in the same way, so some standardization was necessary.

The most common statistical design for determining the certification premium, used in 15 of the 20 primary studies, was a multiple regression model across a large number of individual properties. This regression had the general form

$$\ln(P) = \alpha + b_{CERT}CERT + b_1X_1 + b_2X_2 + b_3X_3 + \cdots + \varepsilon$$

where $\ln(P)$ is the natural log of sales price P, which is in currency units such as dollars; α is a constant; $CERT$ is a dummy variable indicating certification status, where 0=uncertified and 1=certified; b_{CERT} is the coefficient for $CERT$; X_1, X_2, X_3, etc. are characteristics of homes, either continuous or dummy variables, useful for predicting property prices (number of bedrooms, zip code membership, etc.); b_1, b_2, b_3, etc. are the coefficients for those characteristics, and ε is the residual error.

Note this is a “log-linear” regression, where the dependent variable is the natural log of sales price. At first glance this appears to present an issue, in that homebuyers do not pay in log-transformed currency. We are interested in unlogged sales prices, in particular the ratio $(P_{CERT=1}/P_{CERT=0})$. That ratio, minus 1, is the certification premium. However the log-linear equation has a convenient mathematical property, where, other terms being equal, $P_{CERT=1}/P_{CERT=0}$ is equal to $e^{b_{CERT}}$. Also conveniently, $e^{b_{CERT}} - 1 \approx b_{CERT}$, when b_{CERT} is low, as it usually is in studies of this subject. For example, when $b_{CERT} = 0.03$, the transformation $e^{b_{CERT}} - 1 = 0.0305$.

Accordingly, nearly all authors using the loglinear model to find the certification premium have simply used b_{CERT} directly as their estimate of the certification premium, and not performed any back-transformation. We have followed this convention. We used b_{CERT}’s taken from the contributing studies directly as b_c’s for our meta-analysis.

The wide use of the loglinear model means that 15 of our 20 primary data points are regression coefficients. Though it is unusual to perform a meta-analysis on regression coefficients, there is nothing wrong with it. A meta-analysis can be performed on any topic where multiple studies have measured the same effect on the same scale. Given that most of our studies use very similar regressions, by Becker and Wu (2007)'s criteria, certification premiums look like a good candidate for meta-analysis.

The remaining five studies used a different design to estimate the certification premium: paired samples analysis. These studies, which are identified in the Appendix, calculated their premiums based on unlogged price data. We converted these certification premiums b_{c0} into the "logged" scale of the results from the loglinear regression studies, using the transformation $\ln(b_{c0} + 1) = b_c$. Likewise, we adapted any standard errors associated with b_{c0}'s into the "logged" scale. Though we performed these transformations for consistency, the resulting changes were so small at typical magnitudes of b_c and b_{c0} , that there was likely little effect on the outcome of the meta-analysis. For example, $\ln(0.0400 + 1) = 0.0392$.

7 of the 20 primary studies (4 based on loglinear models, 3 on paired samples) did not report standard errors along with their certification premiums. The meta-analysis requires standard errors for each of the contributing b_c's, in order to calculate weights for the mean summary effect $\overline{b_c}$. When standard errors were missing, we imputed them based on the 13 primary studies which did report standard errors. Several papers (Idris and Robertson 2009; Furukawa et al. 2006) have defended the use of imputed standard errors in meta-analyses, as a way to preserve valuable data that would otherwise be thrown away. After reviewing Wiebe et al. (2006), which reviews numerous methods of imputing these values, we chose to impute standard errors based on the mean coefficient of variation observed in the fully-reported studies.

The meta-analysis calculations were executed with the R package 'metafor' (Viechtbauer and others 2010), procedure 'rma.uni()', with the 'DL' option for the DerSimonian and Laird method.

Meta-analysis results

The meta-analysis of the 20 primary studies is shown in Figure 1. As the annotations on this figure show, studies were available across a wide range of geography (the US, the Pacific Rim, Europe) and for 9 or more (depending on how you count them) different certification brands. The estimates ranged from -0.056 to 0.18, but that range is deceptively broad. 90% of the values were between 0.017 and 0.117, and 70% were between 0.032 and 0.092.

The weighted mean certification premium was 0.043, with standard error 0.006. Put another way, the mean was 4.3% $\pm$ 1.0% (ninety percent confidence intervals for the mean). The heterogeneity statistics were Q=197.9 ($p<0.001$), I^2=90%, and tau=0.0219. This suggests that a large part (90%) of the variability among studies was due to variation in actual effects in different studies, and not merely sampling error. The tau statistic suggests that, if a very large number of studies were conducted, 90% of the studies would show premiums between 0.6% and 8.1%.

Possible change over time

Earlier studies had a wider range of values, and perhaps slightly higher premiums, than more recent ones. The studies in Figure 1 are sorted by the last year of data collection. Studies at the bottom are newer than studies at the top. The first 10 studies, which represent data collections ending from 2004 to 2009, had effect sizes ranging from -5.6% to 18.0%, and a median of 5.7%. Meanwhile the latter 10 studies, which represent data collections ending from 2010 to 2014, had a smaller range, from 1.7% to 8.0%, and a slightly smaller median of 5.0%.

Robustness checks

We checked the robustness of the 4.3% weighted mean, by running a number of variant analyses visible in Figure 2.

- The top result repeats the results of the meta-analysis of the primary studies for reference: a weighted mean effect of 4.3% ± 1.0% (ninety percent confidence intervals for the mean).
- The "trim/fill" analysis (Borenstein et al. 2009, chapter 30) looks to counter the "publication bias" issue of concern to meta-analysts. It is possible the systematic review did not uncover small studies that were never published because they had “undesirable” results: in this case, negative or nonsignificant results for the premium. The trim/fill analysis repeats the existing meta-analysis using the 20 primary studies, but adds hypothetical studies of lower precision

which have a contrasting (in this case, more negative) effect, mirroring the existing studies of lower precision. This calculation was executed by the 'metafor' package 'trimfill' (Viechtbauer and others 2010). The resulting weighted mean was 3.0% ± 1.0%.

- The "primary dataset without MLS sources" variant addresses the data quality problem, described earlier, associated with MLS records (Amado 2007; Shewmake and Viscusi 2015; Stephenson 2012). Despite the poor track record of MLS sources in identifying certified properties, removing MLS-dependent sources from the meta-analysis changed the results very little, with a weighted mean of 4.2%±1.2%.
- Similarly, estimated standard errors ("SE's") are a possible source of error for the meta-analysis. Removing sources with estimated SE's resulted in a mean of 4.2%±1.4%.
- Limiting the meta-analysis to “loglinear models only” makes the contributing data more consistent in method, at the cost of taking away some studies. Weighted mean: 4.5%±1.3%.
- Limiting the meta-analysis to “paired samples only” makes the contributing more data consistent in method, but uses the less common statistical model. Weighted mean: 3.9±1.6%.

Subgroups and themes

The remaining results in Figure 2 are not robustness checks on the primary results, but new meta-analyses that focus on particular subgroups and themes of interest. These analyses bring in studies labeled "supplemental" in the Appendix, as appropriate to the topic. As before, only one result was allowed for each data source in each market.

- "SFR's in USA" refers to single-family-residences (houses) in America. Weighted mean with 90% confidence limits: 4.1%±1.1%.
- "SFR's in USA, no MLS sources" repeats the above analysis, but omits studies which have a potentially problematic dependence on "multiple listing services" (as described earlier). Weighted mean: 4.2%±1.5%.
- "SFR's in N. America, MLS sources only," for comparison, considers *only* sources dependent on multiple listing services. Weighted mean: 4.2%±2.0%.

- "Condominiums only" summarizes the available data for this common alternative to SFRs. Only one of the 7 studies is from the United States (see Appendix). Weighted mean: 3.3%±2.5%.
- "Energy Star only" summarizes the results for the most common certification in the United States. These are like entirely SFR's (see Appendix). Mean effect: 3.9%±1.8%.

