The ‘Green Value’ Proposition in Real Estate: A Meta-Analysis

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In recent years, mandatory government-led environmental rating systems have gained traction in several countries. At the same time, there has been a proliferation of voluntary eco-labels, such as BREEAM in the UK, Green Star in Australia and LEED in the US. The very existence of the voluntary labels is indicative of a market-led environmental agenda. Any voluntary initiatives that exceed regulatory requirements and national building codes could potentially create 'green value' which should, at least hypothetically, be capitalised into prices and rents. The existence of a green premium would also reflect consumer willingness to pay, which studies have found to be primarily related to increased energy-efficiency; therefore, a premium may also indicate the ability to successfully and credibly convey a property’s energy efficiency.

Amongst the issues that may hinder energy-efficient investment include those that stem from principle-agent problems and a vicious circle of blame. Finding evidence for a green premium, and analysing its dynamics within a transaction-setting, may be able to provide a clearer understanding of the incentives available to stakeholders.

Evidence-based policy depends on reliable and robust analytical results, particularly in innovative areas such as green real estate finance. However, the growing body of literature on the green premium is disjointed and at least partly inconclusive. The general incentives and disincentives of energy efficiency and broader sustainability are now widely researched but the empirical studies are often limited in terms of geography and time periods analysed. Hardly any studies have tried to consolidate the burgeoning green premium literature and place the individual studies in a larger context. This chapter attempts to achieve this objective via a meta-analysis of green premium studies in a real estate context and illustrates the implications arising from the green premium consensus on property investment using a simple DCF model.

Background

The real estate sector revolves around reshaping the environment, and thus has an inevitable impact on it. Given that buildings reportedly account for 32% of final energy consumption (International Energy Agency, 2016), there should be an impetus for property owners and investors to improve the energy efficiency and environmental performance of their assets. Prior to 2010, the majority of the literature concerning the environmental performance of property emerged from engineering disciplines and focused on construction systems and technology, rather than the implications for financial stakeholders (Eichholtz et al., 2010; Sayce et al., 2007). Although investors suspected that premia for environmental performance was available (Sayce et al., 2007), the evidence was largely anecdotal.

Voluntary eco-labels, sometimes also referred to as environmental labels (*see* Fuerst and McAllister, 2011c) or green ratings (*see* Eichholtz et al., 2010), aim to reduce harmful emissions through communicating an asset's environmental impact; thereby, influencing consumer preferences, supplier production, and the overall market supply and demand (Fuerst and McAllister, 2011b; Fuerst and McAllister, 2011a; Cole, 2005). Since the inception of BREEAM in the UK in 1990, eco-labels have gained significant momentum, with many countries following suit (*see* Figure 1). Many regulators and government bodies, e.g. Welsh Assembly Government, now require attainment of certain eco-labels. As such, the idea of a 'green building' is becoming increasingly institutionalised (Cole, 2005) and has provided eco-labels with what Fuerst and McAllister (2011a, 2011b) describe as a "quasi-compulsory" status; however, they are not without criticism. There is ongoing debate concerning the attribution of weightings to environmental impacts (*see* Lee, 2013), from which a clear tension between actual measures and theoretical measures emerges; the rating is usually based on the theoretical energy efficiency of the building's services and fabric, rather than its actual efficiency (Ingle et al., 2014).

