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Les études hédoniques soutiennent-elles une valeur verte élevée dans le bâtiment ? Une réponse par la méta-analyse

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Résumé

La place majeure occupée par le secteur du bâtiment dans la consommation d'énergie (40%) et les émissions de gaz à effet de serre (1/3 des émissions) explique le développement du débat scientifique axé sur la réduction de l'impact environnemental du bâti et sur ses leviers. Ces dernières années ont notamment vu croître une littérature considérable relative à la disposition à payer du public pour les bâtiments « verts » labélisés par des écolabels, cette « valeur verte » étant estimée dans la grande majorité des études via des modèles hédoniques. Dans cet article, nous proposons d'offrir une synthèse de ces résultats dans le cadre d'une méta-analyse portant sur plus d'une cinquantaine d'études à travers le monde. Deux résultats sont produits. Grâce à un modèle à effets aléatoires multi-niveaux et une régression MCO pondérée robuste au regroupement, nous fournissons tout d'abord une estimation moyenne ainsi qu'un intervalle de confiance du premium de prix concédé par les agents économiques (prix de vente) pour accéder à un bâtiment vert. Cette estimation nous permet de corroborer l'intérêt et la pertinence économique de l'investissement dans la rénovation du bâtiment. Toutefois, un important biais de publication semble affecter cette thématique et sa correction amène à une division par deux de la valeur verte immobilière (de 8 à 4 %). Ensuite, nous analysons les facteurs susceptibles d'être à la source de la dispersion des résultats via une méta-régression basée sur différents modérateurs (type de publication, période d'analyse et zone géographique de l'échantillon, technique économétrique employée...). Divers tests statistiques et méthodes alternatives de sélection sont également réalisés pour étayer la robustesse de ces résultats. Nous terminons par un certain nombre de recommandations à destination des recherches futures permettant une meilleure comparabilité des résultats ainsi que par des suggestions aptes à éclairer l'efficacité des politiques publiques visant la soutenabilité du secteur du bâtiment.

Mots-clés : labels – certification – efficacité énergétique – bâtiment – modèle hédonique – méta-analyse

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

Does the literature support a high willingness to pay for green label buildings? An answer with treatment of publication bias

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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 energy 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, bibliometric variables, 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 have taken a growing interest in environmental issues relating to the building sector (Kok et al., 2012). Today it 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 building sector. 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-Kong³ have been precursors in the development of global green labeling. In contrast, parts of Asia⁴ and Europe⁵ have been slower to develop their own labels. We also observe differences between regions in the way they manage the development of green labels. For example, Europe has mostly supported the development of mandatory labels using regulation while voluntary labels have been privileged in other part of the world. 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?⁶ 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

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.

⁶ The cost premium estimation associated with green buildings as well as the cost of refurbishing are beyond the scope of this paper. Readers interested in these topics should see Dwaikat and Ali (2016).

for buildings. But while most studies (92% of the literature) 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 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 a suitable subject for such surveys and applications.

To our knowledge there have been only two attempts, not published yet, to perform a meta-analysis of the willingness to pay (WTP) for green buildings (Ankamah-Yeboah and Rehdanz, 2014; Brown and Watkins, 2015). The first study reaches the conclusion that the WTP for green buildings is nearly 7.6% more higher than for traditional buildings. With a really more restricted sample (20 studies), the second study gets a weighted average effect size of 4.3%. Despite the great interest of these unpublished works, we have still caveats about the results found in these studies. First, the second meta-analysis only shows the weighted average effect found in literature and omits the possibility to explain the dispersion via a meta-regression. Second, the two studies only use one model: multilevel random effect model for the first one and random effect model for the second one. Third, they explore a limited number of moderators: 17 and 5 respectively. Fourth, they offer no test of publication bias and do not take into account the possibility that the final result could be affected by this phenomenon.

In this respect, we propose in this paper to overcome the limitations of ongoing studies in order to improve knowledge and results about the green housing value. We increase the number of references (54 studies), we deal with the presence of duplicate results and we introduce a larger set of moderators. Most of all, we analyze, estimate, and correct the publication bias affecting this literature. Publication bias refers here to the tendency for small studies to present very different results from studies using broader sample size (due to censoring bias or significance bias). If not corrected, this could greatly impact the average effect estimated in the literature (Doucouliagos and Stanley, 2013; 2009). Therefore, the correction of publication bias must be achieved in order to avoid misleading results which in return lead to support or refute an economic theory, and to give spurious recommendations for policy makers (and thus their actions).

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 more than 30 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

Meta-analysis aims at summarizing some main results derived from studies of a specific issue. Among others, Borenstein et al. (2009), Laroche (2012) or Stanley (2005) state that meta-analysis seems to outperform conventional narrative review because it is transparent, comprehensive, objective, and replicable. 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.

Our paper has been calibrated to meet the meta-analysis standardization principles provided by Nelson and Kennedy (2009) in Environmental and Resource Economics and 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:

$$\log(p_s) = \alpha + \rho E_s + \delta X_s + e_s \quad (1)$$

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 .

Following equation (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)⁷:

$$ES = \exp(\rho) - 1 \quad (2)$$

ES can be interpreted as a percentage when multiplied by 100 (for instance, $0.12 \times 100 = 12\%$). In this case it means that, all other things being equals, economic agents tend to value green buildings 12% more than traditional buildings in terms of price. In a linear model, the premium (in \$ or €) is expressed as a share of the average building price of the sample. The variable E in equation (1), 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 the highest level A (or B in the absence of A) and the medium 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).