Cost & components of the premium: an exploration

Context

Having established that the premium exists, we feel ready to explore its meaning in practical terms. How much are buyers effectively paying? What are they paying for? And are they getting a good deal?

In this portion of our work, we calculate the size of the premium, and estimate its composition, from a homeowner's perspective in a real marketplace. By size we mean the yearly expense of the premium, and by composition, we mean the collection of specific benefits that give the premium a positive value. As (we think) the first effort of its kind, it will be necessary to abandon the formality that characterized our meta-analysis. To build any picture of the composition of the premium, we must mix and match diverse and imperfect sources of information. Our goal is to start a discussion, not provide the final word.

Perspective from end-user surveys

The most obvious way to investigate why consumers pay the certification premium would be to simply ask them. A handful of surveys of buyers of certified homes exist (Bernstein 2007; Guild Quality 2013; Northwest Energy Efficiency Alliance 2012). These are key references in that the buyers themselves speak of their intentions, answering questions like “What were the main factors that made you decide to purchase a [certified] home?”

Unfortunately, these sources are also problematic. Questions are not compatible across surveys, either in language or in the way they are summarized numerically. Perhaps more significantly, the questions asked may reflect the foci or marketing messages of the certification programs themselves. For example, a survey of owners of LEED homes (Lee 2012) had specific questions about indoor air quality and pro-environmental activities, while a survey about Energy Star homes (Northwest Energy Efficiency Alliance 2012) focused mostly on energy- and appliance-related matters.

These surveys cannot be meaningfully summarized in a single chart or table. But nonetheless consistent themes emerge.

- None of the sources suggest that a single reason dominates. All the sources suggest that certification represents a collection of benefits.
- The most common reason buyers say they choose a certified home is utility savings. For example, "lower energy bills" tied for first place as the biggest reason why buyers chose certified in a survey of Energy Star for Homes owners (Northwest Energy Efficiency Alliance 2012, Table 31). Similarly, "operational cost savings" were the top-rated decision factor in a 2007 study of green home purchasers for the National Association of Home Builders (Bernstein 2007).
- Another common reason is the notion of doing something good for the broader environment outside the home. "Environmental concerns" were the second leading decision factor in the NAHB study (Bernstein 2007). In a study of "National Green Building Standard" certified home owners, 90% of respondents said they gained satisfaction knowing they had "done the right thing" buying green (Guild Quality 2013).
- Finally, there is a third category of reasons, benefits that are simultaneously tangible to buyers and residents of certified homes, but hard to quantify on an individual basis. These reasons include the perceived comfort, quiet, and reduced maintenance of their homes (noted as benefits by respondents in Guild Quality 2013); a belief that a green home is healthier (the third leading decision factor in the NAHB study); and a general sense that

certified buildings are higher quality (Northwest Energy Efficiency Alliance 2012, Table 31).

A three-part breakdown

This reading of end-user surveys provides an evidence-based outline for a breakdown of the certification premium. The total value of the premium can be seen as the sum of values of: (i) utility savings, (ii) “externalized” environmental benefits (that is, benefits that affect the wider world, not conditions inside the home), and (iii) a set of “comfort and quality benefits” in and around the home.

Utility savings and externalized environmental benefits make a fascinating contrast. Utility savings are a practical, "selfish" feature that could appeal to a buyer regardless of their concern for the environment. The homebuyer gets a clearly quantifiable financial benefit every month, in the form of reduced operating expenses compared to a similar noncertified home.

Meanwhile, externalized environmental benefits (hereafter, simply called “environmental benefits”) are utterly abstract and “selfless,” in the sense that the homebuyer receives no tangible reward; any benefits to the natural world or human sustainability are remote in time or space. This is especially true for a commonly mentioned environmental benefit, carbon footprint reduction. For example, an Energy Star infographic states that each home “reduces greenhouse gasses (GHG) by 3700 lbs. per year, which is the equivalent of the GHG emissions absorbed by planting 43 trees” (EnergyStar.gov 2015b).

We will use carbon mitigation to represent the external environmental benefits associated with a certified home. There are two rationales for this.

First, carbon emissions are strongly associated with nonrenewable energy use, which represents the bulk of a residence’s long-term impact on the environment. A general review of life cycle analysis results in the construction field (Buyle, Braet, and Audenaert 2013) found that the “use” phase dominated many environmental impacts of buildings, not just climate change impacts, mainly through heating and cooling. For example, the Oregon Department of

Environmental Quality (2010, Table 8) estimated that energy use over a dwelling's lifetime, and not the dwelling's materials, construction, or demolition of the building, was associated with 86% of the dwelling's lifetime carbon impact, as well of 92% of ozone depletion effects, 63% of ecotoxicity effects, and 67% of acidification effects. Carbon impacts and other environmental impacts are often correlated.

Second, carbon mitigation is quantifiable, and available to consumers in the marketplace. Many products and lifestyle choices, such as the purchase and use of an electric vehicle, are associated with carbon benefits and available to consumers. Consumers can also purchase carbon offsets from agencies such as terrapass.com and nativeenergy.com.

Once the market values of utility savings and carbon mitigation have been subtracted from the premium, the remainder is our estimated market value for everything else certification has to offer, in the form of that collection of "comfort and quality" benefits. (Also included in the "comfort and quality" category would be any environmental benefits that are not correlated with carbon benefits.)

Local data source, parameters, and calculations

We pursued this three-part breakdown with a set of certified homes in Portland, Oregon. With the assistance of the Energy Trust of Oregon, we obtained the addresses and utility and carbon characteristics for 43 "Earth Advantage" certified homes sold as new between 2008 and 2014. We obtained sale prices for these properties from the local real estate listing service (rmls.com).

Earth Advantage certification is similar to other popular certifications in its energy performance requirements. Earth Advantage homes must show a 15% improvement compared to a similar home built merely to code standards (Earth Advantage 2015), though in practice many homes score better (an average of 21% in our 43 homes). This standard is the same as Energy Star's, which requires a 15% improvement vs. code (EnergyStar.gov 2015a); and LEED's, which qualified the “Energy and Atmosphere” aspect of its homes with Energy Star standards (US Green Building Council 2008; note in October 2014 LEED changed this requirement, see Foss 2014).

These characteristics mean that our sample of 43 certified homes are representative of the great majority of certified homes in the United States. They are a “basic” or “entry-level” green homes, generally made in volume by corporate builders, not super-high performance custom buildings.

“EPS” modeling results (Energy Trust of Oregon 2015) were provided for each home by Energy Trust of Oregon. These contained estimated energy use per year, estimated carbon footprint per year, utility costs, and, for comparison, estimated energy use and carbon footprint if the home had been built merely to code standards. To keep the analysis simple, we assumed the predictions of the EPS model were correct.

To find the premium for each of our 43 homes, we referred back to the weighted mean from our meta-analysis. We assumed that the sales prices of our homes included a cash premium of 4.3%.

However, the cash premium is not the amount typically paid by buyers. 68% of home buyers in the United States use a mortgage, according to CoreLogic (2015). Approximately 90% of buyers’ mortgages have 30 year terms (Freddie Mac 2015). The key parameter for financed cost is not term of the loan, but interest rate. We created three interest rate scenarios, mean (5.06%/yr.), low (3.31%), and high (6.8%), based the mean, minimum, and maximum values in a record of weekly average mortgage rates from 2005-2014 inclusive (Federal Reserve Bank of St. Louis 2015).

While the cost of the premium stays constant, given a fixed rate mortgage, utility costs tend to rise each year. We projected the energy cost savings from the EPS model into the future, based on a government estimate of energy cost increases (US Energy Information Administration 2015, page A-8). In the residential sector, combining gas and electricity, this source predicts prices will rise an average of 2.7% per year from 2013 to 2040. We call this the "mean" scenario, and create "low" and "high" scenarios by adjusting up or down a percent (1.7% and 3.7% per year).