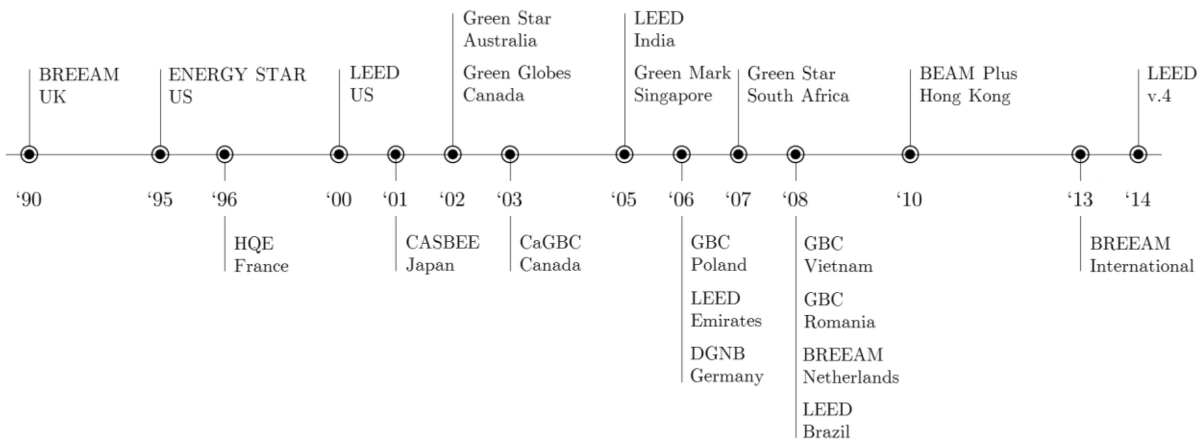


Figure 1: An international timeline of eco-label development. Adapted from Arup (2014).

Research Strategy

To our knowledge, only one meta-analysis of the green premium has been undertaken in a real estate context. Brown and Watkins (2015) analyse the green premium for environmentally certified homes, through a review sample of 20 studies primarily focused on the US residential market. The present study focuses on commercial real estate in a large number of countries. Whilst there are several systematic review databases for medicine and health, such as the Cochrane Database of Systematic Reviews (CDSR), no such database exists for finance and economics. A search within Google Scholar reveals other previous systematic reviews of relevant literature; although, their methods exhibit fundamental flaws. The only two systematic reviews available on the green premium have been undertaken by McAllister (2013; n.d.); however, they are not within peer reviewed journals, nor were they intended to be (hence the title of the 2013 paper, “An ‘off the record’ record”). This is evident by the absence of any search and selection strategy, which leaves readers questioning the validity of the review, given that it cannot be reproduced and may give rise to author bias.

The other, peer-reviewed, papers that undertake a systematic review of green-real estate, often do so in a far broader context. A paper by Zhang (2015) employs broad search terms to draw general themes from the literature, rather than narrow search terms to focus on a particular aspect of green real estate or to perform a meta-analysis. Moreover, the review is focused on the Chinese market, which the author notes to have predominantly government-led sustainability and environmental initiatives; whereas western markets such as the US and UK, as identified in the preliminary literature review, are largely market-led. Another recent systematic review, by Olubunmi et al. (2016), explores the incentives and disincentives for green building and green procurement. However, their broad search terms produced broad results, and the green premium was therefore overlooked.

The systematic review within this chapter follows the procedure proposed by Klewitz and Hansen (2014) as illustrated in Table 1.

Table 1: The six step review process, from Klewitz and Hansen (2014, p.60)

Overall process	Individual steps	Analysis	Resulting no. articles
Search process	Step 1: Identify keywords (17 keywords)	Previous research and reviews	NA
	Step 2: Develop exclusion/inclusion criteria	NA	NA
	Step 3: Specify relevant search engines	Title and abstracts (automated based on keywords)	21267
	Step 4: Develop A, B, C list		
	C-list	NA	21267
	B-list	Title and abstracts (manual)	299
	A-list	Full content	42
Meta-Analysis	Step 5: Code A-list for their methodology, effects and errors		
	Step 6: Aggregate the study effects. Estimate overall and subgroup effects.		

Steps 1-4: Search Process

Step 1: The research question necessitates a literature search comprised of keywords related to four key components (search groups): energy-efficient, real estate, price, premium. An overall total of 32 keywords were considered to describe the four search groups (*see* Table 2). The exemplary search syntax in Table 2 will only return studies that contain at least one word from each search group.