⁷ 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) and without transformation. It only marginally changes our results (third digits after the decimal point).

The following keywords: “energy efficiency premium building OR housing”, “green housing value OR appraisal”, “label premium housing OR building”, or “hedonic valuation of green housing OR 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, EVRI, 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 market (dwellings and office buildings in residential and tertiary sector). We deal with the heterogeneity coming from this mix in the robustness analysis of the paper.
- 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. We are aware of the existence of studies using stated preference as well as rent prices in order to assess the green value of buildings. However nearly all references related to meta-analysis reviewed in the paper [Laroche 2012, p.23; Borenstein et al. 2009, p.359] discourage to mix studies using different designs (i.e. stated preference and hedonic valuation). In addition, the meta-analysis guidelines of Nelson and Kennedy in ERE (2009) underline the failure of past meta-analyses to provide separate analyses of hedonic valuation and stated preference. Concerning rents, we chose to not include the estimated rent green value for multiple reasons. First of all, renters do not have the same goals and the same thinking process as owner occupiers. We could expect that for instance the comfort is not as interesting for a renter. Also, concerning renting, we are confronted to the split incentive issue; the owner pays but the tenant benefits from the investments, resulting in fewer incentives to adopt green building (Charlier, 2015). While we can consider that there is a weak relationship between rents (occupation prices) and housing prices, we must also recognize that the former has other determinants that make the comparison very difficult (for instance the price to rent ratio can be very volatile over time). Overall, effect-sizes associated with rents and housing prices are not directly comparable because they do not value the same object (at least temporally speaking).
- 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.

When data were incomplete (usually the lack of the estimated 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 of our data base⁸. The whole process is described in the appendix to the paper (Appendix 2). At the end of the process, 54 studies met the criteria described above. According to Stanley and Doucouliagos (2012)⁹, 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 data¹⁰. Of these 54 studies, 36 provide one estimate while the remaining 18 studies offer more than one estimate.

⁸ 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.

⁹ Of 87 meta-analyses reviewed by Doucouliagos and Stanley (2013), the median of the number of analyses covered is 36 and the mean 41.

¹⁰ 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.

Our meta-analysis covers 20 labels and 19 countries around the world during the period 1996–2015 (see Appendix 1).¹¹ Overall, research on green building value began in North America and then spread to Europe and Asia. However, since 2011, the number of studies related to the green premium of building has stabilized.

(ii) Moderators

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 34 potential moderators (see tables 1 and 2). These moderators can be split into four categories: study characteristics, label characteristics, data characteristics, and regression methodology.

METHODOLOGY OF ESTIMATION

As often addressed in the literature, estimating the effect size of a meta-analysis involves considering and fixing three types of issues, namely: the treatment of the dependence effect (several estimates in one study), multicollinearity, and outliers. In addition, we consider in this paper the publication bias issue, which is often present but rarely covered in meta-analyses (Doucouliagos et al., 2012).

This section describes the methodologies used to address these issues. The general specifications of the estimation model are available on pages 9-10 (equations 5.2 and 6).

(i) *Treatment of the dependence effect*

When 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 methods¹² (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):

$$ES_i = \gamma_0 + \eta_i + \varepsilon_i \quad (3)$$

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:

$$ES_{i,g} = \gamma_{00} + v_{0,g} + \eta_{i,g} + \varepsilon_{i,g} \quad (4)$$

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 $\varepsilon_{i,g} \sim N(0, v_i)$, $\eta_{i,g} \sim N(0, \tau_2)$, $v_{0,g} \sim N(0, \tau_1)$. τ_1 is the between-study variance while τ_2 is the between-unit variance. The estimators of the different variances were obtained from the Restrained Estimator of Maximum Likelihood (for more details see Konstantopoulos, 2011).

¹¹ Here, the time period of analysis associated with the hedonic studies. The oldest study is from 2007.

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 synthesize results from studies which have very different characteristics is inappropriate (Borenstein et al., 2009).

(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. Conversely Nelson and Kennedy (2009, p.358) argue that no reason exists to prefer clustering methods to hierarchical multilevel methods. This is why we estimate the two models.

Table 1 Dependent variable and moderators

| Meta-analysis variables | | |
|-------------------------|--------------------|---|
| 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 |
| | Building 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 |
| | ShareGreen | = 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 |
| | Insulation | = 1 if the model includes an energy variable or the insulation level, 0 otherwise |
| | Distance | = 1 if the model includes the distance, 0 otherwise |
| | Location | = 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 |
| | Nb.moderators | = Number of moderators employed in the hedonic price study |
| External variables | Mean Temp | = Mean Temperature in the country during the year of the estimation |
| | Range Temp | = Temperature Range in the country during the year of the estimation |
| | Income | = GPP per capita in the country during the year of estimation (2011\$PPP/year) |

Table 2 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 |
| Sector | 0.38 | 0.49 | 0 | 0.00 | 0.00 | 1.00 | 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 |
| NbObs | 38 810 | 188 337 | 2661 | 9 120 | 1 030 | 13 971 | 51 | 1 609 879 |
| Distance | 0.30 | 0.46 | 0 | 0.00 | 0.00 | 1.00 | 0 | 1 |
| Location | 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 |
| 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 |
| Nb.moderators | 20.92 | 21.54 | 16.5 | 18 | 11 | 22 | 7 | 166 |
| Mean Temp | 10.58 | 5.39 | 9.3 | 9.3 | 8.8 | 11.1 | -5 | 27.6 |
| Range Temp | 10.22 | 2.68 | 12.2 | 12.3 | 7.9 | 12.3 | 4.6 | 14.6 |
| Income | 43721 | 10097 | 47134 | 48558 | 39742 | 49568 | 7948 | 68340 |

(ii) Treatment of multicollinearity

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 of the between study variance T, and the I² proposed by Higgins et al. (2003).

