Green exuberance: Do studies really support high eco-premiums for buildings?

Florian FIZAINE[a], Pierre VOYE[a], Catherine BAUMONT[a]

[a]*Univ. Bourgogne Franche Comté, LEDi - Laboratoire d'Économie de Dijon, 2 Boulevard Gabriel, 21066 Dijon, France*

Abstract

Increasing attention is being paid to the building sector due to its importance in the climate change debate. In recent years, a growing literature on the price premium paid by consumers to access more efficient and sustainable buildings has emerged as a common topic in hedonic model estimations. In this paper, we aim to provide a summary of this literature by conducting a meta-analysis of more than 50 studies from around the world. In this way, based on a random effects models and weighted OLS robust clustering estimations, we offer an average estimation of the price premium accepted by economic agents (in terms of sale prices) in order to enjoy energy efficient and sustainable buildings. This supports the argument that investing in building refurbishment is worthwhile and economically relevant. However, our data seem to show a major publication bias. Correcting for this bias leads us to halve the original estimation (from 8% to 4%). In addition, we analyze the sources of result dispersion by performing a meta-regression using different moderators (type of publication, sample analysis period, econometric method, etc.). We also carry out different statistical tests and use alternative selection criteria in order to check whether our estimations are robust. Finally, we make recommendations for future hedonic studies as well as for upcoming meta-analyses of the green building premium.

Keywords: labels – certification – energy efficiency – building – hedonic model – meta-analysis

JEL classification: R5 – Q48 - Q5 – H54 – C19

INTRODUCTION

In recent years, academics and policy-makers alike have taken a growing interest in environmental issues relating to green building (Kok et al., 2012). Today the building sector accounts for 40% of global final energy consumption, 30% of global greenhouse gas emissions (UNEP, 2016), and an equally large share of raw material consumption (Eichholtz et al., 2010). Considering both the increasing size of dwellings and the growing proportions of the service sector (Chotard et al., 2011), it is to be expected that buildings will contribute substantially to increased energy demands. At the same time, as reported by Eichholtz et al. (2010), energy costs may account for as much as 30% of office building operating costs. In this context, building refurbishment or green building construction may serve as a tool with which to cut discounted costs and generate asset value.

Green value (or green premium) can be defined as enhanced real-estate value derived from improved environmental performance (CERQUAL, 2011; Chotard et al., 2011). This environmental performance combines a complex set of green characteristics which varies with the intended purpose of the real estate. In the real-estate sector, green building means lower energy consumption, enhanced comfort, shorter unoccupied periods, and a longer lifetime. In the office sector, in addition to reduced energy consumption, green buildings mean lower staff turnover, greater productivity, and less absenteeism (Dwaikat and Ali, 2016). Furthermore, the adoption and development of green buildings may project a favorable image of a company for its customers and trading partners. Therefore, green building premiums cannot be equated to mere capitalization on energy savings through improved energy efficiency. We need to better identify the sources of value deriving from other real-estate characteristics in order to provide investors and consumers with a greater appreciation of green building. The stakes involved in this valuation may call into question public policies of eco-label development as well as their purposes.

One way to generate and synthesize information about the green characteristics of a good may be to develop and promote green labels. The United States,[1] Japan,[2] and Hong-Kong[3] have been precursors in the development of global green labeling. In contrast, parts of Asia[4] and Europe[5] have been slower to develop their own labels. Whether voluntary or mandatory, most of these labels have proved highly successful. For instance, in the tertiary sector, a voluntary label such as Energy Star saw the number of its labeled buildings surge from 86 to 4400 between 1999 and 2010 (Kok et al., 2012). This acceleration is also supported by the accrediting agencies. LEED reports that it certifies more than 17,000 square meters per day (LEED, 2016).

In view of this surge, many academics have sought to determine whether or not the green characteristics associated with a building are valued by the market. If so, is this green value enough to trigger and motivate building refurbishment and green building construction? Finally, do any starting conditions need to be met to ensure the development and spread of green values throughout the market?

To answer these questions, the economic literature has produced a broad spectrum of empirical analyses over the last two decades. Nonetheless, the results associated with these analyses cannot be interpreted independently of their real-estate sector, country, time period of analysis, or the methods employed to ascertain these values. Most of the literature seems to confirm there is a green premium for buildings. But while most studies indicate a significantly positive green value, the economic literature shows a very broad spread of values, precluding any consensus. For instance, Mudgal et al. (2013) report a negative green value (-10%) while Ramos et al. (2016) measure a green premium of nearly 50%. At first sight, it might be thought that this heterogeneity is an artifact of the temporal or

[1] Energy Stars in 1999 for the Building sector and Leadership in Energy and Environmental Design [LEED] in 2000.
[2] Comprehensive Assessment System for Built Environment Efficiency [CASBEE] was launched in 2001.
[3] Building Environmental Assessment Method [HK-BEAM] was created in 1996.
[4] Chinese Green Building Label [CGBL] in 2008.
[5] Energy Performance Certificate [EPC] was generalized in 2008.

regional context, but this discrepancy persists when we observe results for the United States alone, with the study by Rahman (2014) supporting a small negative green value being a far cry from the 42% reported by Fuerst and McAllister (2009). In this context, neither generalization nor synthesis are easy tasks, especially using the conventional narrative review.

Instead, we can set about “the analysis of analysis” (Borenstein et al., 2009; Glass, 1976), that is, meta-analysis in order to reach a conclusion. The green value of buildings is currently subject to such surveys and applications. In this respect, we propose in this paper to overcome the limitations of ongoing studies by increasing the number of references (54 studies), by dealing with the presence of duplicate results, by introducing a larger set of moderators, and by analyzing, estimating, and correcting the publication bias affecting this literature. Our contribution to the literature on green premium building is threefold. First, we show that the detection and correction of the publication bias present in the hedonic green value literature leads to a considerable revision of the value ascribed to the green premium (from 8% to 4%). Second, by exploring 29 moderators, we suggest that the inclusion of spatial and environmental variables in hedonic models leads to very different outcomes. Third, we examine the impact of the economic crisis on changes in the green building premium.

The data and inclusion/exclusion criteria are presented in the next section. Then we outline what a meta-analysis is and provide an explanatory statistical analysis. In the third section, we explain the methods used in this paper, especially how to deal with the dependence effect, outliers, and multicollinearity, and how to detect and correct for publication bias. In the fourth section, we show that the additional value of green labeled buildings is likely to be about 3.5–4.5% of the building price, once the publication bias is removed. The introduction of moderators such as geographical area, type of literature (published or not), and the inclusion of spatial and environmental characteristics in the econometric regression seem to explain much of the heterogeneous character of the results. In the fifth section, we discuss the robustness of our results and suggest some further research for future hedonic studies and meta-analyses. We draw a conclusion in the sixth section.

DATA AND PROCESSING METHOD

Conventionally, narrative conclusions and/or statistical facts are derived from a body of literature. Likewise, meta-analysis aims at summarizing studies of a specific issue. But meta-analysis seems to outperform conventional narrative review because it is transparent, comprehensive, objective, and replicable (Borenstein et al., 2009; Laroche, 2012; Stanley, 2005). In order to ensure the meta-analysis is transparent, authors must clearly state their weighting system as well as their study inclusion and exclusion criteria. To be comprehensive, the meta-analysis must include all those studies that meet the inclusion criteria. Although each researcher may have some inborn or acquired *a priori* judgments, a transparent meta-analysis means that results are replicable and the science objective. Last but not least, a meta-analysis can check and correct for any potential publication bias affecting the literature.
This paper has been calibrated to meet the meta-analysis standardization principles provided by Stanley et al. (2013) in the *Journal of Economic Surveys*.
When observed, these principles enable us to determine both whether the green value of a building is significantly different from zero and the strength of this effect. In the more refined version of meta-analysis, we are also able to explain the dispersion of results arising from the characteristics of the studies. To do so, a set of explanatory factors, termed moderators, is collected for each study.

(i) Data collection and processing

More specifically, the effect size – statistics which measure the strength of the effect – studied here is the premium attached to a green or energy-efficient building certification. Most of the economic literature is based on the hedonic price methodology, formalized and standardized by Rosen (1974) in the following form:

$$\log(p_s) = \alpha + \rho E_s + \delta X_s + e_s \quad (1.1)$$

With s dwellings included in the studies, p is the dwelling price, E is a dummy variable attesting to the green certification of the building, and X a matrix of the other covariates affecting price (building characteristics and environmental and geographical variables). The parameter of interest is ρ. The variable E, which represents the energy performance of a building is often measured by a label. A distinction is made between two types of label. For simple labels (e.g. LEED Certified) we collected the parameter associated with the first level of certification. For mandatory labels providing different levels (e.g. EPC), we systematically compared level A (B in the absence of A) and level D. This comparison is supported by two facts. First, this comparison is the most widely used specification in the literature and is therefore widely available. Second, this comparison may meet the public perception of the difference between the best building rated A for environmental performance and the average building rated D for performance (most common label in the European building stock).

The following keywords: “energy efficiency premium building/housing”, “green housing value/appraisal”, “label premium housing/building”, or “hedonic valuation of green housing/building” were systematically used to identify studies falling within the scope of the meta-analysis. We checked the outcome returned by several bibliographic databases: Science Direct-Elsevier, Jstor, Emerad, Cairn, Springer, Wiley-Blackwell, Web of Science, Business Source Premier, Google scholar, and Google. In order to be included, the analysis had to meet several inclusion criteria:

- Only studies published after 2000 and written in English or French were considered.
- The analysis had to explicitly provide exclusive and quantitative results about the green premium value.
- The study had to cover the building sector (dwellings and office buildings) except for the primary and secondary sectors.
- The study had to mention the use of hedonic price methodology which excluded either stated preferences or economic computations but also studies based on rental prices or occupancy rates.
- Duplicates were systematically removed by excluding working papers and other grey literature in the event the work was available in a later version published in a peer-reviewed journal.

Where data were incomplete (usually the standard-error), we sent an email to the authors. In some cases, the authors did not answer our queries and so, following a precise methodology, we imputed the standard error for 14 observations[6] (table 1). The whole process is described in the appendix to the paper (Table 8). At the end of the process, 54 studies met the criteria described above. According to Stanley and Doucouliagos (2012),[7] this figure is higher than in most meta-analyses in economics. Nonetheless, in this paper we present only the results derived from the non-imputed data.[8] Of these 54 studies, 36 provide one estimate while the remaining 18 studies offer more than one estimate. Table 1 summarizes the observations for the entire sample depending on the number of estimates in the study and the presence or absence of an imputed standard-error.

[6] One possibility for allocating missing standard errors is to estimate the following relationship on the remaining data: $\ln(Se) = a + b \times ln(|ES|)$ and then use it to predict missing data. With Se the standard-error and ES the effect size.

[7] Of 87 meta-analyses reviewed by Doucouliagos and Stanley (2013), the median of the number of analyses covered is 36 and the mean 41.

[8] The full results for the non-imputed and imputed data are available upon request. Considering the issues that may arise from the use of this methodology, especially in the interpretation of the publication bias test, we decided not to reproduce them in this paper.

Table 1 Distribution of the observations for the entire dataset by various characteristics

Estimations	One estimate	Multiple	Total
Non-imputed	30	35	65
Imputed	6	8	14
Total	36	43	79

Our meta-analysis covers 20 labels and 19 countries around the world during the period 1996–2015 (see table 2).[9] Overall, research on green building value began in North America and then spread to Europe and Asia (figure 2).[10] However, since 2011, the number of studies related to the green premium of building has stabilized.