*Table 2: Search keywords. Wildcards: ? = one character (e.g. capitalise, capitalize); * = zero or more characters (e.g. environment, environmental); $ = zero or one character.*

Search groups				Search syntax
Energy-efficient	Real estate	Price	Premium	
Green, environ*, eco, responsible, RPI, sustainab*, energy-efficient, energy efficient, energy rating, energy performance, energy certificat*, environ* rating, environ*, performance, environ* certificate, EPC, performance certificat*, eco-label, BREEAM, LEED, Energy Star	Real estate, property, properties, building$	Price$, value$, rent$, transaction$, sale$	Premium$, capitali?ed, capitali?e	("green" OR environ* OR "eco" OR "responsible" OR "RPI" OR sustainab* OR "energy-efficient" OR (("energy" OR environ*) AND (efficien* OR "rating" OR "performance" OR certificat*)) OR "EPC" OR performance certificat* OR "eco-label" OR "BREEAM" OR "LEED" OR "Energy Star") AND ("real estate" OR "property" OR "properties" OR building$) AND ("price" OR "value" AND "premium" OR capitali?ed OR capitali?e)

Step 2: Borenstein et al. (2009) emphasise that a systematic review does not rid the review process of subjectivity and bias; rather, there are different biases that threaten the review's validity (Hopewell et al., 2009). Ensuring methodological quality at this step in the process can be crucial in alleviating systematic bias (Bennett et al., 2012), particularly publication bias - whereby studies with results that favour a certain direction, with higher statistical significance and perceived importance, are more likely to be published (Hopewell et al., 2009). As such, the exclusion of the non- peer reviewed or 'grey' literature from a meta-analysis may lead to overestimation of an effect (Borenstein et al., 2009; Hopewell et al., 2007) as positive and large findings may have a better chance of getting published. Whilst the inclusion of grey literature should reduce publication bias, it will also provide exposure to industry publications that may present first-hand insights into the incentives/disincentives for green property.

Step 3 and 4: The review, which was undertaken in June 2016, digitally searched the content of studies within several large complementary academic and general databases: Web of Science, Wiley Online Library, Taylor and Francis Online, Science Direct, Emerald Insight, Sage Journals, Google, Business Source Complete. The general databases, Google and Business Source Complete, should capture the grey literature. It must be noted that the search syntax varies for some databases; the eight databases required three moderate adaptations of the exemplary search syntax in Table 2. Following Klewitz and Hansen (2014), the initial search results form a 'C-list' of 21,267 articles which may be largely irrelevant. The article titles and abstracts were downloaded into *Endnote* and were manually reviewed in order to further categorise the relevant articles into a 'B-list' of 299 articles. After removing 29 duplicate studies, a review of the full text of these articles, based on the inclusion and exclusion criteria in Table 3, formed the 'A-list' of 42 most relevant articles (Figure 2).

Table 3: Inclusion and exclusion criteria

Inclusion	Exclusion
Studies by government, academics, business and industry (commercially and non-commercially published)	Studies not available in English
Studies that estimate the relationship between the energy efficiency of individual properties, and their rental and capital values (based on transaction data/proxies). Note: due to the Energy Performance of Buildings Directive 2002/91/EEC mandating EPCs for property transactions, studies in which energy efficiency is measured using EPCs are benchmarked against other levels of EPC. As a result, this meta-analysis will only include the highest group of EPC levels provided e.g. A-C (similar to Brown and Watkins).	Studies prior to 2007
Studies where the price effect is provided as a percentage relative to the expected value (based on comparables).	Summary articles that lack a detailed methodology
Studies that exhibit adequate methodological quality and transparency	
Studies that analyse different data - when encountered by this problem, only the most credible source will be included (as was also done by Brown and Watkins 2015).	