(iii) Treatment and outliers

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.

(iv) Identification and correction of publication bias

The possibility that scientific literature is biased by publication bias has long been a recognized phenomenon in medicine and psychology (Begg and Berlin, 1988; Rosenthal, 1979). In economics, the seminal paper by De Long and Lang (1992) suggests that even a careful review of the existing literature does not provide an accurate view of the topic if the literature reflects a selection bias, especially the file drawer problem related to the exclusion of non-significant results. In addition, Doucouliagos and Stanley (2013) have shown that publication bias without being systematic, could affect nearly two-thirds of topics.

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 all cases, meta-analysis must include an analysis relative to the detection of a potential publication bias to avoid unreliable results.

In this context, it could be relevant to include unpublished papers or grey literature¹³ in the meta-analysis. Such unpublished results do 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. As for published results, Stanley (2005, p. 337) observed that, grey literature is also likely to be biased (bias of type I or II) because many working papers remain motivated by publication incentives¹⁴.

The different tests employed to identify a publication bias try to determine whether there is a link between the effect size and its standard error. Indeed, 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).

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

$$ES_i = \beta_1 + \beta_0 Se_i + \varepsilon_i \quad (5.1)$$

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 5.2 to equation 5.1:

$$\frac{ES_i}{Se_i} = t_i = \beta_0 + \beta_1 \left(\frac{1}{Se_i} \right) + e_i \quad (5.2)$$

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 ($\beta_1 = 0$). This last test is known as *Precision Effect Testing* (PET) and has a high statistical power (Stanley, 2008). The FAT-PET tests are therefore an efficient way to adjust for all publication bias (censoring or significance bias) leading to an asymmetric funnel plot. We also perform a variety of other tests of publication bias (TRIM and FILL, MST, PBF) described by Begg and Mazumdar (1994), Stanley, (2008), Duval and Tweedie (2000a, 2000b), Stanley et al. (2010), Borenstein et al., (2009), and Nelson, (2013)¹⁵.

After identifying publication bias, we estimated an extended form of equation 5.2 including moderators of the effect size as described in Doucouliagos and Stanley (2009):

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 See the FAERE working paper version of this paper to know more about these methodologies.

$$t_i = \beta_0 + \sum_{j=1}^J \omega_j M_{ij} + \beta_1 \left(\frac{1}{Se_i} \right) + \sum_{l=1}^L \varphi_l H_{il} \left(\frac{1}{Se_i} \right) + e_i \quad (6)$$

Where β_0 is the parameter associated with the publication bias, M_j 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).

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 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 1, 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. In addition, the cumulative meta-analysis which shows the mean effect as a function of increasing standard error also moves in the same direction (Appendix 7). At first sight, our case of publication bias 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 to validate these initial comments.

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 in table 3). According to the figures suggested by Doucouliagos and Stanley (2013), a β_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%)¹⁶ in the presence of publication bias.

The genuine effect remains discernable beyond the publication bias as demonstrated by the PET, MST, and PBE 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%).¹⁷ These results are consistent with the work of Stanley (Doucouliagos et al., 2012; Doucouliagos and Stanley, 2013) and indicate that most empirical economic facts are exaggerated due to the selection process of results. Overall, a first conclusion can be drawn: at the first sight (without controlling heterogeneity via moderators) the literature seems to indicate that green label buildings tends to increase the WTP of economic agents by 3.5% to 4.5% (see table 3 variable “PET”). These conclusions (publication bias and weighted average effect) do not change when we restrict our sample to published studies by the exclusion of unpublished papers.

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.

¹⁶ The results with fixed effects are not reported in order to save space.

¹⁷ The PEESE test also provides a value in this range (4.96%).