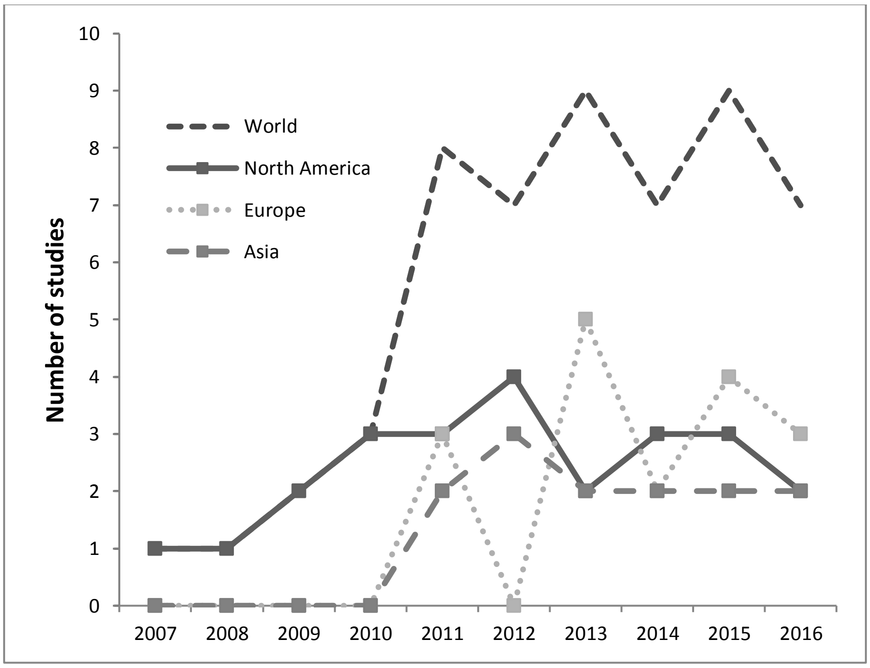


Figure 1 Spatial and temporal distribution of the studies in the dataset

Following equation (1.1), we selected the impact of a green label on building price as the effect size of the meta-analysis.

In order to obtain a comparable measure, we systematically applied the transformation described by Halvorsen and Palmquist (1980) [11]:

$$ES = \exp(\rho) - 1 \tag{1.2}$$

ES can be interpreted as a percentage when multiplied by 100 (for instance, 0.12×100 = 12%).

In a linear model, the premium (in \$ or €) is expressed as a share of the average building price of the sample.

(ii) Moderators

[9] Here, the time period of analysis associated with the hedonic studies. The oldest study is from 2007.
[10] Full details are available per year and per country in the appendix.
[11] We are aware of the debate over the transformation and interpretation of a dummy variable in a semi-logarithmic model. This is why we have replicated the methodology with the other transformations described by Giles (1982) and Kennedy (1981). It only marginally changes our results (third digits after the decimal point).

In order to assess the importance of several characteristics of the studies in the dispersion of the effect size, we encoded the information related to 29 potential moderators (see table 3). These moderators can be split into four categories: study characteristics, label characteristics, data characteristics, and regression methodology. General trends can be observed in a preliminary analysis which can be very informative as to the direction taken by the research.

For instance, spatial variables (distance, localization, or amenity) seem to be included less in more recent models (Figure 2). The difference in the average year of publication of the studies integrating these variables and the other studies is significantly attested by a test for equality of means (one year). The studies including spatial variables are thus older than the other analyses (t-test = -2.31, P-value = 0.0235). The change in the ratio between the two types of studies also follows a significant downward trend.

In addition, we do not observe a breakthrough with matching techniques. Studies using these techniques were in a minority whatever the year studied (see table 4: 32% of the whole dataset). The use of matching techniques in hedonic regressions – which are, however, recommended – do not increase over time (see Figure 3).

Furthermore, the average number of authors per study follows an upward trend. This probably reflects the increasing sophistication of the studies and the cooperation needed in order to collect the data and perform an original analysis (see Figure 4).

Recent and current studies focus more on office buildings (Figure 5).

Lastly, it seems that the most cited studies in our sample are: (i) published in prestigious high ranking reviews (American Economic Review, Journal of Environmental Economics and Management…) or (ii) precursors to the eco-premium building issue (see network graphs in appendix 2 and 3). Nonetheless, these studies cited by the major part of the literature are neither the most precise nor the less biased studies (appendix 4).

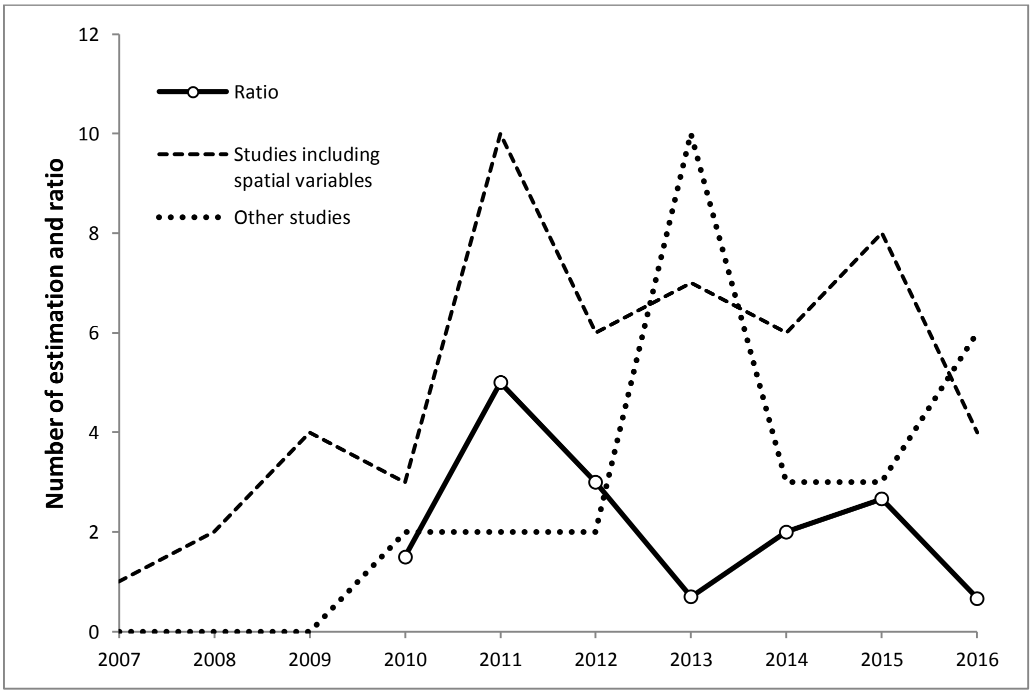


Figure 2 Changes in the number of studies including spatial variables

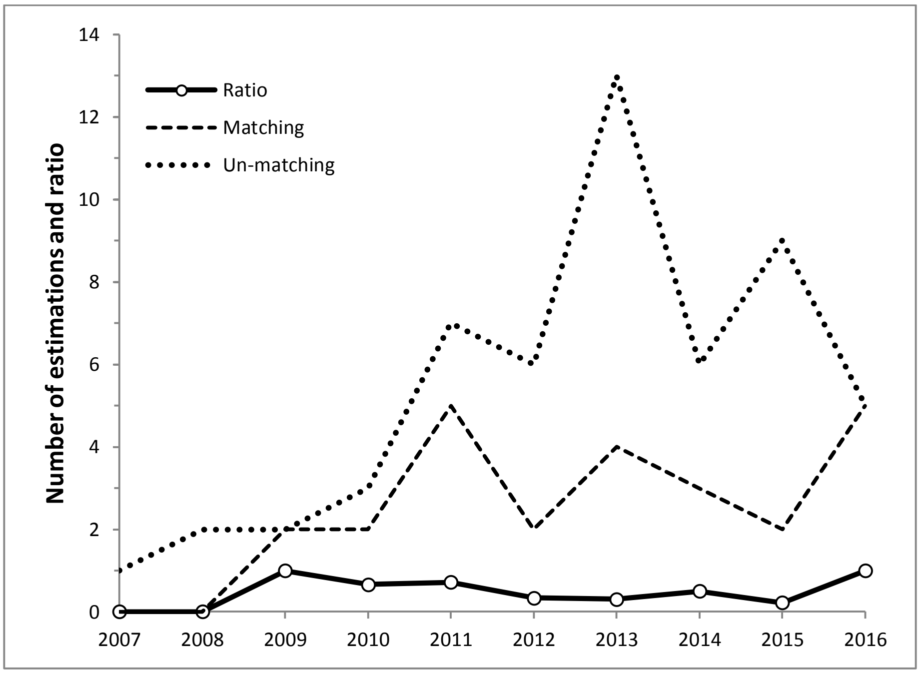


Figure 3 Changes in the use of matching techniques in hedonic price studies

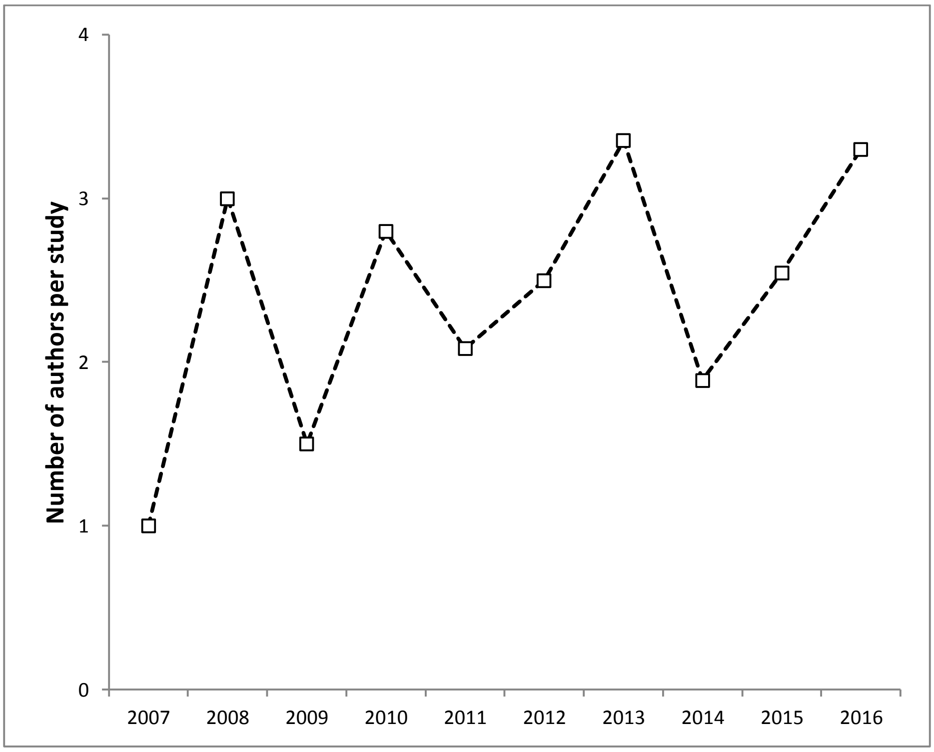


Figure 4 Changes in the average number of authors per study

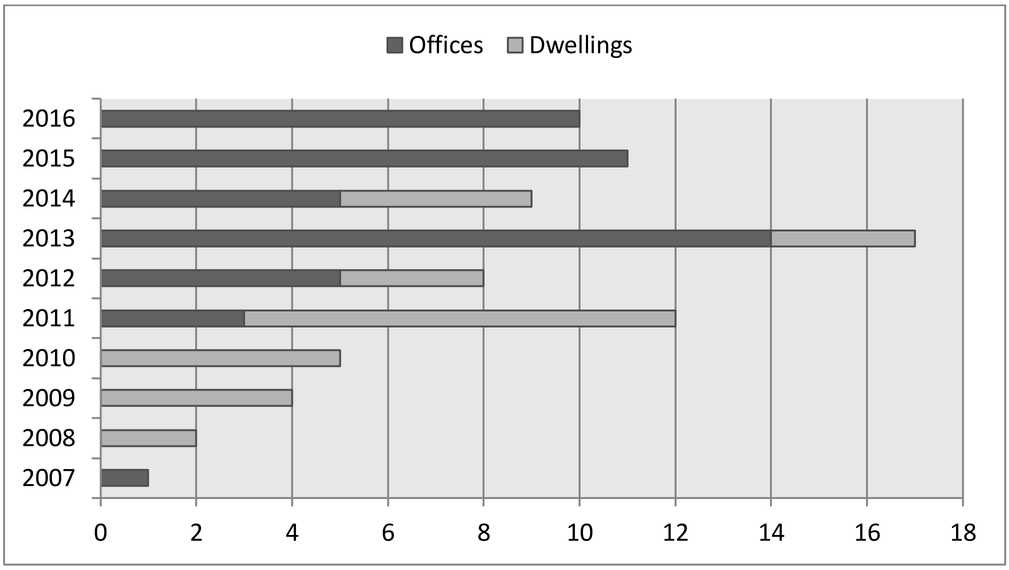


Figure 5 Distribution of studies by the sector studied.