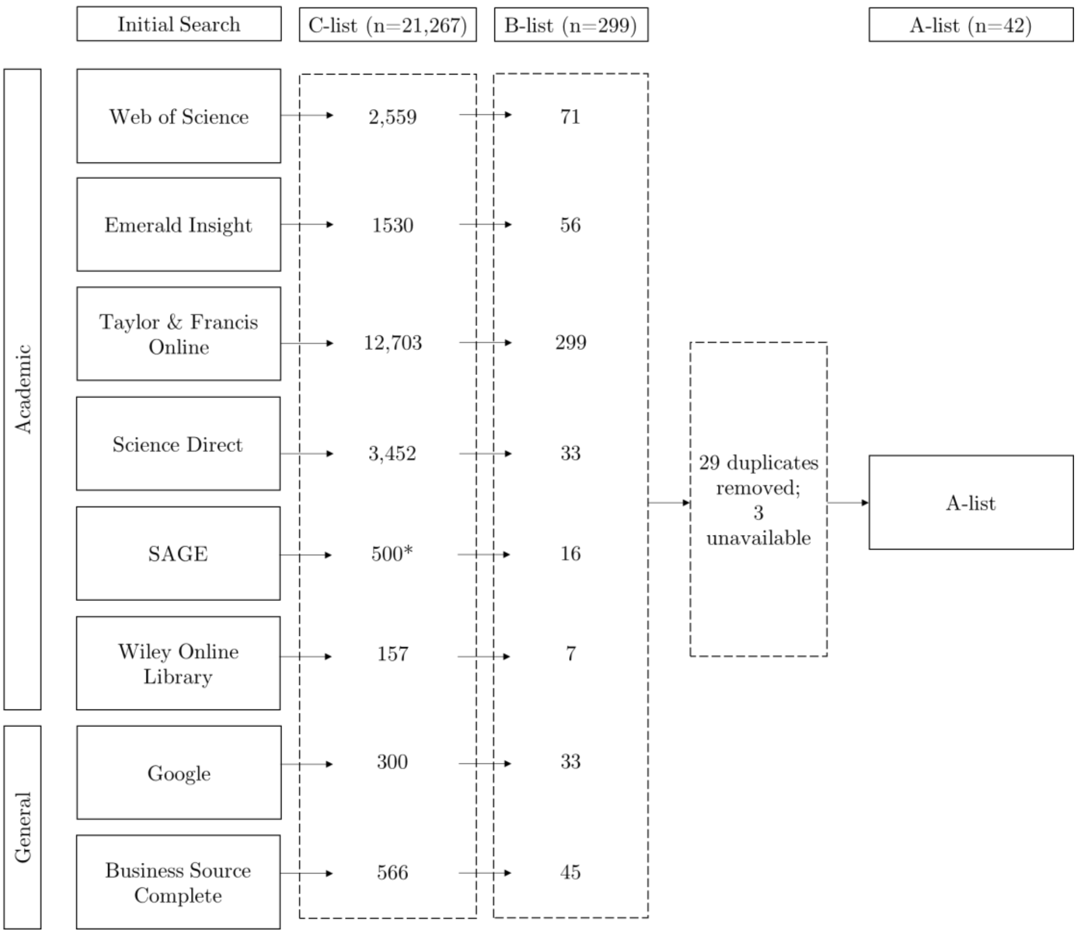


Figure 2: Step 4 - developing the A-list of studies to be included in the meta-analysis.
**Due to the limited search string-length in the SAGE search engine, 73,321 results were returned. Therefore, the results were ordered by relevance and the first 500 studies were taken.*

Steps 5-6: Aggregating studies and estimating an effect size

Step 5: The final sample comprises 42 unique studies which have been coded by: measure of energy efficiency; methodology; sample market; sales and rental premiums; and estimate standard errors (dataset available upon request from author). All of the selected studies were published in journals; a search of the grey literature did not return any non-commercially published studies that met the inclusion criteria. Of the 29 journals in which the studies were published, the most influential appear to Energy Policy (4 studies); Journal of Real Estate Finance and Economics (4 studies); and Regional Science and Urban Economics (3 studies). The publication of green premium studies peaked during 2013 and 2014, and may be in decline (*see* Figure 3).