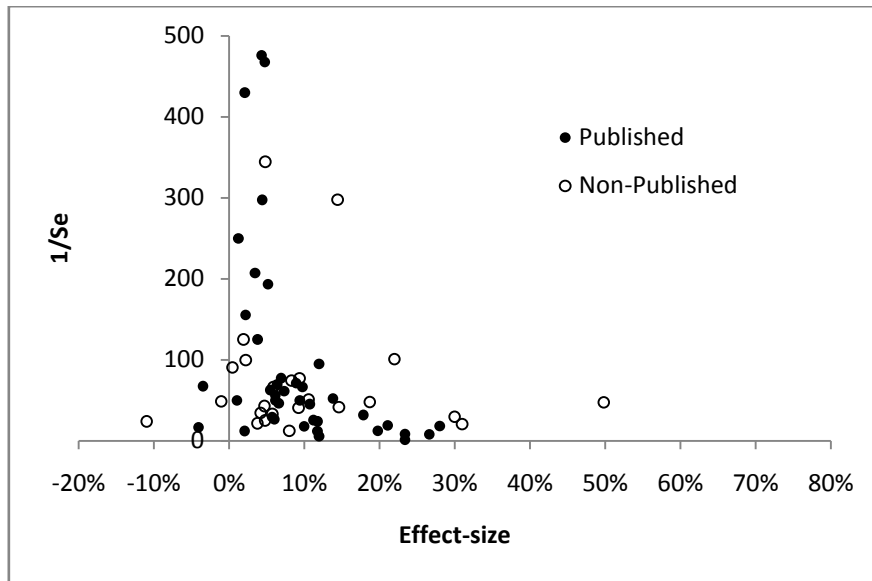


Figure 1 Funnel graph of green building values. Note: non imputed studies, N=65

Table 3 Identification of publication bias by several methods

| Tests | | Methodologies | | | |
|--------------------|---------------|----------------------------|----------------------------|-----------------------------|-----------------------------|
| | | A: No multiple (RE) | B: Random sampling | C: REML | D: Clustered WOLS |
| FAT | β_0 | 2.5769 (2.22)** | 2.0878 1.6182 2.4846 | 1.4771 (1.71)* | 1.7610 (3,38)*** |
| PET | β_1 | 0.0327 (5.33)*** | 0.0338 0.0324 0.0432 | 0.0430 (7.25)*** | 0.0420 (4,12)*** |
| MST | α_0 | -0.3606 (-0.56) | -0.8568 -1.3751 -0.3633 | -1.0793 (-2.14)** | -0.8467 (-1,49) |
| | α_1 | 0.2134 (3.08)*** | 0.2553 0.2048 0.3101 | 0.2786 (4.75)*** | 0.2530 (3,76)*** |
| PBFE | δ_1 | 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%.

(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 4 (column [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 (table 4 [1] variable "1/SE": 3.02% versus table 3 variable "PET" 3-4%).

It is worth noting that geographical disparities absorb most of the heterogeneity in the data (nearly 12% of partial R^2)¹⁸. Estimates based on European samples are on average 12 points of percentage higher than their North American equivalents (table 4 [1] variable “Europe”). Maybe the recentness of the Asian green building market explains why the green value is still 5.5 points higher than in North America (table 4 [1] variable “Asia”). 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: table 4 [1] variable “published”). In contrast, certified office buildings appear to be more value-enhanced than private dwellings (+8 points: table 4 [1] variable “building sector”). One explanation may be that those firms are more willing to pay for goods and services than individuals. 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: table 4 [1] variable “distance”) while environmental amenities (+3 points: table 4 [1] variable “amenities”) or the precise location of real estate (+9 points: table 4 [1] variable “location”) 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 location 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 allows better differentiation between the value linked to 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.

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 (see table 4 [1] variable “estimator”). More surprisingly, studies using robust heteroskedastic estimators have higher green building values (+ nearly 2 percentage points: table 4 [1] variable “heteros.”). Finally, we observe a low but significant downward trend of the green premium over time (-0.7 percentage points per year: see table 4 [1] variable “period”). 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.

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. Second, it can be asked what can be taken away from our work and what kind of recommendations can be made.

¹⁸ Due to limited number of observations, we have also performed regressions without moderators with different sub-samples (North America, Europe, Asia). The results are consistent with our other outcomes and are available in appendix 8.

(i) Robustness and impact of the 2008 crisis

We explore several robustness tests to check the stability of the results. Like Doucouliagos et al. (2012), we 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 column 1 and outliers; and in columns 4 and 5, we withdraw respectively the 10% most and least precise studies from the original sample. As can be seen from table 4, our estimates are only slightly impacted by the change in subsample. Moreover, Column 6 and 7 check the impact of the number of moderators employed in hedonic price studies on the green value estimated (table 4 [6-7] variable “nb.moderators”). Column 8 and 9 assess the explanatory power of the number of observations as a moderator of publication bias (table 4 [8-9] variables “Sqrt(NbObs)” and “NbObs”)¹⁹.

It would be also 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. We performed a Chow test on all the coefficients of model (1). The sample was subdivided into two parts: “pre-crisis period” including studies with a period of estimation before 2008 and “post-crisis” for studies with estimations starting in 2008. 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 ($F^*= 1.137$, $p\text{-value} = 0.3594$). Therefore, the previous test does not support the assumption that the crisis led to a fall in the green building premium. But if we delete the variable capturing the temporal trend (i.e. Period) and do the same test, then we reach the opposite conclusion ($F^*=2.26$, $p\text{-value} = 0.03$). Therefore, we think likely that the temporal trend captures a crisis effect although this effect must be confirmed other studies not present in our meta-base (hedonic valuation using panel data).