Cash & financed costs of the premium

Table 1 describes our sample of Portland homes. The average sale price was $336,000 (range $180,000-$492,900). This implies cash premiums averaging $13,744, and ranging from $7362-$20,159. In the financed terms relevant to the majority of buyers, the average premium cost $891/year, and ranged from $477 to $1308/year, using the mean interest rate scenario. For the low and high interest rate scenarios, the means were $723/year and $1075/year.

Utility savings

Utility savings averaged $327 per home in the first year of ownership, according to the EPS model, and ranged from $95 to $1240 (Table 1). Figure 3 compares these first-year utility savings to the financed costs of the premium. Utility savings are usually only a quarter to a half of the financed cost — a mean of 38% in the first year, assuming the mean interest rate scenario. Only 1 of the 43 properties saved more money than the premium cost in the first year. Alternate scenarios involving the higher and lower interest rate scenarios did little to change the basic tenor of the results (Figure 3).

As years go on, increases in energy costs should make the savings associated with certified homes more valuable. Figure 4 investigates this. To draw it, we calculated cumulative sums for both the cost of the premium, and the utility savings due to certification, and figured the number of years until the total savings equaled or exceeded the total premium expense. The average was 46 years with the mean interest rate and energy cost increase scenarios combined (Table 1). For a low-interest rate, high-energy cost increase scenario, the average was 35 years, and for a high-interest, low-energy increase scenario, 62 years (Table 1). These durations are considerably longer than 13 years, the average length of time homes are held by American buyers (Emrath 2013), and 30 years, the most common length of mortgage (Freddie Mac 2015).

Carbon mitigation and its market value

According the EPS model, the carbon mitigated by the 43 Portland homes averaged 1.2 tons/year, with a range of 0.5-2.0 tons/year (Table 1). Figure 5 plots the carbon mitigated by each home against the financed cost of the premium. In the case of hypothetical homebuyers who are only interested in carbon mitigation, the average cost is about $756 per ton mitigated.

Is this a good buy? Unlike with utility expenses, there is no standard market price for carbon benefits from a homeowner's perspective. However, homebuyers do have other options in the marketplace. They can purchase products and/or make lifestyle changes for which both costs and carbon benefits can be computed on a yearly basis — for example, the purchase and use of a hybrid car, or the purchase of renewably sourced electricity.

All such calculations involve numerous assumptions about lifestyle (for example, the number of miles driven) and costs (for example, the cost of a hybrid car). For such calculations we have relied on a well-documented collection of such consumer options, the University of California Berkeley's CoolClimate household calculator (coolclimate.berkeley.edu, hereafter referred to as "CoolClimate"). This software tool is based largely on the peer-reviewed work of C. M. Jones and Kammen (2011).

Generally, CoolClimate's estimates summarize the effects of *switching* from one product or service to another, for example from a regular car to a hybrid car. Its outputs are the *differences* in costs and carbon impacts due to the switch.

We asked CoolClimate for carbon reduction options for an average Portland household. Most of the resulting options and numbers we used as-is, but we made some modifications for longer-lived items, such as cars and photovoltaics. CoolClimate does not spread costs for such items over multiple years or account for financing (Christopher Jones, personal communication); we did so to make the results more comparable to a certified home. The complete CoolClimate results, and footnotes detailing the methods, are available in Table 2.

Figure 6 combines selected CoolClimate results with the carbon mitigation and expense data from our 43 certified homes. This reveals that, in terms of the quantity of carbon mitigated, choosing a certified home over a code home is low to medium on the range of household options, with 1-2 tons of carbon mitigated per year, whereas installing photovoltaic panels, or switching from a standard car to an electric vehicle, mitigate 5-6 tons/year.

Meanwhile, the CoolClimate calculator says that the average total footprint of a Portland household is 44 tons/year. Thus, the average certified home mitigates only about 3% of the average household footprint. If an idealistic buyer wants to make a large reduction in their carbon footprint, certified housing on its own may not be sufficient for the task.

In terms of annual cost, the 43 certified homes were again neither the best nor the most expensive carbon mitigation option. Switching to an alternative fuel vehicle is more expensive, at around $2000/year, but many lifestyle options are cheaper. Some options save money while they reduce carbon impact — for example, switching to a "low carbon diet," or telecommuting.

The combination of mitigation volume and annual cost makes choosing certified housing over code housing look like an expensive way to purchase carbon benefits. The net costs, if carbon mitigation is the buyer's only goal, typically range from $500-$1000/ton. Meanwhile, switching to a "more efficient vehicle," bought used instead of new, pays the consumer $70 for every ton they mitigate.

CoolClimate offers two numbers that could be used as a "market standard" price for carbon benefits. It prices carbon "offsets," which can be purchased by consumers in any quantity from vendors such as Terrapass.com, at $20/ton (though as of this writing a quick survey of web sites shows prices as low as $10/ton). CoolClimate also assigns the same price, $20/ton, to the carbon benefits obtained via voluntary purchases of "green" sourced electricity from utilities.

Using $20/ton as the standard price, the average market value of the carbon mitigated in our set of certified Portland homes was $24, with a range of $10-$40.

Partitioning the premium

If we apply market prices for utility costs and carbon mitigation to our sample of Portland certified homes, 37% of the premium's value (an average of $327/year) comes from utility savings, and 3% (an average of $24/year) comes from external environmental benefits. This implies that the remaining 60% (or $540/year) of the value of certification comes from a broad set of "quality and comfort" characteristics.

Discussion

Reality and scope of the premium

Our meta-analysis found that "green" certified homes trade at a modest but fairly consistent premium compared to similar uncertified homes, with a weighted mean of 4.3%. This result was fairly consistent. 70% of the primary studies reported certification premiums of 3.2% to 9.2% (Figure 1), despite the wide range of geographic locales and certification brands; only one of the 20 primary studies contained a negative estimate of the premium (Yoshida and Sugiura 2010)[1].

The weighted mean was statistically robust, staying close to 4% despite numerous variations in method and housing types (Figure 2). The most notable deviation came in the trim/fill analysis, where the lower weighted mean premium (3.0% compared to the primary result of 4.3%) implies there may be some publication bias in the field. That is, there may be some smaller, unpublished and "undiscovered" studies, which contain results with lower certification premiums.

Even if so, the trim/fill analysis does not change the basic import of the results. Both 4.3% and 3.0% are significantly more than zero, but less than 5%. The certification premium exists, but on average, it is not large. There is no evidence that the 9% figure, which was mentioned in the Introduction and is still quoted in some marketing materials (US Green Building Council 2014a; US Green Building Council 2014c), applies widely.

There is statistical heterogeneity in our meta-analysis (I^2=90% for the data in Figure 1), but we do not see this as a problem. We did not anticipate homogenous results; we believe the

[1] These authors speculated that the green Tokyo condominiums they studied traded at a discount for several possible reasons, including: buyer concerns about increased maintenance costs, given unusual systems and materials; a general lower level of quality compared to similar noncertified buildings; and excessively expensive investments in energy systems. These concerns were not echoed in the other 19 primary studies.

premium probably does vary according to local factors, for example the condition of the local real estate market, the certification brand, the architectural form, etc.

Though some of these factors are available in our data set, we did not have enough observations to reliably report differences between groups. For example, it may be that the highest levels of certification are associated with bigger premiums. DePratto (2015) found that the premium for LEED Gold was twice that of LEED Silver (see the Appendix). However we could not reliably test this interesting proposition, since DePratto's study is the only one in our data set with a result for LEED Gold.

We do see one possible trend, though, an effect of time and market experience. The more variable results from the earliest studies (the top half of Figure 1) may well represent conditions of market inexperience — where neither buyers nor sellers were well-informed about the value (financial or functional) of certified homes compared to others in the marketplace. In more recent studies (the bottom half of Figure 1), estimates of the certification premium seem to have stabilized, perhaps because expectations have become more realistic. The market may now be closer to the ideal spoken of in appraisal literature, where transactions are conducted between buyers and sellers who act "prudently" and "knowledgeably" (e.g. Appraisal Institute 2013).