Table 2 Studies included in the meta-analysis

Studies (54)	Nb Estimations	Label	Localization
Addae-Dapaah & Chieh [2011]	1	GM	Singapore
Amado [2007]	1	AGBP	USA
Aroul & Hansz [2012]	1	FRGBP	USA
Brounen & Kok [2011]	1	EPC	Netherlands
Bruegge et al. [2016]	1	ES	USA
Cajias & Piazolo [2013]	1	EPC	Germany
Cerin et al. [2014]	1	EPC	Sweden
Chegut et al. [2011]	1	BREEAM	UK
Chegut et al. [2013]	1	BREEAM	UK
Chen et al. [2015]	1	EEWH	Taiwan
Copiello & Bonifaci [2015]	1	EPC	Italy
Das & Wiley [2014]	2	ES	USA
Davis et al. [2015]	1	EPC	Ireland
Deng & Wu [2014]	1	GM	Singapore
Deng et al. [2012]	1	GM	Singapore
Depratto [2015]	1	LEED	Canada
Dermisi & McDonald [2011]	2	ES	USA
Dermisi [2009]	2	LEED	USA
Eichholtz et al. [2010]	2	LEED	USA
Eichholtz et al. [2013]	2	LEED	USA
Fregonara et al. [2014]	1	EPC	Italy
Freybote et al. [2015]	1	LEED	USA
Fuerst & McAllister [2009]	2	ES	USA
Fuerst & McAllister [2011]	2	ES	USA
Fuerst & McAllister [2011]	2	ES	USA
Fuerst & McAllister [2011]	2	BREEAM	UK
Fuerst & Shimizu [2016]	1	CASBEE	Japan
Fuerst et al. [2012]	2	LEED	USA
Fuerst et al. [2015]	1	EPC	UK
Fuerst et al. [2016]	1	EPC	UK
Högberg [2013]	1	EPC	Sweden
Hyland et al. [2013]	1	BER	Ireland
Jaffee et al. [2012]	1	ES	USA
Jayantha & Man [2013]	2	HK-BEAM & HK-GBC	Hong-Kong
Jensen et al. [2016]	1	EPC	Denmark
Kahn & Kok [2014]	1	ES+LEED	USA
Miller et al. [2008]	2	LEED	USA
Mudgal et al. [2013]	7	EPC	Various countries
Newell et al. [2014]	1	NABERS	Australia
Pivo & Fisher [2010]	1	ES	USA
Rahman [2014]	2	BOMA	Canada
Ramos et al. [2015]	1	EPC	Portugal
Shewmake & Viscusi [2015]	3	EFL	USA
Shimizu [2012]	1	CASBEE	Japan
Stanley et al. [2016]	1	BER	Ireland
Stephenson [2012]	1	ECHC	USA
Walls et al. [2016]	3	ES	USA
Wiley et al. [2010]	2	LEED	USA
Yang [2013]	1	LEED	USA
Yoshida & Sugiura [2011]	1	TGBP	Japan
Yoshida & Sugiura [2015]	1	TGBP	Japan
Zhang & Liu [2013]	1	CGBL	China
Zhang et al. [2016]	2	LEED	China
Zheng et al. [2012]	1	GGI	China
Total	79	20	19

Note: Label acronyms are explained in the appendix.

Table 3 Definition of the dependent variable and moderators

Meta-analysis variables		
Type of variable	Name	Operationalization/measure
Dependent variable	ES	= Effect-size (green premium elasticity)
	Se	= Standard error of the estimate
	Moderators	
Paper characteristics	Published	= 1 if published in a peer review journal, 0 otherwise
	IF	= Impact factor, ISI Web of Knowledge
	H-Index	= H-index, Scopus
	EigenFactor	= EigenFactor, Washington University
	Sjr	= Scimago Journal Rank, Scopus
	Yearofpubli	= Year of publication of the paper (base 2007 = 0)
	Nbauthor	= Number of authors
	Gender	= 1 if female (sex of the first author), 0 otherwise
Label characteristics	Mandatory	= 1 for mandatory label, 0 for voluntary
	Age	= Age of the label when the study was performed
	Typevariable	= 1 if transaction prices, 0 otherwise
	Sector	= 1 if offices, 0 otherwise
	Continuous	= 1 for continuous label, 0 otherwise
Data characteristics	Asia	=1 if study covers Asian countries, 0 otherwise
	Europe	=1 if study covers European countries, 0 otherwise
	Period	= Average date of the sample (base 2007=0)
	Length	= Length of the period of analysis
	Panel	= 1 for panel data, 0 for cross-sectional data
	NbObs	= Number of observations in the study
	%Pos	= Percentage of green buildings in the regression
Regression methodology	Matching	= 1 if matching techniques employed, 0 otherwise
	Market FE	= 1 if market fixed effects (dummy for districts, towns), 0 otherwise
	Time FE	= 1 if time fixed effects for years or quarters, 0 otherwise
	Heteroskedasticity	= 1 if robust standard errors, 0 otherwise
	Estimator	= 1 if other than OLS regression technique employed, 0 for OLS
	FunctionalForm	= 1 if the original estimate is from a linear model, 0 otherwise
	Consuiso	= 1 if the model includes an energy variable or the insulation level, 0 otherwise
	Distance	= 1 if the model includes the distance, 0 otherwise
	Localization	= 1 if the localization of the building is used as a variable, 0 otherwise
	Amenities	= 1 if the amenities are included in the hedonic model, 0 otherwise

Table 4 Descriptive statistics

Name	Mean	Standard deviation	Median	Mode	Q1	Q3	Minimum	Maximum
ES	0.17	0.38	0.09	0.23	0.04	0.18	-0.11	2.98
Published	0.66	0.48	1	1.00	0.00	1.00	0	1
Gender	0.32	0.47	0	0.00	0.00	1.00	0	1
Nbauthor	2.62	1.11	2	2.00	2.00	3.00	1	5
IF	0.71	1.05	0	0.00	0.00	1.02	0	3.673
Sjr	1.13	2.17	0.22	0.00	0.00	1.46	0	12.16
Yearofpubli	5.77	2.24	6	6.00	4.00	8.00	0	9
Age	6.55	4.24	5.5	4.00	3.50	9.50	0	21
Mandatory	0.35	0.48	0	0.00	0.00	1.00	0	1
Typevariable	0.22	0.41	0	0.00	0.00	0.00	0	1
Sector	0.38	0.49	0	0.00	0.00	1.00	0	1
Continuous	0.09	0.29	0	0.00	0.00	0.00	0	1
Asia	0.19	0.39	0	0.00	0.00	0.00	0	1
Europe	0.30	0.46	0	0.00	0.00	1.00	0	1
Period	1.37	3.20	2	3.00	-1.50	4.00	-6	8
Length	4.18	3.74	4	0.00	0.00	7.00	0	12
Panel	0.03	0.16	0	0.00	0.00	0.00	0	1
NbObs	38 810	188 337	2661	9 120	1 030	13 971	51	1 609 879
%Pos	0.21	0.21	0.12	0.07	0.04	0.34	0.00	0.93
Consuenergy	0.11	0.32	0	0.00	0.00	0.00	0	1
Insulation	0.05	0.22	0	0.00	0.00	0.00	0	1
Consuiso	0.14	0.35	0	0.00	0.00	0.00	0	1
Distance	0.30	0.46	0	0.00	0.00	1.00	0	1
Localization	0.28	0.45	0	0.00	0.00	1.00	0	1
Amenities	0.38	0.49	0	0.00	0.00	1.00	0	1
Matching	0.32	0.47	0	0.00	0.00	1.00	0	1
Market.FE	0.82	0.38	1	1.00	1.00	1.00	0	1
Time FE	0.67	0.47	1	1.00	0.00	1.00	0	1
Heteroskedasticity	0.34	0.48	0	0.00	0.00	1.00	0	1
Estimator	0.23	0.42	0	0.00	0.00	0.00	0	1
FunctionalForm	0.06	0.25	0	0.00	0.00	0.00	0	1

METHODOLOGY OF ESTIMATION

Generally, estimating the effect size of a meta-analysis involves considering and fixing three types of issues (often addressed in the literature), namely: the treatment of the dependence effect (several estimates in one study), multicollinearity, and outliers. Moreover, the literature is often affected by a publication bias which is rarely covered in meta-analyses (Doucouliagos et al., 2012). In this section, we describe the methodologies used to address these issues. The general specifications of the estimation model are available on pages 13-14 (equations 5 and 8).

(i) Treatment of the dependence effect, multicollinearity, and outliers

Sometimes a study offers more than one estimate. It may be thought that the estimates of such studies share a common effect and that residuals derived from these estimates are auto-correlated. We employed different methodologies to address this issue. With multiple estimates from different specifications, we selected the authors' preferred choice (when indicated) or the estimate from the model with the most control variables. If the study offered more than one estimate due to different labels, we used four types of methods[12] (a-b-c-d):

(a): After eliminating all studies providing more than one estimate, we estimated the following specification via a random-effect model (Hedges and Olkin, 1985) (moderators were dropped for simplicity):

[12] The fixed effects model has been excluded for two reasons. First, this model is really close to the weighted OLS model and second, the use of the fixed effects model in order to synthetize results from studies which have very different characteristics is inappropriate (Borenstein et al., 2009).

$$ES_i = \gamma_0 + \eta_i + \varepsilon_i \tag{3}$$

Where ES is the effect size, γ_0 the overall mean, ε_i the error term, and η_i the study specific random effect.

(b): Random sampling of one estimate per study, then estimation of the specification described in equation 3 and replication 10 000 times. The median and superior and inferior percentiles were recovered from the replications.

(c): Use of a random effect multilevel model separating the level of estimations from the level of studies. This model can be specified as:

$$ES_{i,g} = \gamma_{00} + \upsilon_{0,g} + \eta_{i,g} + \varepsilon_{i,g} \tag{4}$$

Where ES is the effect size of the observation i and the study g, γ_{00} is the overall mean, and the error terms are distributed under the following laws $\varepsilon_{i,g} \sim N(0, v_i)$, $\eta_{i,g} \sim N(0, \tau_2)$, $\upsilon_{0,g} \sim N(0, \tau_1)$. τ_1 is the between-study variance while τ_2 is the between-study-within-level-3 unit variance. The estimators of the different variances were obtained from the Restrained Estimator of Maximum Likelihood (for more details see Konstantopoulos, 2011).

(d): Estimation by the weighted OLS with robust clustering standard error. Some authors such as Stanley and Doucouliago (2015) clearly advocate this method, claiming it is more robust and efficient than the random effects model.

Multicollinearity between moderators was checked with the correlation matrix and by computing the Variance Inflation Factor (VIF). Variables with a VIF greater than 10 were not simultaneously introduced into the model. For instance, considering the near perfect intersection between the "Europe" and "Mandatory" variables, the VIF rule prevented them from being used at the same time. Variables were selected by a general to specific process.

Several measures were employed to handle heterogeneity, namely the Cochrane Q statistics (excess of variation beyond the sampling error), the estimator τ of the between study variance T, and the I^2 proposed by Higgins et al. (2003).

To prevent outliers greatly affecting the results, we applied the methodology described in Viechtbauer and Cheung (2010). This methodology uses the Cook distance, the value of standardized residuals, and the influence of each observation on the average prediction of the regression model. In our case, implementing this method led to three observations being rejected. Two of them had very high values (0.49 and 2.97) and the third outlier (0) was based on a study including only one green certified building. All three outliers were from two Europeans studies.

(ii) Identification and correction of publication bias

The possibility that scientific literature is skewed by publication bias has long been a recognized phenomenon in medicine and psychology (Begg and Berlin, 1988; Rosenthal, 1979). In economics, publication bias, without being systematic, could affect nearly two-thirds of topics (Doucouliagos and Stanley, 2013) and seems to have surfaced in studies since the paper by De Long and Lang (1992).

Two main forms of bias have been identified. Type I bias, or direction bias, is characterized by a censoring of results, which depends on the "expected" direction of the effect size. Some academics often call this phenomenon dogmatic bias or theory bias (this may also be related to the orientation of the journal's editorial board). Type II bias or significance bias occurs when a study has a better chance of being submitted and/or accepted if significant results and/or high effect sizes are reported. Less discussed, research bias consists of choosing research or research protocols in such a way that there is a better chance of deriving significant results (Gurevitch and Hedges, 1999).

In this context, it could be relevant to include unpublished papers or grey literature[13] in the meta-analysis. That such results are not published does not necessarily imply poor quality work for several reasons. First, not all research is intended for publication in academic journals, especially that supported by private institutions, firms, think-tanks, and governmental agencies. Second, the study author may not want to pursue an academic career (case of thesis work).
We were careful not to exclude grey literature from our meta-analysis. This precaution is reflected in the high unpublished paper rate (33%) of our work compared to other meta-analyses. Nonetheless, as observed by Stanley (2005, p. 337), grey literature is also likely to be skewed because many working papers remain motived by publication incentives. In such circumstances, the authors of working papers have incentives to present skewed results (bias of type I or II) in order to increase their chances of being published.[14]

In all cases, meta-analysis must include an analysis relative to the detection of a potential publication bias to avoid unreliable results. In this part, we describe the different tests employed to identify a publication bias.