Some academics expressed also concerns about the heterogeneity linked to mixing the effect of WTP for dwellings and offices. In addition, although many specialists of meta-analysis recommend to introduce a high share of grey literature (Nelson, 2013; Stanley and Doucouliagos, 2012), others suspect that this important share of unpublished papers is the source of the publication bias. This is why we perform separate analyses for dwellings only and for published papers only. In the two cases, it does not change our results (see specifications 10 and 11 in table 5). In addition, we note that the exclusion of grey literature (in both FAT-PET tests without moderator and in Meta-regression analysis) tends to reinforce the publication bias found in literature (see value and significance of “intercept” in table 5 specification 11). Interestingly, 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. Nonetheless, these studies cited by the major part of the literature are neither the most precise nor the less biased studies (Appendix 5 and 6). Indeed, the studies cited by more than half of our sample are all included in the first quartile of precision (lowest precision). Conversely, the studies with the highest precision (highest precision quartile) are only cited in average by 5% of our sample. These conclusions do not change when we take the SJR or the Impact factor of the review publishing the studies of our sample (see appendix 6). This observation is in line with the book on meta-analysis by Stanley and Doucouliagos (2012). This also underlines that citations (or journal rank indicators) are probably not a good proxy of the quality of study or at least of the precision quality of outcomes. Moreover, the heterogeneity between the labels is also questioned. It requires to include as many dummy variables as labels. With our sample size, we cannot introduce too many dummy variables thus we use an intermediary solution by coding three dichotomous variables for the main labels of our sample (Energy Star, LEED and Energy Performance Certificate = 70% of sample). Two out of three

¹⁹ We have also replicated the methodology of Stanley (2005) using the square root of the number of observations instead of $1/SE$. It does not change our conclusions.

of dichotomous variables are non-significant while the last one (EPC) is significant (table 5 [12] variables “Energy star” “LEED” and “EPC”). This alternative specification only changes the coefficient of Europe falling from 12.92 to 8.03. In fact, the sum of the regression coefficient of EPC (4.28) and the new coefficient of Europe (8.03) is approximately equal to the old coefficient of Europe (table 4 [1] variable “Europe”). It indicates the difference between a green label in Europe (like the BREEAM label) and the EPC and shows that EPC is more valued than local green labels in Europe. Finally, one suggestion is to include and control the effect of income and temperatures thus we check their impact on green building value in the full model (table 5 columns [13-15-17]). Unfortunately, results are associated with high multicollinearity ($VIF > 50$) forcing us to explore their effect in a more parsimonious model (table 5 columns [14-16-18]). In this last model, positive signs associated with the income and temperature range are in the line with the expected effect. Conversely, it seems that mean temperature is positively linked to green premium building which involves that cooling needs are more valued than warming needs. This last result should be considered cautiously due to the weak significance of the coefficient. Overall, the effects related to income and temperature seem to be quite low, less than one point of percentage. This means that the observed spatial heterogeneity could come from other factors.

(ii) Recommendations for public policies and investors

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. At this stage, this premium created by lower energy costs remains a subset of the total green value and it could be worthwhile to have more studies distinguishing the part attributable to the former. 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 reducing greenhouse gases). Then we have to keep in mind that green value in a broad sense is higher than our estimate. Moving on to consideration of the extra cost of green buildings; there are few studies which focus on this. Regardless the range of estimations of extra cost generated by these studies is very close to the WTP for green buildings. For instance, based on 12 European projects, Schnieders and Hermelink (2006) report an average additional cost of 8%. A more recent Sweden survey led by Zalejska-Jonsson et al. (2012) recalls that 47% of individuals surveyed estimate this extra-cost to be less than 5% (and 38% between 5% and 10%). More recently in Turkey, Uğur and Leblebici (2018) provide a range of estimations between 7.43 and 9.43% for LEED buildings. This additional cost of green buildings is really close to the WTP for green buildings of those European people surveyed (between 10-12%). For USA, the difference is likely to be even narrower. According to Kats (2009), the average additional cost of 170 American green building cases is 1.4% while Dwaikat and Ali (2016) report that only 25% of green building projects incur no additional cost in comparison to traditional buildings (and 30% between 0% and 5%). These estimates are nearly equivalent to the WTP of American people for green buildings (nearly 1-2% once the publication bias is corrected).

As WTP of North American people seems to be very low, we recommend to use mandatory labels and/or the generalization of green buildings in order to capture the important external benefits associated with it. This could be a more effective way to avoid important social losses due to the inability of private economics agents to value the external benefits of green buildings. Conversely, firms have a higher capability to value green buildings maybe due to the important private benefits already mentioned in the literature (lower staff turnover, greater productivity, and less absenteeism...). This is why we recommend to avoid to target firms in case of green buildings public program support. Such joint public help (individual and companies) could lead to important windfall effects.

We also observed that the EPC label over-performs by comparison to other European labels (like BREAM or BER) therefore we recommend the wider application of this label. We also recommend to avoid the coexistence of multiple labels in one geography as this could distort the effectiveness of green labels in communicating their goals and messages.

Although the range of impact is yet to be confirmed, it seems that the temperature gap increases the WTP for green buildings. It could then be worthwhile targeting new constructions or regeneration initiatives in such geographies because of the anticipated larger return on private or public investments. It creates higher energy saving potentials and higher greenhouse gas emissions reductions (depending on the energy mix).

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

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 fact that data were not available anymore (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).

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.