Magnitude of the premium from a homeowner perspective

The certification premium is modest in several ways. In terms of household finances, 4.3% of the purchase price equated to an average financed cost of $891/year in our Portland sample, or $74/month. In a market where the average monthly mortgage payment is >$1800, the cost of owning certified each month has the same magnitude as everyday purchases such as tanks of gasoline, dinners at restaurants, etc.

Similarly, 4.3% is moderate in terms of premiums paid for home features. Some of the studies in our meta-analysis reported premiums for features unrelated to certification. Shewmake and Viscusi (2015) found the presence of a pool added 13% to the natural log of home price. Aroul and Hansz (2012) found an additional full bath added 9%. Stephenson (2012) also looked at bathrooms, and found a premium of 6.8%. Kahn and Kok (2014) found that a garage added 4.7%, a cooling system 4.4%, an additional bathroom 4.3%, a "view" 3.8%, and an additional bedroom 2.9%, while a "distressed" sale came with a -12% premium (that is, a discount).

These numbers suggest that certification, with a weighted mean premium of 4.3%, has value to the owner as a perk or a positive that could influence their purchasing behavior. Certification does not appear to be a necessity for many buyers.

Composition of the premium and marketing messages

Our breakdown of the premium (37% utility savings, 3% carbon mitigation, and 60% a basket of "comfort, quality, and other" benefits) is an estimate based on market prices for utilities and carbon mitigation. This is a rather academic perspective, given that most homeowners are unlikely to do a complete analysis of the utility savings or carbon mitigation for a prospective home. However, it is still revealing.

Nearly all certification programs promise their homes deliver utility savings (Earth Advantage 2015; EnergyStar.gov 2015b; US Green Building Council 2014c) and imply they offer environmental benefits, though the specificity of marketing messages varies. Our examination of a sample of certified homes in Portland shows utility and environmental benefits do exist, but (at least in the common type of certified home we studied), their scale is often limited.

We found that utility savings were almost never sufficient to cover the financed cost of the premium (Figures 3, 4), a result also implicit in the work of Walls, Palmer, and Gerarden (2013). Even starker was the relatively small impact of certified housing in terms of climate mitigation (about 4% of an average household's carbon footprint), and its small value in the market ($24 on average).

Are marketing messages exaggerating the value of certified homes? The answer depends on the perspective of buyers.

For buyers who are looking *only* for utility savings and carbon mitigation, certification will not often be a good deal. If such buyers are common, the implication is that in the future the certification premium will decline, as consumers slowly come to understand the value of what certification offers vs. other options in the marketplace (e.g., Figure 6).[2]

However, there are no indications buyers are so restrained in their interests. As noted earlier, surveys of certified home owners consistently suggest they associate a diverse set of benefits with certification. These benefits are often tangible but hard to quantify, for example, less draftiness, more quiet, and greater ease of cleaning (Guild Quality 2013), and high levels of comfort and "pleasant"-ness (Lee 2012). 82% of LEED owners said their quality of life had improved in the certified home (Lee 2012).

Those surveys suggest buyers are satisfied with their homes, even as they are aware they may have paid a premium. In the NAHB's 2007 survey (Bernstein 2007), 85% of green home owners were more satisfied or much more satisfied with their current home than their past one; and 85% would also recommend a green home to others. In another survey (Guild Quality 2013), 94% would recommend a green home to others, and 55% agreed that they both knew their home cost a little more, but felt the benefits "outweighed the cost." Meanwhile, only 5% agreed that the home cost more *and* doubted the benefits "outweighed the cost."

In short, it may not currently matter if homeowners are fully aware of the limited scope of utility and carbon benefits associated with their homes. They seem to be happy with the diverse collection of benefits they receive, and generally perceive certified homes as higher quality products.

In this context, our draft breakdown of the certification premium -- 37% for utility savings, 3% for carbon mitigation, and 60% for a basket of "quality and comfort" features -- seems very reasonable. Further research on the value embodied by the premium might investigate the contents of that basket. How much are qualities like reduced noise inside the home, and consistent air temperatures worth individually?

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[2] This assumes that utility prices maintain a predictable rise, and that certifications keep their current energy and climate standards.

The value of voluntary whole-home certification

Voluntary certification programs have taken a leadership role in housing, one that has changed the field for the better. With every certified home, they demonstrate that higher-performing, lower-impact residences are practical. Some "green" materials and techniques may be on the verge of becoming standard. McGraw-Hill Construction (2014) estimates that by 2016, "green" construction will be about 30% of the US housing market in dollar terms. There are also suggestions that building certified homes can change the way builders work on every job, and thereby lower the impact of noncertified homes (Hassel, Blasnick, and Hannas 2009).

But as the understanding and practice of green construction expands, the distinctiveness of certified housing, and the size of any premium associated with it, threatens to fade. The possible time trend noted for Figure 1, where the newest studies coalesce around a premium of 3-5%, suggests this may have already begun to happen. Analyses of individual benefits, such as the examination of utility savings and carbon mitigation in this paper, may also restrain the premium, in the sense that they demystify a quantity that was previously opaque, giving buyers more information about exactly what they are buying.

Standards that were once progressive, for example, the use of computer models to qualify homes for energy performance, may no longer be stringent enough. LEED for Homes recently changed its energy standard from a HERS score of <=85 to <=70 (compare US Green Building Council 2008 and Foss 2014). Meanwhile, in the realm of commercial building, a growing movement aims to replace energy evaluations based on modeling with measurements of actual building performance (Frankel and Edelson 2015; Carassus 2011).

Home certification programs have done a great service by showing the industry and the public what is possible. As real estate markets and green building techniques evolve, home certification programs may need to evolve as well, to continue to prove their homes are distinctive enough to merit a higher price. # # #

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Tables

Table 1. Characteristics of the 43 Earth Advantage certified homes in Portland, Oregon, USA.

Characteristic	*Scenario (when relevant)*	*mean*	*minimum*	*maximum*
Home area (square feet)		2,220	1,424	3,184
Sale price		$336,049	$180,000	$492,900
Cash premium ($)		13,744	7,362	20,159
Yearly cost of premium ($)	Mean interest	$891	$477	$1,308
Yearly cost of premium ($)	Low interest	$723	$387	$1,061
Yearly cost of premium ($)	High interest	$1,075	$576	$1,577
Energy cost saved in year 1 ($)		$327	$95	$1,240
Energy savings proportion of first year premium	Mean interest	0.375	0.079	1.298
Energy savings proportion of first year premium	Low interest	0.462	0.098	1.602
Energy savings proportion of first year premium	High interest	0.311	0.066	1.076
Years to repay premium via energy savings	Mean interest, mean energy cost increase	45.8	0.8	91.3
Years to repay premium via energy savings	Low interest, high energy cost increase	34.8	0.6	69.1
Years to repay premium via energy savings	High interest, low energy cost increase	61.7	0.9	130.7
Carbon emissions prevented (tons/year)		1.2	0.5	2.0
Market value of carbon mitigation ($20/ton)		$24	$10	$40
Implied cost of mitigating 1 ton CO_2 ($) (see text)	Mean interest	$756	$442	$1,857
Implied cost of mitigating 1 ton CO_2 ($) (see text)	Low interest	$614	$359	$1,507
Implied cost of mitigating 1 ton CO_2 ($) (see text)	High interest	$913	$533	$2,240

Table 2. Cost effectiveness of consumer actions for carbon mitigation for an average Portland household, expanded from coolclimate.berkeley.edu.