Considering that the authors of small studies obtain high standard errors, they tend to seek and promote specifications that reject the null assumption (insignificant parameters). All other things remaining equal, they tend to provide high values for the parameter associated with the effect size (in order to have a t-stat higher than 1.96). This is why most of the following tests try to determine whether there is a link between the effect size and its standard error.

Funnel Asymmetry Testing (FAT) aims at estimating the following relationship (Card and Krueger, 1995):

$$ES_i = \beta_1 + \beta_0 Se_i + \varepsilon_i \tag{4}$$

with ES, the effect size, and Se, its standard error. To compensate for high standard errors, small studies look for the specification that leads to a high effect size and a significant associated t-stat. However, as most studies are characterized by various sample sizes and modeling, the residuals are often highly heteroskedastic (Stanley, 2005). Therefore, we generally preferred equation 5 to equation 4:

$$\frac{ES_i}{Se_i} = t_i = \beta_0 + \beta_1 \left(\frac{1}{Se_i}\right) + e_i \tag{5}$$

FAT aims at testing the null assumption of the absence of publication bias ($\beta_0 = 0$). The positive or negative sign indicates a right-side and left-side bias and can be interpreted as an index of the asymmetry of the funnel graph (Egger et al., 1997). At the same time, we can also test for the absence of an authentic effect beyond the publication bias ($\beta_1 = 0$).[15] This last test is known as *Precision Effect Testing* (PET) and has a high statistical power (Stanley, 2008).

Another way of identifying the publication bias is based on *Meta-Significance Testing* (MST). This test uses the expected relationship between the Student statistic of a parameter and the square root of the degree of freedom of the estimation (df):

$$E(\ln|t_i|) = \alpha_0 + \alpha_1 \ln(df_i) + \xi_i \tag{6}$$

where $\alpha_1 = 0$ when there is no authentic effect (null assumption) and $\alpha_1 = \frac{1}{2}$ when the statistical relationship theory presented above is observed. It is conventional to test whether $\alpha_1 > 0$ in order to check the presence of an authentic effect beyond the publication bias.

[13] i.e. working papers, conference papers, theses, reports, and book chapters.
[14] Doucouliagos and Stanley (2013) show that in the absence of theory competition, the selection process behind publication bias can prevent the rise of some unexpected results even in the form of working papers.
[15] Some academics sometimes use the square root of the number of observations ($\sqrt{n}$) instead of Se^{-1}.

The *Publication Biais Filtered Effect* (PBFE) is very similar to the FAT-PET because it uses a correction of the dependent variable and then checks for the presence of a genuine effect ($\delta_1 \neq 0$):

$$|t_i| = \beta_0 + \beta_1\left(\frac{1}{Se_i}\right) + \upsilon_i \tag{7.1}$$

$$|t_i| - \beta_0 = T_i = \delta_1\left(\frac{1}{Se_i}\right) + \psi_i \tag{7.2}$$

Other non-parametric methodologies have been employed such as the *Rank Correlation Test* (RCT) based on a rank correlation (Spearman) and proposed by Begg and Mazumdar (1994), but also the *Mean PET Estimator* (MPETE), which is less affected by a downward bias than the PET estimator (Stanley, 2008). We also reproduced the *Trim and Fill* methodology described by Duval and Tweedie (2000a, 2000b). Unlike the usual statistical wisdom whereby a larger sample often leads to a better estimation, in meta-analysis, Stanley et al. (2010) recommend instead discarding 90% of the less precise data in order to avoid publication bias. It is along those lines that we also computed the top 10% index which is the mean of the 10% most accurate studies. Finally, we proposed a cumulated meta-analysis where studies (and effect-size) are sorted by increasing standard error. This methodology is often a good and efficient way to perform a visual check for publication bias (Borenstein et al., 2009; Nelson, 2013).

After identifying publication bias, we estimated an extended form of equation 5 including moderators of the effect size as described in Doucouliagos and Stanley (2009):

$$t_i = \beta_0 + \sum_{j=1}^{J} \omega_j M_{ij} + \beta_1\left(\frac{1}{Se_i}\right) + \sum_{l=1}^{L} \varphi_l H_{il}\left(\frac{1}{Se_i}\right) + e_i \tag{8}$$

Where β_0 is the parameter associated with the publication bias, Mj the set of variables impacting the publication bias, β_1 the effect-size, and H_l the moderators linked to the effect-size (control variables).[16]

RESULTS

In this part, we present the estimates related to green building value with and without removing publication bias. In a second subsection, we also explain the heterogeneity of results by introducing several moderators.

(i) Estimation of effect size without moderators and impact of publication bias

The visual interpretation of the funnel graph and radial graph can be a good way both to observe the dispersion of outcomes and to assess the possibility of an asymmetric pattern associated with a publication bias. As shown in figure 6, study outcomes mostly concentrate on the 0–10% range. Nonetheless the distribution of green building value estimates seems to be skewed to the right. The same applies to published and unpublished results alike. We better understand why a simple regression is likely to be biased and dragged to the right by inaccurate studies. The radial graph (figure 7) is another visual test and could be seen as a graphical analysis of the FAT-PET (equation 5). Here, t-stats of the coefficients of the green building value are expressed as a function of the precision of the studies. We note that more very small studies (75%) have t-stats exceeding 1.96. In other words, with a near zero precision, the t-stats associated with the coefficients of small studies should be centered on zero. Therefore, the positive intercept (2.15) of the distribution indicates a publication bias. In addition, the cumulative meta-analysis which shows the mean effect as a function of increasing standard error also moves in the same direction (figure 8). At first sight, our case of publication bias

[16] The different models and methodologies have been estimated with the “metaphor” and “rms” packages in R software.

seems to be related to both direction bias (few small studies offer negative green building values) and significance bias (many small studies have significant results due to the high value of their effect size). However, we need to take the analytical tests further in order validate these initial comments.

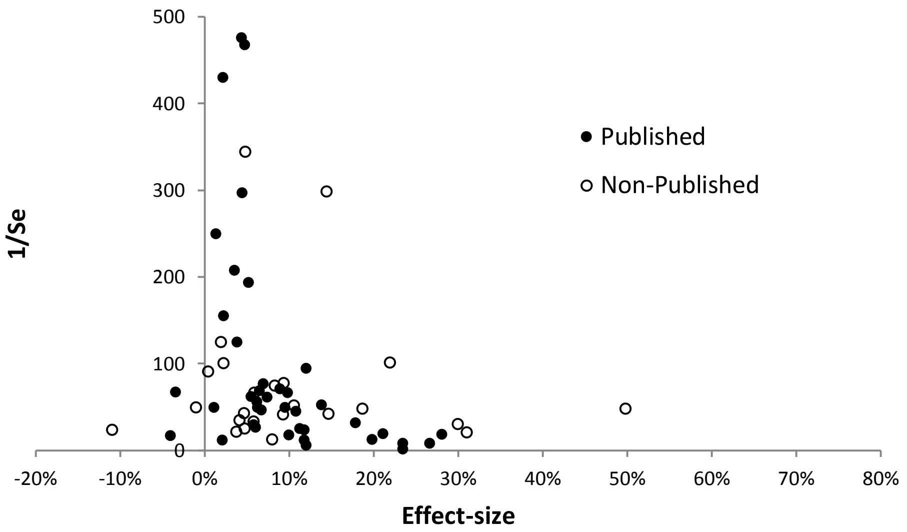


Figure 6 Funnel graph of green building values. Note: non imputed studies, N=65

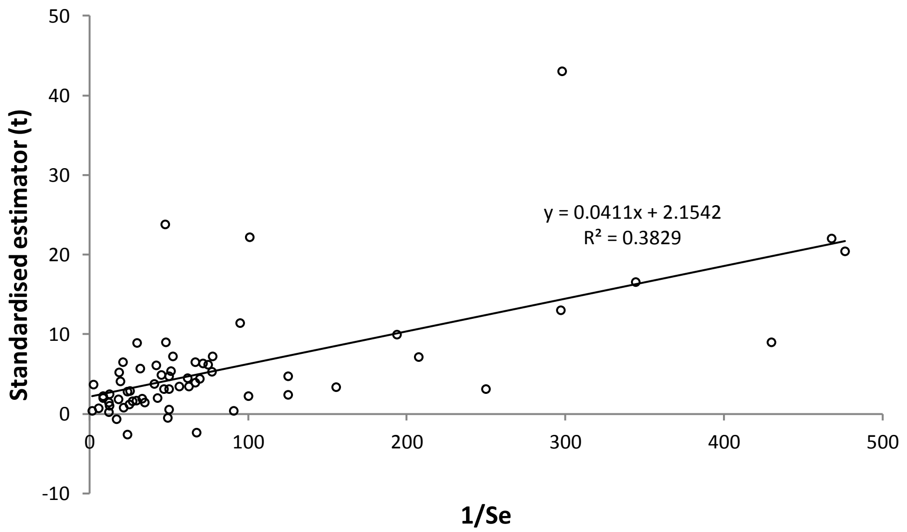


Figure 7 Radial graph of observations

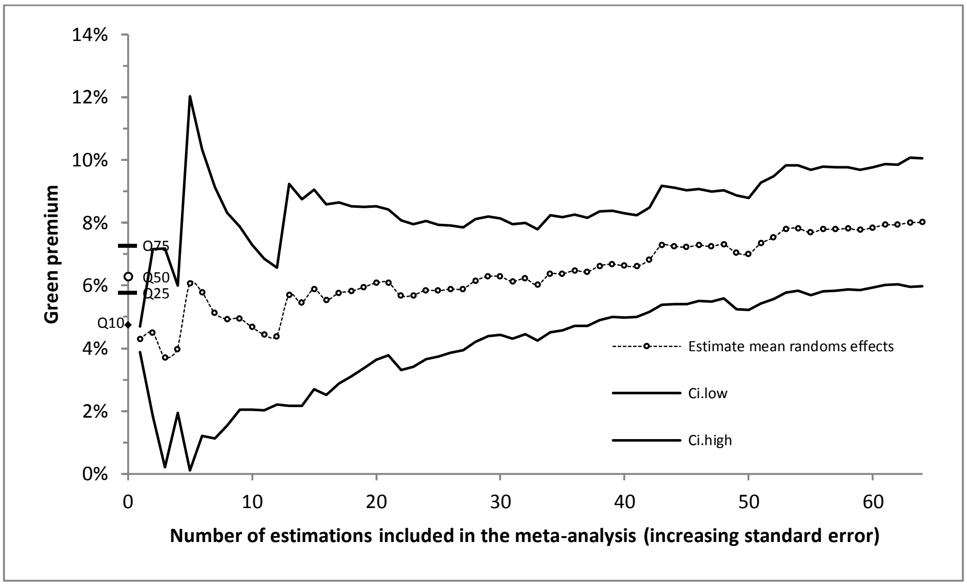


Figure 8 Changes in mean effect size as a function of the number of estimations included in the meta-analysis (decreasing precision). Q10: Top 10% most precise studies, Q25: 25%, Q50: 50%, Q75: 75%

Table 5 Identification of publication bias by several methods

Tests		Methodologies			
		A: No multiple (RE)	B: Random sampling	C: REML	D: Clustered WOLS
FAT	β0	**2.5769** (2.22)**	2.0878 1.6182 2.4846	1.4771 (1.71)*	**1,7610** (3,38)***
PET	β1	**0.0327** (5.33)***	0.0338 0.0324 0.0432	**0.0430** (7.25)***	**0,0420** (4,12)***
MST	α0	-0.3606 (-0.56)	-0.8568 -1.3751 -0.3633	**-1.0793** (-2.14)**	-0,8467 (-1,49)
	α1	**0.2134** (3.08)***	0.2553 0.2048 0.3101	**0.2786** (4.75)***	**0,2530** (3,76)***
PBFE	δ1	**0.0319** (5.47)***	0.0333 0.0319 0.0427	**0.0427** (7.46)***	**0,0413** (7,11)***
RCT	Kendall's tau	0.0642 (p-value = 0.63)	-	0.1649 (p-value= 0.054)*	
TRIM and FILL	MS (p -value)	p = 0.0625	-	p = 0.0312	
	Effect size	**0.0575** (3.45)***	-	**0.0711** (6.67)***	
Top10% (Mean)		0.0398	-	0.0513	
Without correction		**0.0749** (5.77)***	0.0757 0.0673 0.0847	**0.0784** (8.13)***	**0,1145** (4,29)***
Mean		0.0963	-	0.1204	

*Note: N=29(A), 53(B), 64(C). t-stat or z value in parentheses. For specifications using random effects, the Knapp and Hartung (2003) standard error correction has been employed. For methodology B, we indicate the median value for 10,000 replications as well as the superior and inferior percentiles below. *** denotes significant at 1%, **5%, *10%.*

Unsurprisingly, the FAT and the TRIM and FILL methodologies validate the presence of publication bias in almost all cases ($\beta 0 \neq 0$ and p-value<0.1). According to the figures suggested by Doucouliagos and Stanley (2013), a $\beta 0$ value between 1 and 2 denotes a large selection bias (while a $\beta 0$>2 indicates severe publication bias). Another way to confirm this publication bias is to compare the top 10% most precise studies (5.13%) to the average value of the whole sample (12.04%). In these circumstances, ignoring publication bias leads to skewed conclusions for the green building value. Our results also support the suggestion of Stanley and Doucouliagos (2012, p. 47) that random effects (7.84%) are more skewed than fixed effects (4.99%)[17] in the presence of publication bias.