Table 4 Meta-regression of the building green premium for different specification and robustness values

| Dependent variable : t | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | |
|--------------------------------|------------------------------|--------------------------------|------------------------------|------------------------------|------------------------------|------------------------------|-----------------------------|----------------------------|-----------------------------|-------------------------------|
| | Clustered WOLS | REML† | Clustered WOLS | Clustered WOLS | Clustered WOLS | Clustered WOLS | Clustered OLS | Clustered OLS | Clustered OLS | Clustered OLS |
| Intercept | 0.5774 (1.17) | 0.5754 (1.0755) | 1.3885 (1.90)* | 0.8993 (1.49) | 1.1130 (2.72)*** | 0.4474 (0.80) | 0.5515 (1.16) | 0.6686 (1.21) | 0.4714 (0.93) | 0.5135 (1.04) |
| 1/SE | 0.0302 (3.10)*** | 0.0302 (3.1787)*** | 0.0318 (2.22)** | 0.0278 (2.65)*** | 0.0193 (3.13)*** | 0.0309 (3.12)*** | 0.0292 (2.81)*** | 0.0041 (0.57) | 0.0311 (3.05)*** | 0.031 (3.14)*** |
| Published | -0.0736 (-5.96)*** | -0.0736 (-8.13)*** | -0.0707 (-4.74)*** | -0.0750 (-5.98)*** | -0.0681 (-7.06)*** | -0.0738 (-5.94)*** | -0.0694 (-4.3)*** | | -0.0744 (-6)*** | -0.0749 (-5.9)*** |
| Sector | 0.0846 (5.48)*** | 0.0846 (3.5983)*** | 0.0742 (3.62)*** | 0.0768 (4.48)*** | 0.0697 (4.07)*** | 0.0865 (5.42)*** | 0.0847 (5.58)*** | 0.0624 (3.62)*** | 0.0861 (5.58)*** | 0.087 (5.6)*** |
| Asia | 0.0542 (8.15)*** | 0.0542 (6.3674)*** | 0.0521 (5.27)*** | 0.0524 (7.19)*** | 0.0659 (6.88)*** | 0.0540 (7.97)*** | 0.0516 (7.00)*** | 0.0273 (7.50)*** | 0.0542 (7.88)*** | 0.0547 (7.98)*** |
| Europe | 0.1292 (7.62)*** | 0.1292 (9.0674)*** | 0.1081 (4.94)*** | 0.1286 (8.09)*** | 0.1082 (7.89)*** | 0.1290 (7.58)*** | 0.1223 (6.44)*** | 0.0786 (2.70)*** | 0.1276 (7.57)*** | 0.1289 (7.54)*** |
| Distance | -0.0565 (-5.61)*** | -0.0565 (-5.156)*** | -0.0539 (-4.07)*** | -0.0501 (-4.03)*** | -0.0419 (-4.25)*** | -0.0563 (-5.56)*** | -0.0543 (-5.4)*** | | -0.0572 (-5.4)*** | -0.0573 (-5.5)*** |
| Amenities | 0.0311 (4.61)*** | 0.0311 (3.5904)*** | 0.0317 (3.32)*** | 0.0302 (4.24)*** | 0.0423 (3.86)*** | 0.0310 (4.53)*** | 0.0259 (2.61)** | | 0.0305 (4.44)*** | 0.0306 (4.47)*** |
| Location | 0.0880 (5.91)*** | 0.0880 (7.1167)*** | 0.0684 (3.70)*** | 0.0835 (5.65)*** | 0.0703 (7.15)*** | 0.0881 (5.87)*** | 0.0783 (3.71)*** | | 0.0873 (5.87)*** | 0.0876 (5.86)*** |
| Heteros. | 0.0196 (2.25)** | 0.0196 (2.6213)*** | 0.0157 (1.55) | 0.0234 (2.35)** | 0.0203 (2.09)** | 0.0198 (2.24)** | 0.0176 (1.79)* | | 0.0196 (2.25)** | 0.02 (2.3)** |
| Estimator | 0.0211 (2.43)** | 0.0211 (2.6228)*** | 0.0246 (2.10)** | 0.0295 (2.36)** | 0.0267 (1.84)* | 0.0213 (2.42)** | 0.0195 (2.03)** | | 0.0208 (2.38)** | 0.0211 (2.42)** |
| Period | -0.0069 (-2.25)** | -0.0069 (-3.1522)*** | -0.0045 (-1.36) | -0.0061 (-2.15)** | -0.0084 (-4.29)*** | -0.0068 (-2.19)** | -0.0061 (-1.83)* | | -0.0068 (-2.22)** | -0.0069 (-2.23)** |
| Nb.moderators (effect size) | | | | | | | 0.0002 (0.72) | 0.0008 (2.44)** | | |
| Sqrt(NbObs) (Mod. Publi. bias) | | | | | | | | | 0.0013 (1.09) | |
| NbObs (Mod. Publi. bias) | | | | | | | | | | 1.427*10-6 (2.30)** |
| n | 64 | - | 78 | 65 | 59 | 59 | 64 | 64 | 64 | 64 |
| K | 43 | - | 54 | 44 | 39 | 42 | 43 | 43 | 43 | 43 |
| R ² | 0.883 | - | 0.7 | 0.801 | 0.722 | 0.884 | 0.885 | 0.739 | 0.884 | 0.885 |
| \bar{R}^2 | 0.858 | - | 0.649 | 0.76 | 0.681 | 0.856 | 0.858 | 0.716 | 0.857 | 0.857 |

(1) Reference model, (2) with imputed data and outliers, (3) with outliers, (4) Without 10% most precise studies, (5) without 10% most imprecise studies. Note: t-stat or z value in parentheses. *** denotes significant at 1%, ** 5%, and *10%. †To save space, REML estimations are not reported. These estimations are available in the FAERE working paper version of this study.