This table expands on the parameters provided for the average Portland household by the model at coolclimate.berkeley.edu/calculator. The goal is to make the calculations more comparable to the annual carbon mitigation and costs represented by the certified homes in Figure 5, which are largely bought with mortgage financing over a span of many years. The leftmost four columns come from the CoolClimate model. The model provides numbers for some long-lived items (for example cars and solar panels). Though the "upfront costs" given by the model do reflect factors like automobile trade-in value, they do not break up that cost over years or incorporate any expense of financing (Christopher Jones, personal communication). Accordingly, we have added an estimated "longevity" for each item, indicating the length of time the asset or action is likely to be held and/or used by the household. For long-lived items that are paid for with cash, we assume the upfront cost is spread equally over the longevity. For long lived items bought with financing, we assume a fixed-rate loan over the longevity and provide an interest rate.

Consumer action	Tons carbon mitigated per year	Savings per year ($)	Upfront cost ($)	Longevity (years)	Interest rate per year	Annual cost including financing when relevant ($)	Cost of mitigation ($ per ton and year)
offset shopping footprint	19.63	0	393	1.0	0.0000	393	20
offset transportation footprint	13.08	0	262	1.0	0.0000	262	20
offset housing footprint	11.28	0	226	1.0	0.0000	226	20
buy an electric vehicle (cash)	5.54	1551	15,000	6.5[3]	0.0000	763	138
buy an electric vehicle (financed)	5.54	1551	15,000	6.5[3]	0.0406[4]	1,084	196
purchase "green" electricity from utility	5.11	0	102	1.0	0.0000	102	20
install PV panels (cash)	5.11	760	21,240	25.0[5]	0.0000	90	18
install PV panels (financed)	5.11	760	21,240	25.0[5]	0.0506[6]	739	145
buy a hybrid vehicle (cash)	2.52	788	15,000	6.5[3]	0.0000	1,526	605
buy a hybrid vehicle (financed)	2.52	788	15,000	6.5[3]	0.0406[4]	1,847	733
buy an alternative fuel vehicle (cash)	1.85	601	17,000	6.5[3]	0.0000	2,021	1,092
buy an alternative fuel vehicle	1.85	601	17,000	6.5[3]	0.0406[4]	2,386	1,290
buy a more efficient vehicle (cash)	1.75	547	2,000	5.3[7]	0.0000	-166	-95
buy a more efficient vehicle (financed)	1.75	547	2,000	5.3[7]	0.0406[4]	-123	-70
eat a low carbon diet	1.72	1047	0	1.0	0.0000	-1,047	-609
telecommute to work	0.98	545	0	1.0	0.0000	-545	-556
carpool to work	0.85	362	0	1.0	0.0000	-362	-426
practice eco-driving	0.82	256	0	1.0	0.0000	-256	-312
maintain vehicles	0.64	200	0	1.0	0.0000	-200	-313
turn down thermostat in winter	0.55	129	0	1.0	0.0000	-129	-235
ride my bike	0.53	165	0	1.0	0.0000	-165	-311
take public transportation	0.42	165	0	1.0	0.0000	-165	-393

[3] Average length of time a new car is held by a consumer (IHS Automotive 2015). This is similar to the average length of loans for new cars, 5.6 years (Zabritski 2015).
[4] Minimum finance rate for auto loans over the span of May 2010 to May 2015 (Federal Reserve Bank of St. Louis 2015a).
[5] Typical warranty length for photovoltaic module (Jordan and Kurtz 2012, Figure 4).
[6] Mean 30-year mortgage interest rate over past 10 years (Federal Reserve Bank of St. Louis 2015b).
[7] Average length of time a used car is held by a consumer (IHS Automotive 2015). This is quite similar to the average length of loans for used cars, 5.1 years (Zabritski 2015).

This table expands on the parameters provided for the average Portland household by the model at coolclimate.berkeley.edu/calculator. The goal is to make the calculations more comparable to the annual carbon mitigation and costs represented by the certified homes in Figure 5, which are largely bought with mortgage financing over a span of many years. The leftmost four columns come from the CoolClimate model. The model provides numbers for some long-lived items (for example cars and solar panels). Though the "upfront costs" given by the model do reflect factors like automobile trade-in value, they do not break up that cost over years or incorporate any expense of financing (Christopher Jones, personal communication). Accordingly, we have added an estimated "longevity" for each item, indicating the length of time the asset or action is likely to be held and/or used by the household. For long-lived items that are paid for with cash, we assume the upfront cost is spread equally over the longevity. For long lived items bought with financing, we assume a fixed-rate loan over the longevity and provide an interest rate.

Consumer action	**Tons carbon mitigated per year**	**Savings per year ($)**	**Upfront cost ($)**	**Longevity (years)**	**Interest rate per year**	**Annual cost including financing when relevant ($)**	**Cost of mitigation ($ per ton and year)**
reduce your waste	0.42	17	0	1.0	0.0000	-17	-40
power management of computers	0.37	54	0	1.0	0.0000	-54	-146
install low flow showerheads	0.36	101	30	5.0	0.0000	-95	-264
plant trees	0.34	50	1,000	50.0	0.0000	-30	-88
line dry clothing	0.29	44	0	1.0	0.0000	-44	-152
print double sided	0.26	16	0	1.0	0.0000	-16	-62
switch to CFL's	0.24	36	10	5.0	0.0000	-34	-142
reduce air travel	0.17	38	0	1.0	0.0000	-38	-224
go organic	0.17	0	380	1.0	0.0000	380	2,235
turn off lights	0.14	21	0	1.0	0.0000	-21	-150
switch from T12 to T8 lights	0.08	13	8	1.0	0.0000	-5	-63
choose energy star fridge	0.06	10	30	10.0	0.0000	-7	-117
turn up thermostat in summer	0.05	8	0	1.0	0.0000	-8	-160
replace copier with energy star	0.04	6	400	3.0	0.0000	127	3,183
install solar hot water (cash)	0.04	5	2,500	10.0	0.0000	245	6,125
replace printer with energy star	0.03	4	200	3.0	0.0000	63	2,089
replace desktop PC with energy star	0.03	4	500	3.0	0.0000	163	5,422
install tankless water heater (cash)	0.02	200	500	20.0	0.0000	-175	-8,750
purchase high efficiency heating equipment	0.02	4	300	20.0	0.0000	11	550
install water efficient landscaping	0.01	15	833	20.0	0.0000	27	2,665