The genuine effect remains discernable beyond the publication bias as demonstrated by the PET, MST, and PBFE tests. The whole set of coefficients are significant but the authentic effect of the green building value seems to be much lower than expected (4–5% versus 12%).[18] These results are consistent with the work of Stanley claiming that most empirical economic facts are exaggerated due to the result selection process (Doucouliagos et al., 2012; Doucouliagos and Stanley, 2013).

Moreover, most models show that heterogeneity persists despite the correction for publication bias. Both the Cochrane statistic (Q (df=63) = 1826, p-value < .0001) and the I^2 (>99%) confirm it is worth going beyond this simple specification by integrating moderators.

(ii) Meta-regression with publication bias correction and moderators

The use of the general to specific selection process leads us to promote the model described in table 6 (specification [1]). In this specification, the reference class corresponds to an unpublished American study using OLS estimation focused on dwellings in the year 2007. We can observe that the genuine effect associated with this reference class is significantly positive and very close to the estimate without moderators (3.02% versus 4%).

Geographical disparities absorb most of the heterogeneity in the data (nearly 12% of partial R^2). Estimates based on European samples are on average 12 points higher than their North American equivalents. Maybe the recentness of the Asian green building market explains why the green value is still 5.5 points higher than in North America. These high geographical disparities may arise from the regulatory context relative to the type of label (mandatory or voluntary). Indeed, most mandatory labels are to be found in Europe while other regions clearly promote the use of voluntary labels. Unfortunately, considering the high coefficient of correlation between the two variables (r=0.9 for “Europe” and “Mandatory”), this confounding effect cannot easily be removed.

With more moderate partial R^2 (between 2 and 4% for each variable), publication in a peer review journal, the sector studied, and the spatial characteristics of the regression also affect the estimation of the green building value. More specifically, all other things being equal, studies published in peer review journals seem to provide lower values than unpublished studies (-7 percentage points). In contrast, certified office buildings appear to be more value-enhanced than private dwellings (+8 points). Those firms are more willing to pay for goods and services than individuals are may be one explanation for this outcome. In addition, accounting for the size of the parameters, the introduction of the space and environment of the building into hedonic models is likely to play an important role in determining green building values. In particular, when considered in the model, distance impacts green building values negatively (-5 percentage points) while environmental amenities (+3 points) or the precise localization of real estate (+9 points) tend to raise green building values. The sign of the “distance” parameter suggests that green buildings are closer to the central district or to efficient transportation networks. Ignoring this variable leads to an overestimation of the green building value which is confused with the building’s access value. Moreover, it can be assumed that the precise localization of the building tends to increase the green premium due to more refined geolocated discrimination of green buildings. The same applies to the introduction of amenities which allow better differentiation between the value from local amenities and the value of green building. The concentration of this type of good requires fine-grained discrimination at the local level in order to distinguish the different effects. The use of models integrating space and incorporating spatial data (even geographic information systems) is likely to be necessary for an efficient interpretation of the impact of intrinsic and extrinsic building characteristics on real-estate prices.

[17] The results with fixed effects are not reported in order to save space.
[18] The PEESE test also provides a value in this range (4.96%).

Lastly, three others factors, namely the type of estimator (OLS or other methods), the treatment of heteroskedasticity, and the time period of analysis have been selected although their explanatory power is lower (partial R^2 less than 1%). More precisely, studies that prefer OLS estimates derive on average 2 percentage points more than other studies. More surprisingly, studies using robust heteroskedastic estimators have higher green building values (plus nearly 2 percentage points). Finally, we observe a low but significant downward trend of the green premium over time (-0.7 percentage points per year). Three different reasons can be suggested for this decrease. One assumption is that green buildings are developed over time and tend to be less scarce on the real-estate market and thus less positively discriminated and valued. A second assumption is that this decreasing trend is based on declining demand for efficient environmental building due to adverse market conditions. A third assumption is that publication bias declines over time and consequently leads to outcomes that are less skewed to the right, so causing a decreasing trend in the observed green premium.

Table 6 Meta-regression of the building green premium for different specification and robustness values

Dependent variable : t	(1)		(2)		(3)		(4)		(5)	
	Clustered WOLS	REML	Clustered WOLS	REML	Clustered WOLS	REML	Clustered WOLS	REML	Clustered WOLS	REML
Intercept	0.5774 (1.17)	0.5754 (1.0755)	1.3885 (1.90)*	0.9611 (1.1615)	0.4662 (0.95)	0.4670 (0.8585)	**1.2297** (2.43)**	0.9054 (1.0052)	0.9055 (1.25)	0.6042 (0.6671)
1/SE	**0.0302** (3.10)***	**0.0302** (3.1787)***	**0.0318** (2.22)**	**0.0479** (2.9583)***	**0.0309** (3.20)***	**0.0309** (3.2465)***	0.0310 (1.93)*	**0.0447** (2.0965)**	**0.0276** (2.52)**	**0.0365** (2.3837)**
Published	**-0.0736** (-5.96)***	**-0.0736** (-8.1322)***	**-0.0707** (-4.74)***	**-0.0786** (-5.3879)***	**-0.0737** (-5.92)***	**-0.0737** (-8.1448)***	**-0.0794** (-5.05)***	**-0.0900** (-4.3171)***	**-0.0752** (-6.03)***	**-0.0798** (-5.8089)***
Sector	**0.0846** (5.48)***	**0.0846** (3.5983)***	**0.0742** (3.62)***	**0.0821** (2.4108)**	**0.0866** (5.62)***	**0.0866** (3.6751)***	0.0489 (1.84)*	0.0559 (1.5401)	**0.0778** (4.28)***	**0.0843** (2.3067)**
Asia	**0.0542** (8.15)***	**0.0542** (6.3674)***	**0.0521** (5.27)***	**0.0478** (3.2569)***	**0.0539** (8.02)***	**0.0539** (6.3387)***	**0.0578** (4.74)***	**0.0547** (2.5412)**	**0.0526** (7.20)***	**0.0498** (3.6667)***
Europe	**0.1292** (7.62)***	**0.1292** (9.0674)***	**0.1081** (4.94)***	**0.1026** (4.3717)***	**0.1289** (7.56)***	**0.1289** (9.0500)***	**0.1156** (7.32)***	**0.1144** (4.5497)***	**0.1292** (8.18)***	**0.1266** (5.5014)***
Distance	**-0.0565** (-5.61)***	**-0.0565** (-5.1564)***	**-0.0539** (-4.07)***	**-0.0570** (-3.2217)***	**-0.0563** (-5.56)***	**-0.0563** (-5.1468)***	-0.0180 (-0.83)	-0.0164 (-0.6503)	**-0.0504** (-4.07)***	**-0.0515** (-3.0364)***
Amenities	**0.0311** (4.61)***	**0.0311** (3.5904)***	**0.0317** (3.32)***	0.0264 (1.7778)*	**0.0309** (4.55)***	**0.0309** (3.5734)***	**0.0385** (3.37)***	0.0400 (1.7275)*	**0.0306** (4.29)***	**0.0275** (2.0066)**
Localization	**0.0880** (5.91)***	**0.0880** (7.1167)***	**0.0684** (3.70)***	**0.0667** (3.3311)***	**0.0879** (5.85)***	**0.0879** (7.1207)***	**0.0631** (4.38)***	**0.0547** (2.5774)***	**0.0840** (5.72)***	**0.0835** (4.3364)***
Heteros.	**0.0196** (2.25)**	**0.0196** (2.6213)***	0.0157 (1.55)	0.0168 (1.3781)	**0.0197** (2.24)**	**0.0197** (2.6384)***	0.0041 (0.25)	0.0015 (0.0776)	**0.0234** (2.35)**	**0.0243** (2.1210)**
Estimator	**0.0211** (2.43)**	**0.0211** (2.6228)***	**0.0246** (2.10)**	0.0252 (1.9440)*	**0.0212** (2.42)**	**0.0212** (2.6374)***	0.0670 (1.77)*	**0.0754** (2.8453)***	**0.0297** (2.38)**	**0.0302** (2.4785)**
Period	**-0.0069** (-2.25)**	**-0.0069** (-3.1522)***	-0.0045 (-1.36)	-0.0026 (-0.7663)	**-0.0068** (-2.20)**	**-0.0068** (-3.1055)***	**-0.0102** (-3.84)***	**-0.0104** (-2.9327)***	**-0.0062** (-2.17)**	-0.0053 (-1.5828)
n	64	-	78	-	63	-	59	-	59	-
K	43	-	54	-	43	-	39	-	42	-
R^2	0.883	-	0.7	-	0.885	-	0.575	-	0.798	-

*Note: t-stat or z value in parentheses. For specifications using random effects, the Knapp and Hartung (2003) standard error correction has been employed. *** denotes significant at 1%, ** 5%, and *10%.*

DISCUSSION AND RECOMMENDATIONS

These main results suggest that it would be useful to consider two points for discussion. First, the robustness of these results can be questioned. We therefore explore several robustness tests to check the stability of the results. Second, it can be asked what can be taken away from our work and what kind of recommendations can be made. This will be addressed in a second subpart.

(i) Robustness and impact of the 2008 crisis

Like Doucouliagos et al. (2012), we decided to replicate the analysis with different models (REML and clustered WOLS) and various subsamples in order to assess the robustness of the results. For instance, column 2 replicates the methodology with imputed data and outliers (n=78 versus 64 in specification 1); column 3 corresponds to a similar subsample estimation of (1) and outliers; and in columns 5 and 6, we withdrew respectively the 10% most and least precise studies from the original sample. As can be seen from table 6, our estimates are only slightly impacted by the change in subsample except for the "treatment of heteroskedasticity" and "time period" moderators, which are non-significant in 4 and 3 out of 10 configurations.

It would be interesting to examine the impact of the 2008 real-estate crisis on the estimations of our model. Real estate strongly and lastingly affected the price level of transactions throughout the markets included in our database. It is also to be feared that the financial crisis following the subprime crisis weakened the possibility of investment in green building and so modified the behavior of economic agents. Therefore, we need to ensure that the coefficients of our model are stable over time and especially throughout the economic crisis. With this aim in mind, we performed a Chow test on all the coefficients of model 1. The sample was subdivided into two parts. One for studies with a period of estimation before 2008 (pre-crisis period) and one for analyses with estimations starting in 2008 (post-crisis period). In our case, the value for the computed Fisher test is less than the theoretical Fisher value, indicating the non-rejection of stability of the coefficients of the model ($F^*= 1.137$, p-value = 0.3594). Therefore, the previous test does not support the assumption that the crisis led to a fall in the green building premium.

(ii) Recommendations for future hedonic studies and new research avenues for meta-analysis

This paper suggests the relevance of the investment in green building both for new building and refurbishment. In both cases, the operation generates a supplementary asset value. Our analysis also supports the importance of cost savings capitalized in asset values thanks to energy efficiency. Nonetheless, this premium created by lower energy costs remains a subset of the total green value and it could be worthwhile to distinguish the part attributable to the former. The usual cost-benefit analysis for green building and CO_2 cost abatement curves must therefore cover a broad spectrum of the benefit engendered by green buildings. Furthermore, our estimate of green building premium includes only monetary and non-monetary benefits captured by economic agents, while we know that green buildings generate many other positive externalities (primarily greenhouse gases). We have to keep in mind that green value in a broad sense is higher than our estimate.