Table 5 Meta-regression analysis, robustness analysis (continue)

| Dependent variable : t | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 |
|------------------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|
| | Clustered OLS | Clustered OLS | Clustered OLS | Clustered OLS | Clustered OLS | Clustered OLS | Clustered OLS | Clustered OLS | Clustered OLS |
| Intercept | 0.6670 | 1.4017 | 0.7521 | 0.3020 | 1.0949 | 0.5622 | 1.8568 | 0.6123 | 0.5362 |

| | | | | | | | | | |
|-----------------------|----------------|----------------|----------------|----------------|----------------|----------------|---------------|----------------|---------------|
| | (0.96) | (3.20)*** | (1.61) | (0.61) | (1.61) | (1.13) | (2.77)*** | (1.28) | (0.84) |
| 1/SE | 0.0297 | -0.0286 | 0.0328 | 0.0648 | | 0.0323 | | -0.0125 | |
| | (2.80)*** | (-2.36)** | (2.29)*** | (3.30)*** | - | (2.48)** | - | (-0.23) | - |
| Published | -0.0774 | | -0.0677 | -0.0721 | -0.0384 | -0.0734 | -0.0198 | -0.0732 | -0.0284 |
| | (-6.29)*** | - | (-6.01)*** | (-6.53)*** | (-2.32)** | (-5.90)*** | (-1.38) | (6.12)*** | (-1.84)* |
| Sector | | 0.0669 | 0.0834 | 0.0937 | 0.0521 | 0.0863 | 0.0479 | 0.0835 | 0.0620 |
| | - | (5.52)*** | (5.54)*** | (5.65)*** | (2.28)** | (4.65)*** | (2.15)** | (5.46)*** | (3.00)*** |
| Asia | 0.0548 | 0.0465 | 0.0485 | 0.0580 | 0.0232 | 0.0588 | 0.0186 | 0.0685 | 0.0395 |
| | (8.37)*** | (7.19)*** | (3.99)*** | (10.71)*** | (2.49)** | (2.62)** | (1.09) | (3.38)*** | (4.84)*** |
| Europe | 0.1340 | 0.0806 | 0.0803 | 0.1326 | 0.0712 | 0.1308 | 0.0820 | 0.1484 | 0.0853 |
| | (7.20)*** | (4.05)*** | (3.36)*** | (10.13)*** | (3.58)*** | (7.87)*** | (3.57)*** | (5.00)*** | (4.69)*** |
| Distance | -0.0560 | -0.0306 | -0.0539 | -0.0610 | | -0.0586 | | -0.0575 | |
| | (-5.45)*** | (-2.57)** | (-4.38)*** | (-7.74)*** | - | (-4.32)*** | - | (-5.87)*** | - |
| Amenities | 0.0308 | 0.0275 | 0.0266 | 0.0272 | | 0.0305 | | 0.0316 | |
| | (4.36)*** | (3.43)*** | (2.42)*** | (4.54)*** | - | (4.27)*** | - | (4.69)*** | - |
| Location | 0.0915 | 0.0530 | 0.0838 | 0.0911 | | 0.0872 | | 0.0889 | |
| | (5.75)*** | (3.21)*** | (4.80)*** | (7.26) | - | (5.59)*** | - | (6.22)*** | - |
| Heteros. | 0.0217 | 0.0122 | 0.0190 | 0.0241 | | 0.0204 | | 0.0184 | |
| | (2.43)** | (2.55)** | (2.23)** | (2.61)** | - | (1.99)** | - | (2.12)** | - |
| Estimator | 0.0226 | 0.0168 | 0.0225 | 0.0261 | | 0.0221 | | 0.0196 | |
| | (2.49)** | (3.72)*** | (2.71)*** | (2.67)*** | - | (-2.15)** | - | (2.25)** | - |
| Period | -0.0077 | -0.0050 | -0.0052 | -0.0076 | | -0.0070 | | -0.0075 | |
| | (-2.22)** | (-1.98)** | (-1.64) | (-3.31)*** | - | (-2.46)** | - | (-2.76)*** | - |
| Energy Star | | | -0.0044 | | | | | | |
| | - | - | (-0.33) | - | - | - | - | - | - |
| LEED | | | -0.0261 | | | | | | |
| | - | - | (-1.25) | - | - | - | - | - | - |
| EPC | | | 0.0428 | | | | | | |
| | - | - | (3.63)*** | - | - | - | - | - | - |
| Income (k \$2011 PPP) | | | | -0.0008 | 0.0010 | | | | |
| | - | - | - | (-1.82)* | (2.80)*** | - | - | - | - |
| Mean temperature | | | | | | -0.0003 | 0.0017 | | |
| | - | - | - | - | - | (-0.23) | (1.83)* | - | - |
| Temperature range | | | | | | | | 0.0034 | 0.0036 |
| | - | - | - | - | - | - | - | (0.81) | (2.84)*** |
| n | 43 | 41 | 64 | 64 | 64 | 64 | 64 | 64 | 64 |
| K | 31 | 30 | 43 | 43 | 43 | 43 | 43 | 43 | 43 |
| R ² | 0.886 | 0.886 | 0.899 | 0.890 | 0.741 | 0.883 | 0.689 | 0.887 | 0.742 |
| \bar{R}^2 | 0.850 | 0.848 | 0.870 | 0.864 | 0.719 | 0.855 | 0.662 | 0.860 | 0.720 |

(10) Without the office sector, (11) Without unpublished papers, (12) With dummy variables for the three most important labels, (13-14) with income variable in full and parsimonious model, (15-16) with the average temperature, (17-18) with the temperature range. *t*-stat or *z* value in parentheses. *** denotes significant at 1%, ** 5%, and *10%.