Figures

Figure 1

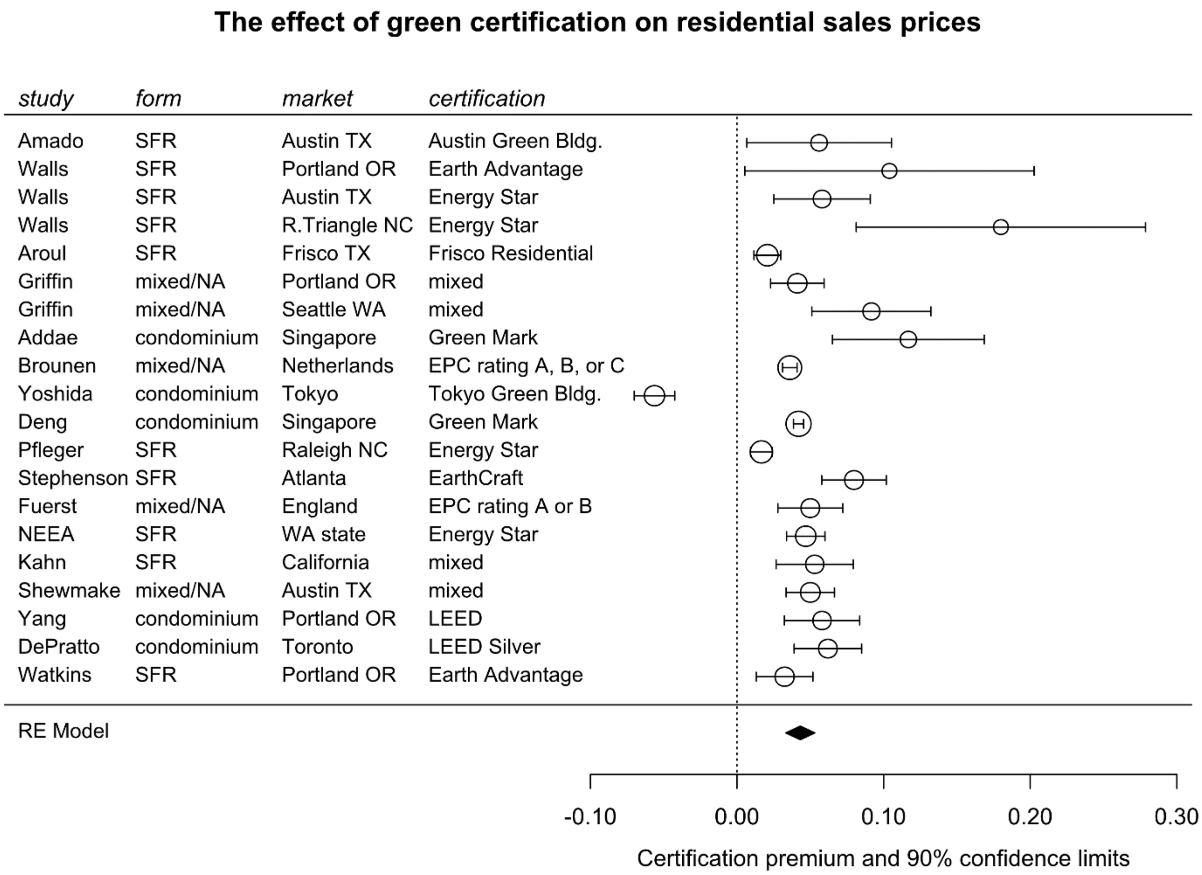

Figure 1. Meta-analysis of the 20 primary studies of the certification premium. The studies are arranged by the last year of data collection, with the oldest studies at the top.

Figure 2

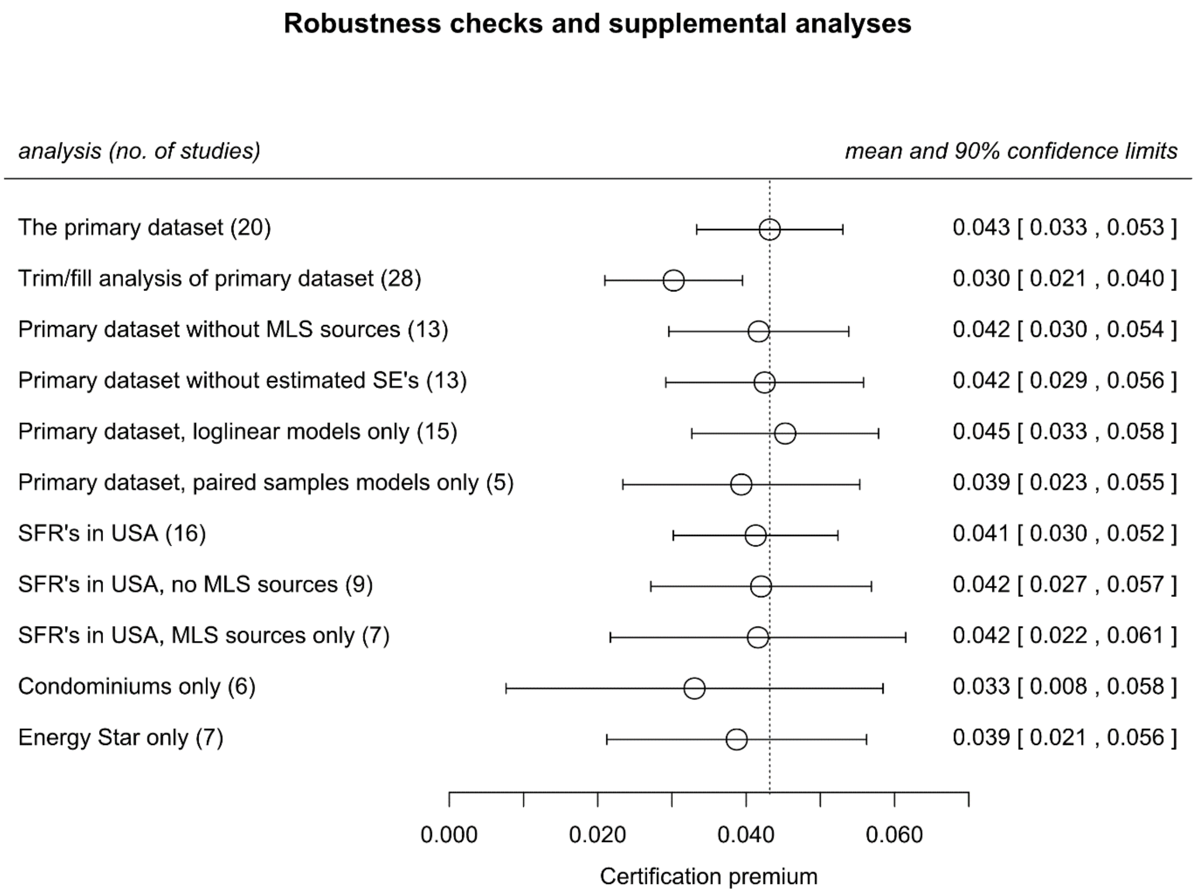

Figure 2. Robustness checks and supplemental analyses on the certification premium. Each row in the graphic summarizes the results of a particular meta-analysis. The first row summarizes the meta-analysis of the primary studies (Figure 1), the next five rows summarize alternative versions of that meta-analysis, described in the text, that are meant to check the primary analysis' sensitivity to various methodological concerns. The remaining five rows summarize meta-analyses that bring in supplemental data to examine specific types of housing in more detail. See text for full details.

Figure 3

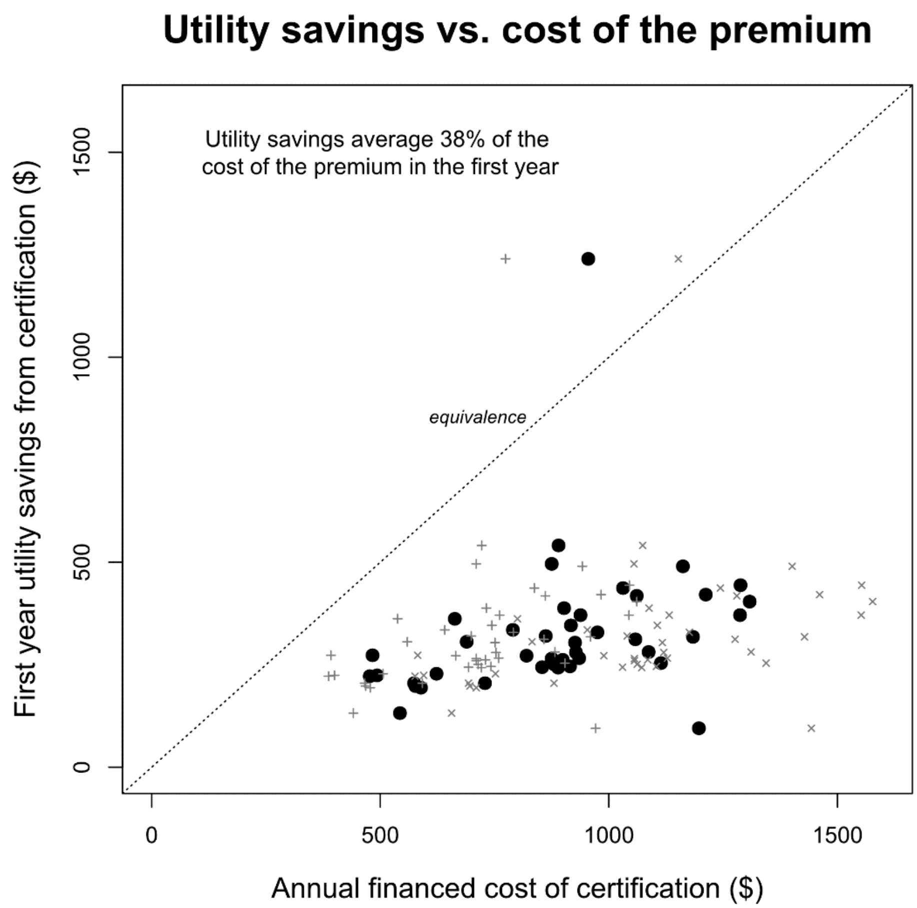

Figure 3. Utility savings and financed cost of the premium, for 43 certified homes in Portland, Oregon. Each bold black dot is one property, using the mean interest rate scenario (see text). + symbols represent the same properties for the low interest rate scenario, and × the high interest rate scenario.