Considering the current shortcomings and in order to facilitate the replication of future meta-analyses, we recommend that future hedonic studies of green building values systematically report standard error (t-value or precise p-values). Of 54 studies, 13 hedonic price analyses (24%) fail to provide enough information to recover the precision linked to the estimate. Despite a high response rate (70%), most authors were unable to answer our queries favorably due to the unavailability of the data (lost data, technical failure, relocation, job change, etc.). Although we fully understand the different issues related to lack of space in scientific journals, we encourage reviews and authors to provide full estimates in the appendix of the publication or on the journal's website.

In addition, in order to improve comparisons of results, studies should provide a letter by letter estimation when the label uses different categories. The reference class should also be the same (e.g. D for EPC). Several studies are in non-retrievable form due to this constraint (e.g. exotic classes like A/B/C/D versus E/F/G as main analysis). Of course, we do not exclude other models but to supplement rather than substitute for letter-by-letter estimations. This constraint is essential to ensure the reproducibility of science so dear to Karl Popper (1934).

Furthermore, the inclusion of space through weighted spatial matrices or variables measuring the presence of nearby amenities seems to substantially impact the estimation of green building value. Yet we observe a decrease in the number of studies including spatial variables in favor of studies ignoring space issues. The low proportion of pure spatial studies (using weighted spatial matrix) can be explained by the difficulty in gaining access to these very specific and expensive data. This is why we recommend georeferencing transaction data but also including a large number of spatial variables (distance, amenities, accessibility, etc.). In the context where some of these bases undergo further development, we suggest that future hedonic studies perform those types of spatial analysis, at least as tests of robustness, compared to standard hedonic models.

Moreover, a substantial research effort should be made in order to highlight economic agents' willingness-to pay-for green buildings in emergent countries. Despite an intense research effort, many dead zones persist in countries where we expect an increasing energy demand – mostly in the form of natural gas, oil, and high-carbon electricity (IEA, 2013a). Given the stakes linked to these countries and the important regional disparities in green value, future replications need to examine the identification of the effect in India, the Middle East, Africa, and Latin America rather than a yet another North American study. There is an urgent need for such studies because green value is associated more with new buildings than refurbishment and because buildings have long life spans (IEA, 2013b).

Concerning research linked to future meta-analyses of green value, it could be useful to explore other moderators especially the encoding of external variables capable of providing us with information about the appropriate conditions for the advent of green value. For instance, it might be worth investigating the impact of energy prices on the asset value of energy efficient buildings. Unfortunately, few hedonic studies provide this option due to the use of cross-sectional data and because energy prices are spatially invariant at local scale. Nonetheless, further meta-analyses could estimate this effect by capturing the energy price context of each study and including this variable as a moderator in the modeling. In this way, the meta-analysis would provide an alternative to panel data when considering the effect of energy prices on green building values. In the same vein, it might be worthwhile breaking down the causes linked to the geographical discrepancies of the green building premium. In particular, whether these differences reflect climatic, cultural, and socio-economic disparities or other factors such as regulatory constraints and sensitivity to environmental protection.

CONCLUSION

In this paper, we offer an estimate of the green building premium regardless of the time and place of the study. To achieve this goal, we have collected a large number of hedonic-price studies on this topic. At the end of this process, 54 studies successfully met the inclusion criteria specified in our meta-analysis. A large set of tests converges toward the existence of a substantial publication bias. Multiple models and several estimation methods lead us to the conclusion that the unconditional estimate of the green building value is likely to fall within the range of 3.5–4.5% of the price, which is half of the original estimation made with no correction for publication bias. Considering the great heterogeneity remaining, we have also explored several potential moderators in order to explain the spread of the results. This spread seems to be attributable mainly to the region of the study (North America, Asia, or Europe) then to the type of publication (published or grey literature), and the inclusion of spatial variables in the hedonic model. To a lesser extent, the effect size also depends on the type of estimator (OLS or other estimators), whether heteroskedasticity is treated, and the time period of analysis.

ACKNOWLEDGMENTS

We are very grateful to the authors of studies who responded favorably to our requests for data. We also wish to acknowledge valuable comments on this paper from A. Bonach, D. Charlier, and M. Coinon.

BIBLIOGRAPHY

Ankamah-Yeboah, I., Rehdanz, K., 2014. Explaining the Variation in the Value of Building Energy Efficiency Certificates: A Quantitative Meta-Analysis. Kiel Working Paper, 26p.

Begg, C.B., Berlin, J.A., 1988. Publication bias: a problem in interpreting medical data. Journal of the Royal Statistical Society (Series A) 151.

Begg, C.B., Mazumdar, M., 1994. Operating characteristics of a rank correlation test for publication bias. Biometrics 50, 1088–1101.

Borenstein, M., Hedges, L.V., Rothstein, H.R., 2009. Introduction to Meta-Analysis. Wiley, Chichester, UK.

Brown, J.B., Watkins, T., 2015. The “green premium” for environmentally certified homes: a meta-analysis and exploration. Working Paper, 43p.

Card, D., Krueger, A.B., 1995. Time-series minimum-wage studies: a meta-analysis. American Economic Review 85, 238–243.

CERQUAL, 2011. Etude économique sur la valeur verte de l’immobilier de logements.

Chotard, D., Million, M., Berthon, C., Laurenceau, S., Giraudet, L.G., 2011. Analyse préliminaire de la valeur verte pour les logements. Ademe.

De Long, J.B., Lang, K., 1992. Are all economic hypotheses false? Journal of Political Economy 100, 1257–1272.

Doucouliagos, C., Stanley, T.D., 2013. Are all economic facts greatly exaggerated? Theory competition and selectivity. Journal of Economic Survey 27, 316–339.

Doucouliagos, C., Stanley, T.D., 2009. Publication selection bias in minimum-wage research? A meta-regression analysis. British Journal of Industrial Relations 47, 406:428.

Doucouliagos, C., Stanley, T.D., Giles, M., 2012. Are estimates of the value of a statistical life exaggerated? Journal of Health Economics 31, 197–206.

Duval, S., Tweedie, R., 2000a. A nonparametric “trim and fill” method of accounting for publication bias in meta-analysis. Journal of the American Statistical Association 95, 89–98.

Duval, S., Tweedie, R., 2000b. Trim and fill: A simple funnel-plot-based method of testing and adjusting for publication bias in meta-analysis. Biometrics 56, 455–463.

Dwaikat, L.N., Ali, K.N., 2016. Green buildings cost premium: A review of empirical evidence. Energy and Buildings 110, 396–403.

Egger, M., Davey Smith, G., Schneider, M., Minder, C., 1997. Bias in meta-analysis detected by a simple graphical test. BMJ 315, 629–634.

Giles, D.E.A., 1982. The interpretation of dummy variables in semilogarithmic equations. Economics letter 10, 77–79.

Glass, G.V., 1976. Primary, secondary, and meta-analysis of research. Educational Researcher 5, 3–8.

Gurevitch, J., Hedges, L.V., 1999. Statistical issues in ecological meta-analyses. Ecology 80, 1142–1149.

Halvorsen, R., Palmquist, R., 1980. The interpretation of dummy variables in semilogarithmic equations. The American Economic Review 70, 474-475.

Hedges, L.V., Olkin, I., 1985. Statistical Methods for Meta-Analysis. Academic Press, Orlando.

Higgins, J.P.T., Thompson, S.G., Deeks, J.J., Altman, D.G., 2003. Measuring inconsistency in meta-analyses. British Medical Journal 327, 557–560.

IEA, 2013a. Transition to Sustainable Building: Strategies and Opportunities to 2050. International Energy Agency, OECD/IEA, Paris.

IEA, 2013b. World Energy Outlook 2013. International Energy Agency, OECD/IEA, Paris.

Kennedy, P.E., 1981. Estimation with correctly interpreted dummy variables in semilogarithmic equations. The American Economic Review 71, 801.

Knapp, G., Hartung, J., 2003. Improved tests for a random effects meta-regression with a single covariate. Statistics in Medicine 22, 2293–2710.

Konstantopoulos, S., 2011. Fixed effects and variance components estimation in three-level meta-analysis. Research Synthesis Methods 2, 61–76.

Laroche, P., 2012. La méta-analyse : Méthodes et applications en sciences sociales, De Boeck. ed, Méthodes & Recherches.

LEED, 2016. Leadership in Energy and Environmental Design, available on 12/15/16 at: http://www.usgbc.org/leed

Nelson, J.P., 2013. Meta-analysis of alcohol price and income elasticities – with corrections for publication bias. Health Economics Review 3, 1–10.

Popper, K., 1934. The Logic of Scientific Discovery. Routledge.

Rosen, S., 1974. Hedonic prices and implicit markets: Product differentiation in pure competition. Journal of Political Economy 82, 34–35.

Rosenthal, R., 1979. The “file drawer problem” and tolerance for null results. Psychological Bulletin 86, 638–641.

Sorrell, S., Dimitropoulos, J., 2008. The rebound effect: Microeconomic definitions, limitations and extensions. Ecological Economics 65, 636–649.

Stanley, T.D., 2008. Meta-regression methods for detecting and estimating empirical effect in the presence of publication selection. Oxford Bulletin of Economics and Statistics 70, 103–127.

Stanley, T.D., 2005. Beyond publication bias. Journal of Economic Surveys 19, 309–345.

Stanley, T.D., Doucouliagos, C., 2015. Neither fixed nor random: Weighted least squares meta-analysis. Statistics in Medicine 34, 2116–2127.

Stanley, T.D., Doucouliagos, C., 2012. Meta-Regression Analysis in Economics and Business. Routledge.

Stanley, T.D., Doucouliagos, C., Giles, M., Heckemeyer, J.H., Johnston, R.J., Laroche, P., Nelson, J.P., Paldam, M., Poot, J., Pugh, G., 2013. Meta-analysis of economics research reporting guidelines. Journal of Economic Surveys 27, 390–394.

Stanley, T.D., Jarrell, S.B., Doucouliagos, C., 2010. Could it be better to discard 90% of the data? A statistical paradox. The American Statistician 64, 70–77.

Viechtbauer, W., Cheung, M.W.-L., 2010. Outlier and influence diagnostics for meta-analysis. Research Synthesis Methods 1, 112–125.

META-ANALYSIS BIBLIOGRAPHY

Addae-Dapaah, K., Chieh, S., 2011. Green Mark certification: does the market understand? Journal of Sustainable Real Estate 3, 162–191.

Amado, A.R., 2007. Capitalization of energy efficient features into home values in the Austin, Texas real estate market. Massachusetts Institute of Technology.

Aroul, R., Hansz, J., 2012. The Value of "Green": evidence from the first mandatory residential green building program. Journal of Real Estate Research.

Brounen, D., Kok, N., 2011. On the economics of energy labels in the housing market. Journal of Environmental Economics and Management 62, 166–179. doi:10.1016/j.jeem.2010.11.006

Bruegge, C., Carrión-Flores, C., Pope, J.C., 2016. Does the housing market value energy efficient homes? Evidence from the Energy Star program. Regional Science and Urban Economics 57, 63–76. doi:10.1016/j.regsciurbeco.2015.12.001

Cajias, M., Piazolo, D., 2012. Green performs better: energy efficiency and financial return on buildings. SSRN Electronic Journal. doi:10.2139/ssrn.2186036

Cerin, P., Hassel, L.G., Semenova, N., 2014. Energy Performance and Housing Prices: Does higher dwelling energy performance contribute to price premiums? Sustainable Development 22, 404–419. doi:10.1002/sd.1566

Chegut, A., Eichholtz, P., Kok, N., 2013. Supply, demand and the value of green buildings. Urban Studies 51, 22–43. doi:10.1177/0042098013484526

Chegut, A., Eichholtz, P., Kok, N., Quigley, J.M., 2011. The value of green buildings: new evidence from the United Kingdom. ERES 2010 Proceedings.

Chen, F., Peng, I., Liang, J., Liang, Y., 2015. Green building, materials and civil engineering: proceedings of the 4th International Conference on Green Building, Materials and Civil Engineering.

Copiello, S., Bonifaci, P., 2015. Price premium for buildings energy efficiency empirical findings from a hedonic model.