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APPENDIX

Appendix 1 Studies included in the meta-analysis

| Studies (54) | Nb Estimations | Label | Country |
|-----------------------------|----------------|------------------|-------------------|
| 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 & Piazzolo [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 | TGBP | 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.

Appendix 2 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; Pflieger 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

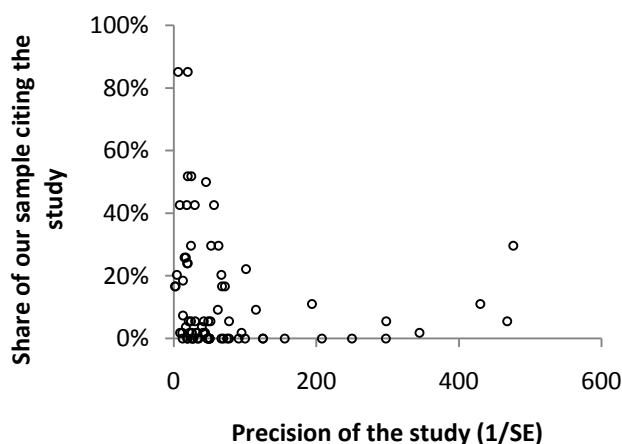
4. Number of remaining studies (55)

Deletions (1). Reasons: other sectors

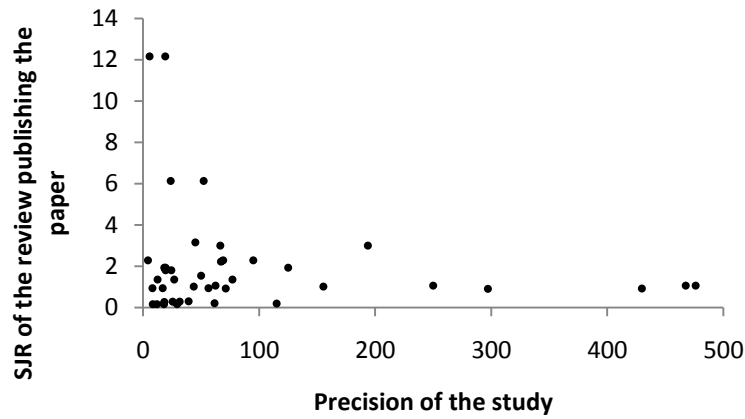
Harrison and Seiler, 2011b

5. Number of studies selected (54)

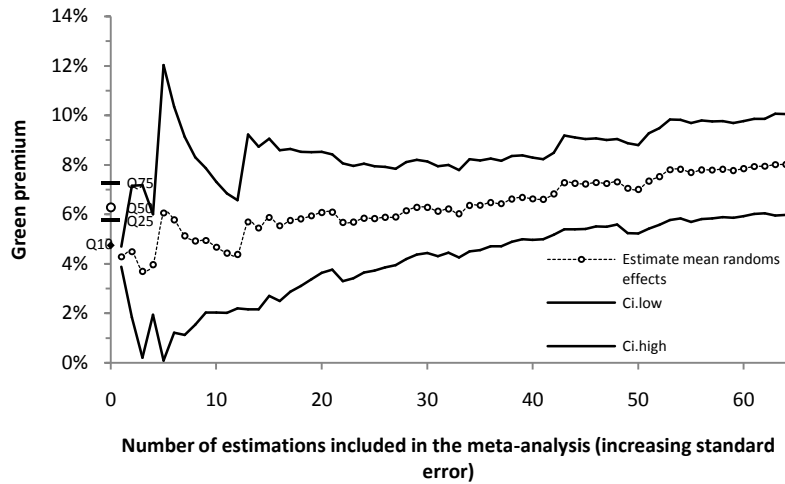
Appendix 5 Relationship between the share of our sample citing the study and the precision of the study



Appendix 6 Relationship between precision of the study and the SJR of the review publishing the study



Appendix 7 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%



Appendix 8 FAT-PET tests with different sub-samples

| Tests | | Comments | |
|--|-----------|---------------------|---------------------------------|
| <i>Depend variable ES/SE = t, Sample : North America</i> | | | |
| 1/SE | β_1 | 0.0141 (4.67)*** | Genuine effect |
| Intercept | β_0 | 2.0107 (5.59)*** | Publication bias |
| n | 33 | | |
| <i>Depend variable ES/SE = t, Sample : Europe</i> | | | |
| 1/SE | β_1 | 0.1022 (3.07)*** | Genuine effect |
| Intercept | β_0 | 0.1434 (0.11) | No significant publication bias |
| n | 18 | | |
| <i>Depend variable ES/SE = t, Sample : Asia</i> | | | |
| 1/SE | β_1 | 0.0422 (9.86)*** | Genuine effect |
| Intercept | β_0 | 1.5760 (0.76) | No significant publication bias |
| n | 13 | | |