Figure 4

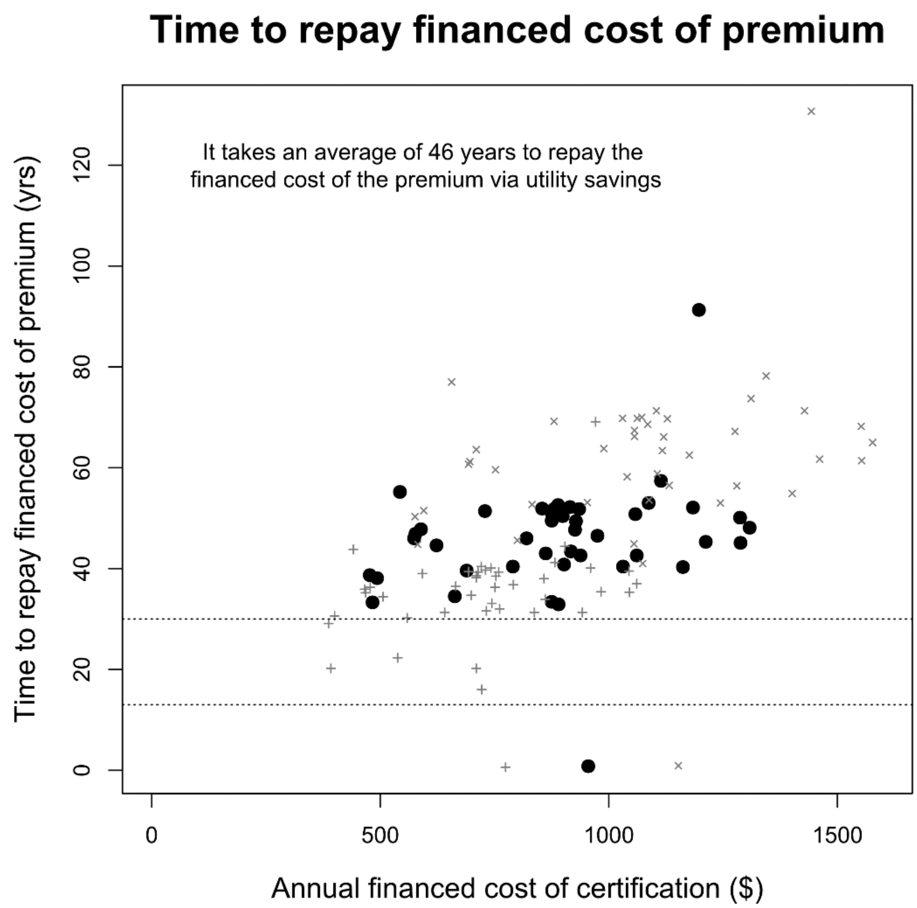

Figure 4. Number of year to pay back premium via utility savings, in 43 certified houses in Portland, Oregon. Each bold black dot is one property, using the mean interest rate, mean energy cost increase scenario (see text). + symbols represent the same properties for the low interest rate, high energy cost increase scenario, and × the high interest rate, low energy cost increase scenario. Horizontal reference lines at 13 and 30 years represent the average time buyers stay in one house (Emrath 2013), and the length of the most common mortgage contract (Freddie Mac 2015).

Figure 5

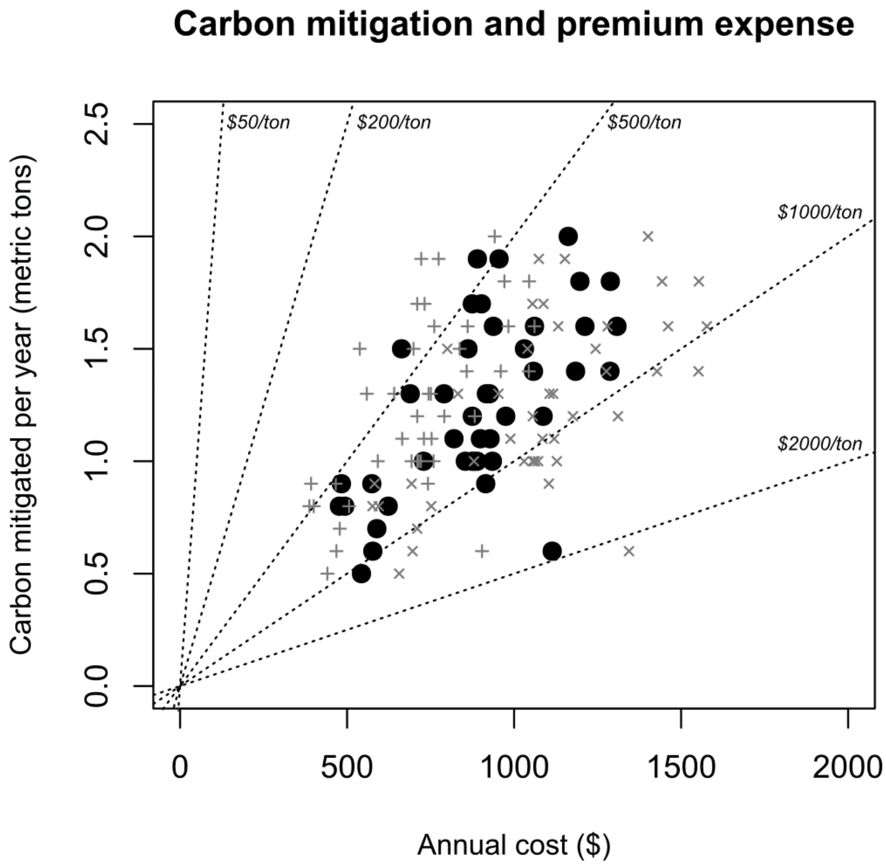

Figure 5. Carbon mitigation and the cost of the premium if 43 certified Portland homes. Each bold black dot is one property, using the mean interest rate scenario (see text). + symbols represent the same properties for the low interest rate scenario, and × the high interest rate scenario. "Carbon mitigation" is the difference in carbon emissions between this house and a similar one built to code, according to the EPS model.