Das, P., Wiley, J.A., 2014. Determinants of premia for energy-efficient design in the office market. Journal of Property Research 31, 64–86. doi:10.1080/09599916.2013.788543

Davis, P.T., McCord, J.A., McCord, M., Haran, M., 2015. Modelling the effect of energy performance certificate rating on property value in the Belfast housing market. International Journal of Housing Markets and Analysis 8, 292–317. doi:10.1108/IJHMA-09-2014-0035

Deng, Y., Li, Z., Quigley, J.M., 2012. Economic returns to energy-efficient investments in the housing market: Evidence from Singapore. Regional Science and Urban Economics 42, 506–515. doi:10.1016/j.regsciurbeco.2011.04.004

Deng, Y., Wu, J., 2014. Economic returns to residential green building investment: The developers' perspective. Regional Science and Urban Economics 47, 35–44. doi:10.1016/j.regsciurbeco.2013.09.015

DePratto, B., 2015. The market benefits of Green Condos in Toronto for educational purposes.

Dermisi, S., McDonald, J., 2011. Effect of "Green"(LEED and ENERGY STAR) designation on prices/sf and transaction frequency: the Chicago office market. Journal of Real Estate Portfolio Management 17, 39–52.

Dermisi, S.V., 2009. Effect of LEED ratings and levels on office property assessed and market values. Journal of Sustainable Real Estate.

Eichholtz, P., Kok, N., Quigley, J.M., 2013. The economics of green building. Review of Economics and Statistics 95, 50–63.

Eichholtz, P., Kok, N., Quigley, J.M., 2010. Doing well by doing good? Green office buildings. American Economic Review 100, 2492–2509. doi:10.1257/aer.100.5.2492

Fregonara, E., Rolando, D., Semeraro, P., Vella, M., 2014. The impact of energy performance certificate level on house listing prices. First evidence from Italian real estate. Aestimum 143–163.

Freybote, J., Sun, H., Yang, X., 2015. The impact of LEED neighborhood certification on condo prices. Real Estate Economics 43, 586–608. doi:10.1111/1540-6229.12078

Fuerst, F., Gabrieli, T., McAllister, P., 2012. A green winner's curse? Investor behavior in the market for eco-certified office buildings. Investor Behavior in the Market for Eco-Certified Office Buildings (July 20, 2012).

Fuerst, F., McAllister, P., 2011a. Eco-labeling in commercial office markets: Do LEED and Energy Star offices obtain multiple premiums? Ecological Economics 70, 1220–1230. doi:10.1016/j.ecolecon.2011.01.026

Fuerst, F., McAllister, P., 2011b. Green Noise or Green Value? Measuring the effects of environmental certification on office values. Real Estate Economics 39, 45–69. doi:10.1111/j.1540-6229.2010.00286.x

Fuerst, F., McAllister, P., 2011c. The impact of Energy Performance Certificates on the rental and capital values of commercial property assets. Energy Policy 39, 6608–6614.

Fuerst, F., McAllister, P., 2009. New evidence on the green building rent and price premium. Available at SSRN 1372440.

Fuerst, F., McAllister, P., Nanda, A., Wyatt, P., 2016. Energy performance ratings and house prices in Wales: An empirical study. Energy Policy 92, 20–33. doi:10.1016/j.enpol.2016.01.024

Fuerst, F., McAllister, P., Nanda, A., Wyatt, P., 2015. Does energy efficiency matter to home-buyers? An investigation of EPC ratings and transaction prices in England. Energy Economics 48, 145–156. doi:10.1016/j.eneco.2014.12.012

Fuerst, F., Shimizu, C., 2016. Green luxury goods? The economics of eco-labels in the Japanese housing market. Journal of the Japanese and International Economies 39, 108–122. doi:10.1016/j.jjie.2016.01.003

Högberg, L., 2013. The impact of energy performance on single-family home selling prices in Sweden. Journal of European Real Estate Research 6, 242–261. doi:10.1108/JERER-09-2012-0024

Hyland, M., Lyons, R.C., Lyons, S., 2013. The value of domestic building energy efficiency — evidence from Ireland. Energy Economics 40, 943–952. doi:10.1016/j.eneco.2013.07.020
Jaffe, D., Stanton, R., Wallace, N., 2012. Energy Factors, leasing structure and the market Price of office building in the US.

Jayantha, W., Man, W., 2013. Effect of green labelling on residential property price: a case study in Hong Kong. Journal of Facilities Management 11, 31–51. doi:10.1108/14725961311301457

Jensen, O.M., Hansen, A.R., Kragh, J., 2016. Market response to the public display of energy performance rating at property sales. Energy Policy 93, 229–235. doi:10.1016/j.enpol.2016.02.029

Kahn, M.E., Kok, N., 2014. The capitalization of green labels in the California housing market. Regional Science and Urban Economics 47, 25–34. doi:10.1016/j.regsciurbeco.2013.07.001

Miller, N., Spivey, J., Florance, A., 2008. Does green pay off? Journal of Real Estate Portfolio Management 14, 385–400.

Mudgal, S., Lyons, L., Cohen, F., Lyons, R., Fedrigo-Fazio, D., 2013. Energy performance certificates in buildings and their impact on transaction prices and rents in selected EU countries.

Newell, G., MacFarlane, J., Walker, R., 2014. Assessing energy rating premiums in the performance of green office buildings in Australia. Journal of Property Investment & Finance 32, 352–370. doi:10.1108/JPIF-10-2013-0061

Pivo, G., Fisher, J., 2010. Income, value, and returns in socially responsible office properties. Journal of Real Estate Research.

Rahman, F., 2014. Do green buildings capture higher market-values and prices? A case-study of LEED and BOMA-BEST properties. Thesis.

Ramos, A., Perez-Alonso, A., Silva, S., 2015. Valuing energy performance certificates in the Portuguese residential sector.

Shewmake, S., Viscusi, W.K., 2015. Producer and consumer responses to green housing labels. Economic Inquiry 53, 681–699. doi:10.1111/ecin.12140

Shimizu, C., 2010. Will green buildings be appropriately valued by the market. RIPESS (Reitaku Institute of Political Economics and Social Studies) Working Paper.

Stanley, S., Lyons, R.C., Lyons, S., 2016. The price effect of building energy ratings in the Dublin residential market. Energy Efficiency 9, 875–885. doi:10.1007/s12053-015-9396-5

Stephenson, R.M., 2012. Quantifying the effect of green building certification on housing prices in metropolitan Atlanta.

Walls, M., Palmer, K., Gerarden, T., Bak, X., 2009. Data center metrics: an energy efficiency model for information technology managers. Management of Environmental Quality: An International Journal 20, 712–731.

Wiley, J.A., Benefield, J.D., Johnson, K.H., 2010. Green design and the market for commercial office space. The Journal of Real Estate Finance and Economics 41, 228–243. doi:10.1007/s11146-008-9142-2

Yang, X., 2013. Measuring the effects of environmental certification on residential property values - evidence from green condominiums in Portland.

Yoshida, J., Sugiura, A., 2015. The effects of multiple green factors on condominium prices. The Journal of Real Estate Finance and Economics 50, 412–437. doi:10.1007/s11146-014-9462-3

Yoshida, J., Sugiura, A., 2011. Which "greenness" is valued? Evidence from green condominiums in Tokyo.

Zhang, L., Liu, H., 2016. Price premium of green-labeled dwellings in China.

Zhang, L., Liu, H., Wu, J., 2016. The price premium for green-labelled housing: evidence from China. Urban Studies. doi:10.1177/0042098016668288

Zheng, S., Wu, J., Kahn, M.E., Deng, Y., 2012. The nascent market for "green" real estate in Beijing. European Economic Review 56, 974–984. doi:10.1016/j.euroecorev.2012.02.012

APPENDIX

Table 7 Meanings of abbreviations in the paper

Label	Name
AGBP	Austin Green Building Program
BER	Building the Education Revolution
BOMA	Building Owners and Managers Association International
BREEAM	Building Research Establishment Environmental Assessment Method
CASBEE	Comprehensive Assessment System for Built Environment Efficiency
CGBL	Chinese Green Building Label
ECHC	Earth Craft Housing Certification
EEWH	Ecology Energy saving Waste reduction Health
EFL	Environment for Living
EPC	Energy Performance Certificate
ES	Energy Star
FRGBP	Frisco's Residential Green Building Program
GGI	Google Green Index
GM	Green Mark
HK-BEAM	Building Environmental Assessment Method
HK-GBC	Green Building Council
LEED	Leadership in Energy and Environmental Design
NABERS	National Australian Built Environment Rating System
TGBP	Tokyo Green Building Program
Method	
FAT	Funnel Asymetry Testing
MST	Meta-Significance Testing
PBFE	Publication Bias Filtered Effect
PEESE	Precision Effect Estimate with Standard Error
PET	Precision Effect Testing
RCT	Ranking Correlation Test
RE	Random Effects
REML	Random Effects Multi-Levels
WOLS	Weighted Ordinary Least Squares

Table 8 Description of the selection process of the studies for the meta-analysis

1. Number of remaining studies (91)

Deletions (16). Reasons: absence of label, no estimate, no hedonic model
Banfi et al., 2006; Bonde and Song, 2013; Geng et al., 2012; Harrison and Seiler, 2011a; Hui et al., 2016, 2014; Leopoldsberger et al., 2011; McAllister, 2009; Muldavin, 2008; NEEA, 2015; Pfleger et al., 2011; Poel et al., 2007; Popescu et al., 2012; Robinson and Sanderford, 2016; Surmann et al., 2015; Thorsnes and Bishop, 2013

2. Number of remaining studies (75)

Deletions (13). Reasons: only estimates for occupation rate or rental prices
(Bond and Devine, 2016; Cajias et al., 2016; Das et al., 2011; Devine and Kok, 2015; Fuerst et al., 2013; Fuerst and McAllister, 2009b; Gabe and Rehm, 2014; Hui et al., 2015; Koirala et al., 2014; Kok et al., 2013; Kok and Jennen, 2012; Reichardt, 2014; Reichardt et al., 2012)

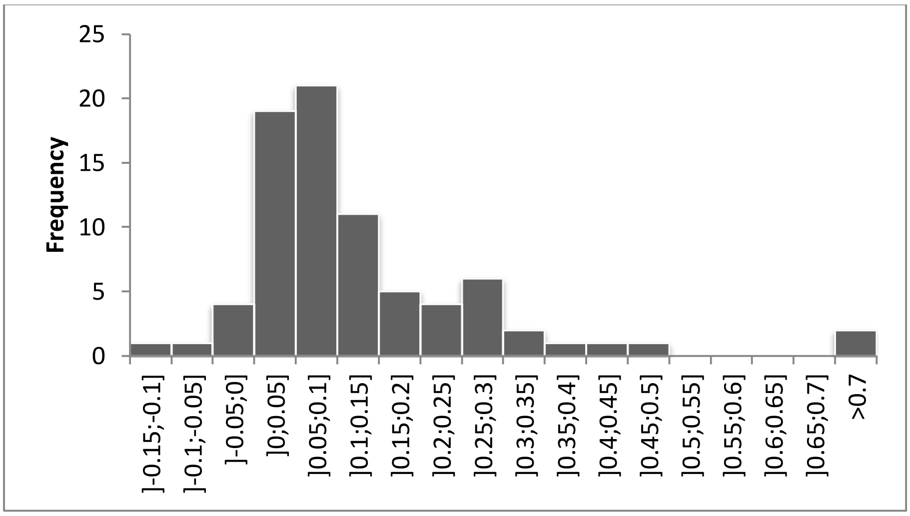
3. Number of remaining studies (62)

Deletions (7). Reasons: non comparable estimates, non-transformable estimates, duplicates
Bloom et al., 2011; Chegut et al., 2016; De Ayala et al., 2016; Dinamic, 2015; Fuerst et al., 2016; Kok and Kahn, 2012; Qiu et al., 2016

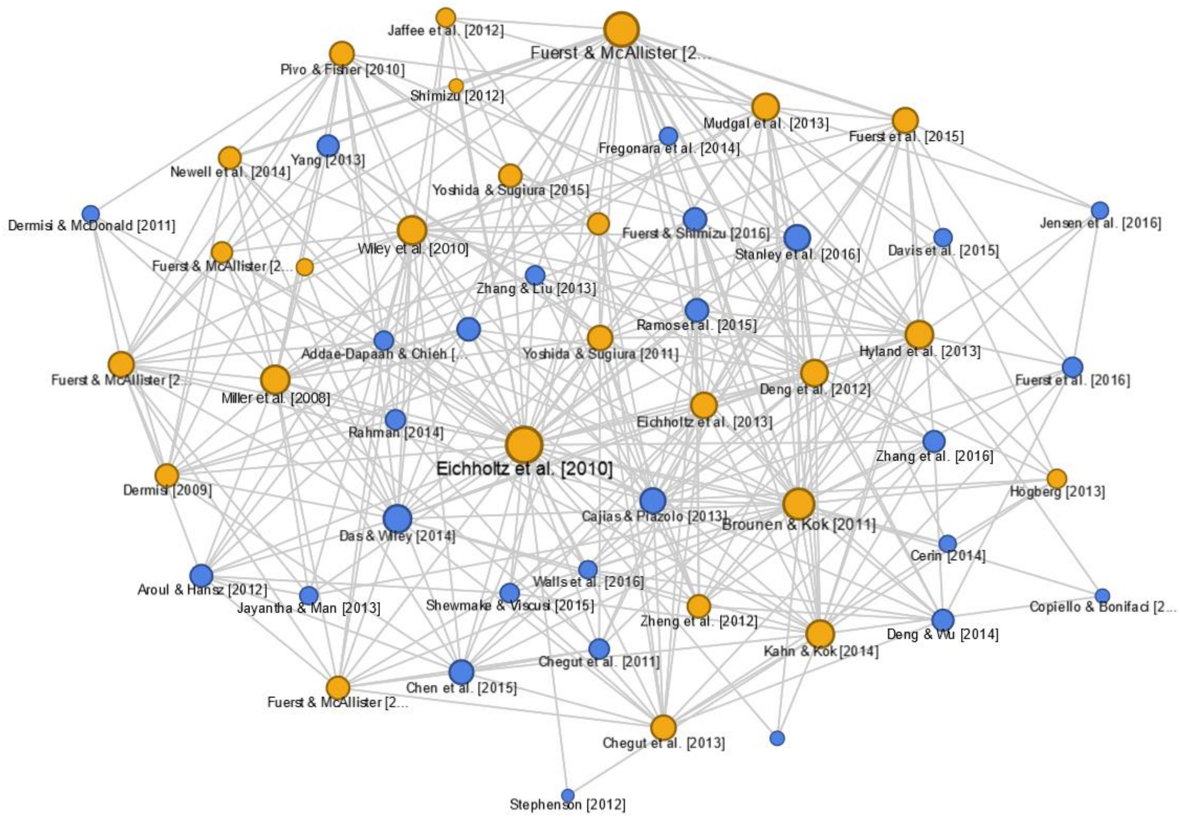
4. Number of remaining studies (55)

Deletions (1). Reasons: other sectors
Harrison and Seiler, 2011b

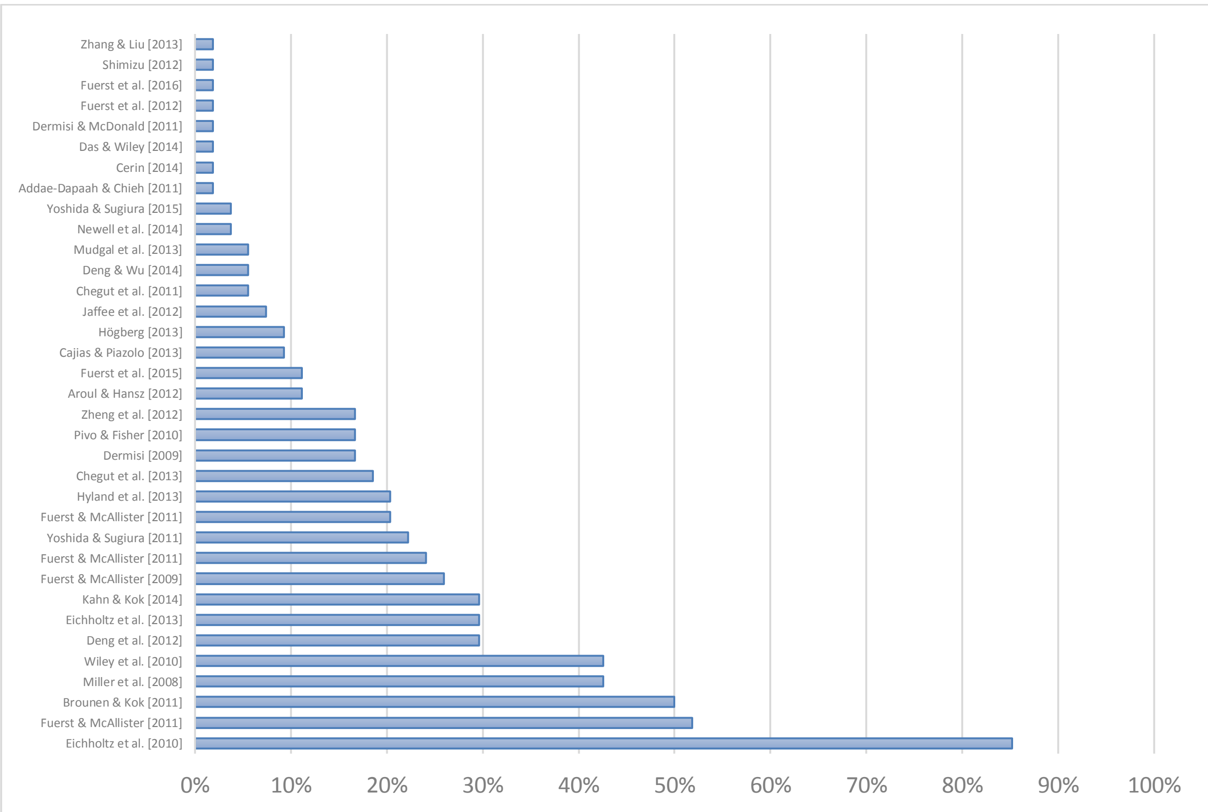
5. Number of studies selected (54)



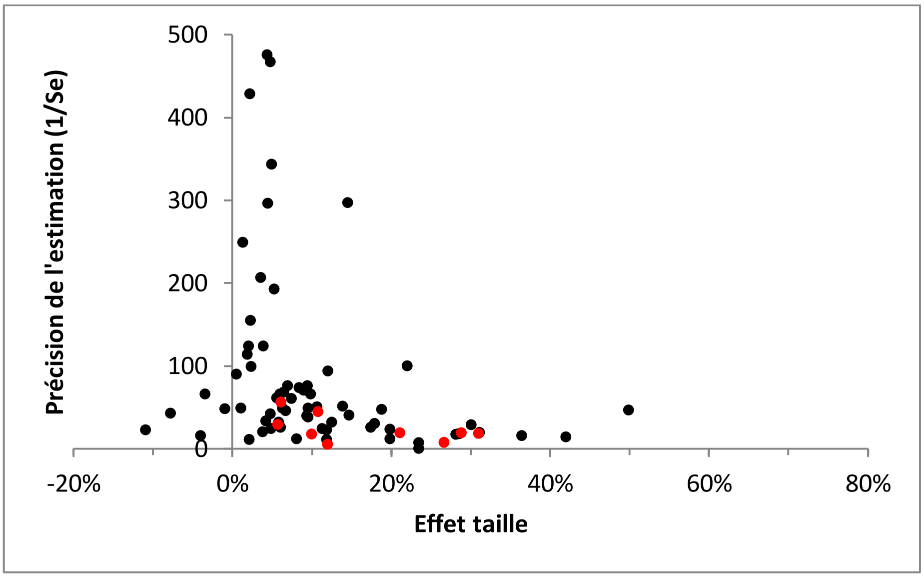
Appendix 1 Distribution of effect size related to green building value



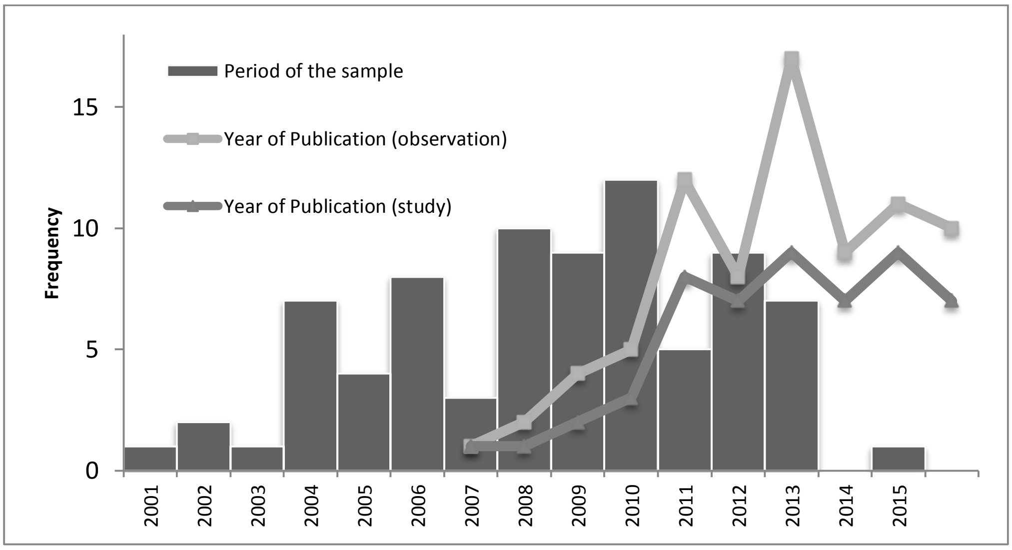
Appendix 2 Citation network of the sample studies. Note for the reader: yellow studies are cited while blue studies are only citing other studies. The size of the circles is proportional to the number of citations.



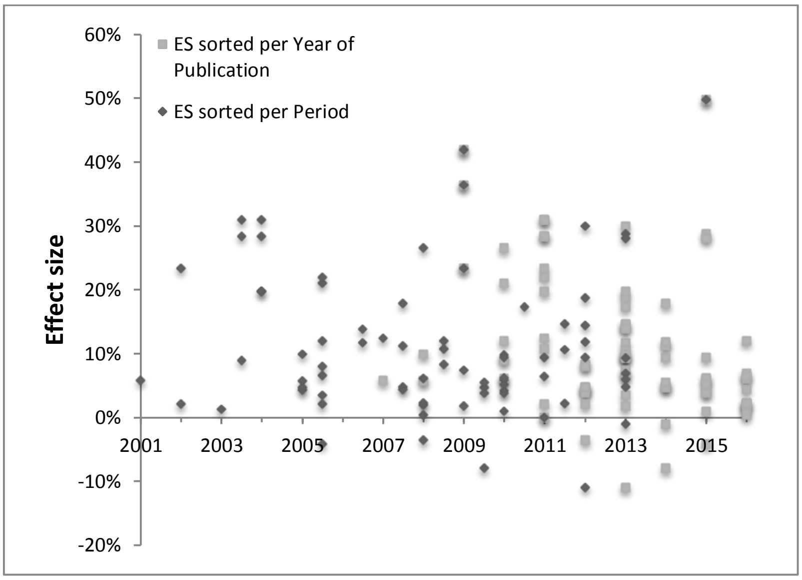
Appendix 3 Share of citations of each survey compared to the total number of the studies. Note for the reader: almost 85% of the sample studies are citing the work of Eichholtz et al. (2010)



Appendix 4 Funnel graph showing the top5 cited studies in comparison to the other papers from our sample.



Appendix 5 Changes in the green premium depending on the sample time period and year of publication



Appendix 6 Time distribution of effect size related to the green premium

Table 9 Time and geographical distribution of the data related to green value

	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	**Total**
Australia	0	0	0	0	0	0	0	1	0	0	**1**
Austria	0	0	0	0	0	0	1	0	0	0	**1**
Belgium	0	0	0	0	0	0	3	0	0	0	**3**
Canada	0	0	0	0	0	0	0	2	1	0	**3**
China	0	0	0	0	0	1	1	0	0	2	**4**
Denmark	0	0	0	0	0	0	0	0	0	1	**1**
France	0	0	0	0	0	0	2	0	0	0	**2**
Germany	0	0	0	0	0	0	1	0	0	0	**1**
Hong-Kong	0	0	0	0	0	0	2	0	0	0	**2**
Ireland	0	0	0	0	0	0	1	0	1	1	**3**
Italy	0	0	0	0	0	0	0	1	1	0	**2**
Japan	0	0	0	0	1	1	0	0	1	1	**4**
Netherlands	0	0	0	0	1	0	0	0	0	0	**1**
Portugal	0	0	0	0	0	0	0	0	1	0	**1**
Singapore	0	0	0	0	1	1	0	1	0	0	**3**
Sweden	0	0	0	0	0	0	1	1	0	0	**2**
Taiwan	0	0	0	0	0	0	0	0	1	0	**1**
UK	0	0	0	0	3	0	2	0	1	1	**7**
USA	1	2	4	5	6	5	3	3	4	4	**37**
Total	**1**	**2**	**4**	**5**	**12**	**8**	**17**	**9**	**11**	**10**	**79**