Figure 6

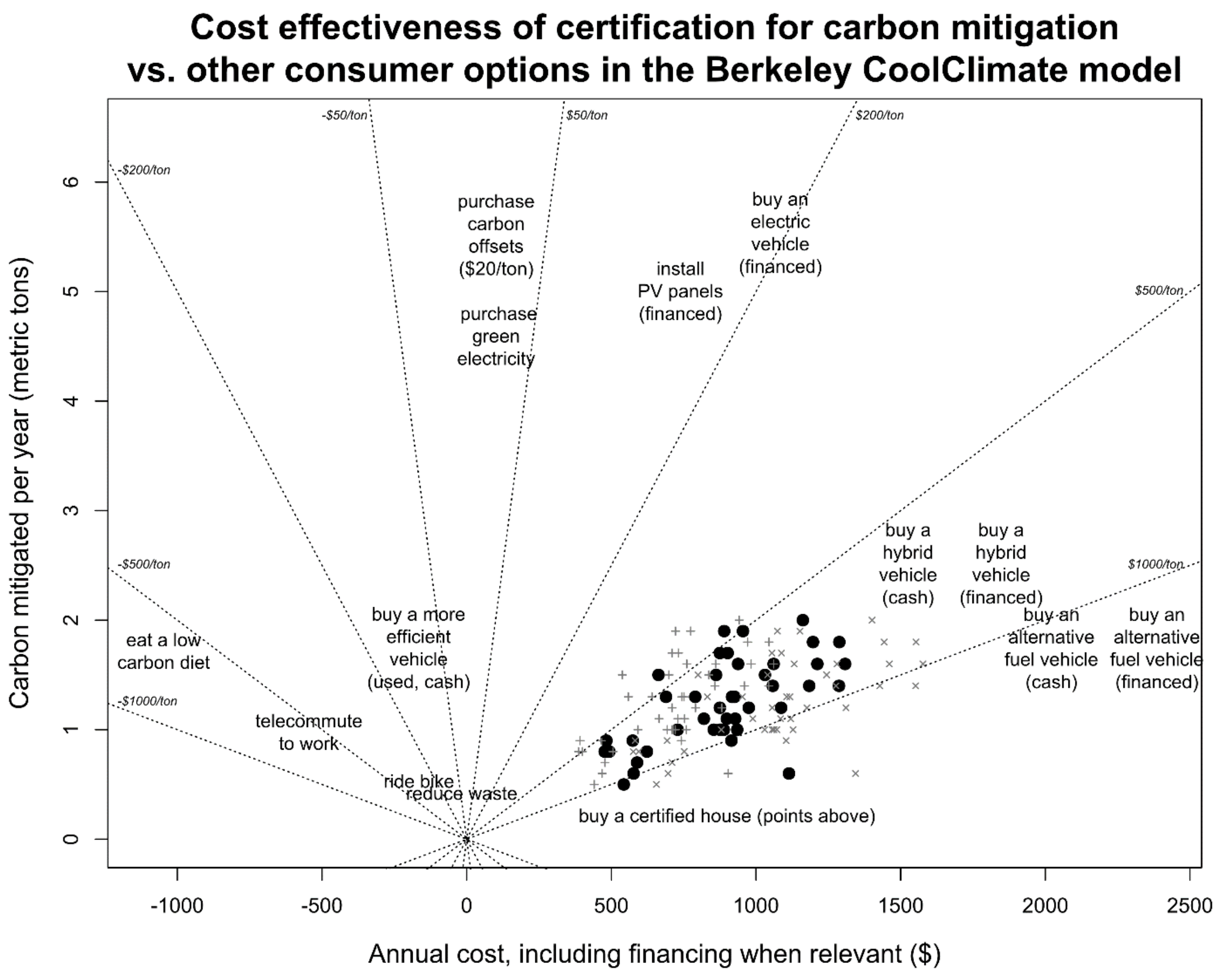

Figure 6. Cost effectiveness of buying certified housing for carbon mitigation, compared to other consumer options suggested by the Berkeley "CoolClimate" model. This graphic expands on Figure 5 by adding selected consumer actions from Table 2.

Appendix: source data for meta-analysis

These are the data as recorded from the meta-analysis sources, before any transformations or imputations of missing standard errors. More details about each column can be found in the section "Systematic Review & Meta-analysis," and full citation information under "References Cited."

Study first author	market	Certification	Certification information source	Role in meta-analysis	Architectural form	Statistical design	Premium (from loglinear model)	Standard error (from loglinear model)	Premium (from paired samples model)	Standard error (from paired samples model)	First year of data collection	Last year of data collection	Details
Addae	Singapore	Green Mark	agency	primary	condominium	loglinear	0.117				2005	2009	Model 1
Amado	Austin TX	Austin Green Bldg.	certifier	primary	SFR	loglinear	0.056	0.03			1998	2004	Model in table 17
Aroul	Frisco TX	Frisco Residential	mixed	primary	SFR	loglinear	0.021				2002	2007	Model 1, sample A
Brounen	Netherlands	EPC rating A, B, or C	certifier	primary	mixed/NA	loglinear	0.036	0.003			2008	2009	Table 3, model 3
Deng	Singapore	Green Mark	agency	primary	condominium	loglinear	0.042	0.0021			2000	2010	Model 2
DePratto	Toronto	LEED Silver	private	primary	condominium	loglinear	0.062	0.014			2006	2014	page 5
DePratto	Toronto	LEED Gold	private	supplemental	condominium	loglinear	0.122	0.016			2006	2014	page 5
Fuerst	England	EPC rating A or B	certifier	primary	mixed/NA	loglinear	0.050				2008	2012	Table 4, model 1
Fuerst	England	EPC rating A or B	certifier	supplemental	semi-detached	loglinear	0.008				2008	2012	Table 4, model 2
Fuerst	England	EPC rating A or B	certifier	supplemental	terraced	loglinear	0.045				2008	2012	Table 4, model 3
Fuerst	England	EPC rating A or B	certifier	supplemental	condominium	loglinear	0.016				2008	2012	Table 4, model 4
Griffin	Portland OR	mixed	MLS	primary	mixed/NA	paired samples			0.042		2006	2007	page 6
Griffin	Seattle WA	mixed	MLS	primary	mixed/NA	paired samples			0.096		2006	2007	page 6
NEEA	WA state	Energy Star	certifier	primary	SFR	paired samples			0.048	0.008	2010	2012	in press
NEEA	King County WA	Built Green	certifier	supplemental	SFR	paired samples			0.047	0.017	2010	2014	in press
Kahn	California	mixed	certifier	primary	SFR	loglinear	0.053	0.016			2007	2012	Table 2, column 4
Kahn	California	Energy Star	certifier	supplemental	SFR	loglinear	0.047	0.016			2007	2012	Table 4
Kahn	California	GreenPoint	certifier	supplemental	SFR	loglinear	-0.02	0.023			2007	2012	Table 4; NS
Kahn	California	LEED	certifier	supplemental	SFR	loglinear	0.041	0.066			2007	2012	Table 4

Study first author	market	Certification	Certification information source	Role in meta-analysis	Architectural form	Statistical design	Premium (from loglinear model)	Standard error (from loglinear model)	Premium (from paired samples model)	Standard error (from paired samples model)	First year of data collection	Last year of data collection	Details
Pfleger	Raleigh NC	Energy Star	MLS	primary	SFR	paired samples			0.017		2009	2010	Table 1, bottom rows
Shewmake	Austin TX	mixed	mixed	primary	mixed/NA	loglinear	0.050	0.01			2009	2012	Table 5, model 1
Shewmake	Austin TX	Austin Green Bldg.	certifier	supplemental	mixed/NA	loglinear	0.060	0.02			2009	2012	Table 5, model 2
Shewmake	Austin TX	EFL	mixed	supplemental	mixed/NA	loglinear	0.090	0.02			2009	2012	Table 5, model 2
Shewmake	Austin TX	Energy Star	mixed	supplemental	mixed/NA	loglinear	0.010	0.02			2009	2012	Table 5, model 2
Stephenson	Atlanta	EarthCraft	certifier	primary	SFR	loglinear	0.080	0.0134			2007	2010	Table 14
Walls	Austin TX	Energy Star	MLS	primary	SFR	loglinear	0.058	0.02			1995	2006	Table 5
Walls	Austin TX	Austin Green Bldg.	MLS	supplemental	SFR	loglinear	0.049	0.03			2000	2006	Table 5
Walls	R.Triangle NC	Energy Star	MLS	primary	SFR	loglinear	0.180	0.06			1995	2006	Table 5
Walls	Portland OR	Energy Star	MLS	supplemental	SFR	loglinear	0.032	0.04			1995	2006	Table 5
Walls	Portland OR	Earth Advantage	MLS	primary	SFR	loglinear	0.104	0.06			2000	2005	Table 5
Watkins	Portland OR	Earth Advantage	MLS	primary	SFR	paired samples			0.033	0.012	2008	2014	Unpublished
Yang	Portland OR	LEED	certifier	primary	condominium	loglinear	0.058				2009	2012	Model 1
Yoshida	Tokyo	Tokyo Green Bldg.	agency	primary	condominium	loglinear	-0.056	0.0084			2002	2009	Table 3, column 6