The literature on green premiums appears to be predominately US-focused, particularly on commercial properties (*see* Figure 4). This does not come at a surprise - the data available on the US commercial market has been acknowledged to exhibit the highest quality, in terms of its sample size and number of variables (McAllister, n.d.). Not to mention that the US is a fitting subject due to its widespread certification schemes, LEED and Energy Star (Eichholtz et al., 2013), in comparison to other countries such as China where government-led green building initiatives have been met with resistance (Zheng et al., 2012). In some cases, authors have circumvented this through constructing indices based on properties that are marketed as 'energy efficient' as a proxy for 'greenness' (e.g. Zheng et al., 2012; Sánchez-Ollero, García-Pozo, and Marchante-Mera, 2014; Aroul and Hansz, 2012; Shewmake and Viscusi, 2015). As such, these studies are prone to error from the energy-efficiency of properties being over/understated or inaccurate. This highlights the well-recognised issue of obtaining quality data in real estate.

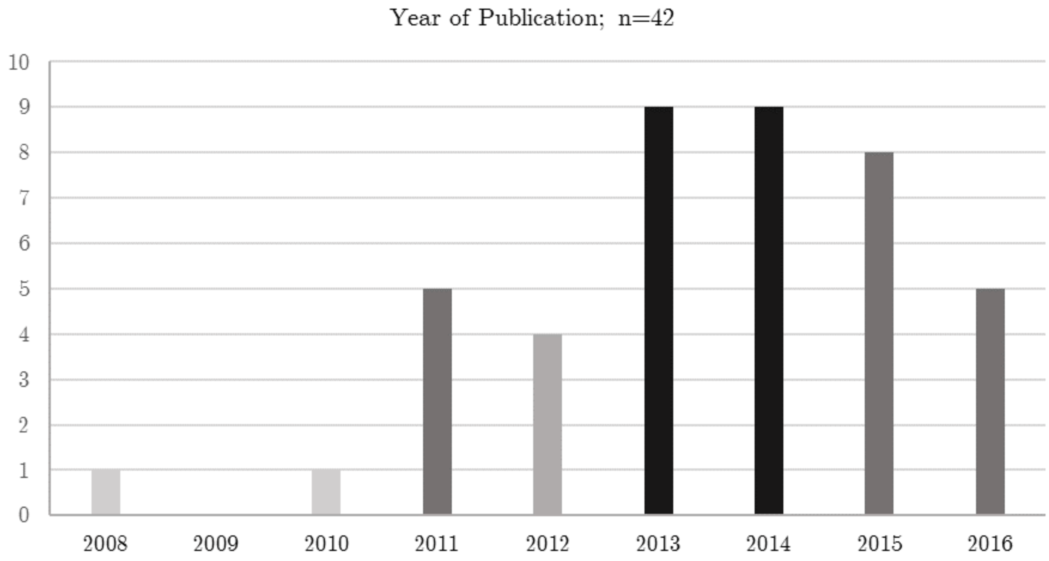


Figure 3: Distribution of selected studies' year of publication.

		Property Type				Energy-efficiency Measure								
						Environmental Certifications						Other		
	Market	Commercial	Residential	Hotels	TOTAL	LEED	ES	EPC	Dual: LEED & ES	BREEAM	Other cert. schemes	Marketing	Actual Energy Consumption	Mixed
Rental Value Observations	US	16	3	0	19	6	6	0	3	0	1	1	0	2
	UK	4	0	0	4	0	0	2	0	2	0	0	0	0
	Japan	0	0	0	0	0	0	0	0	0	0	0	0	0
	Sweden	0	0	0	0	0	0	0	0	0	0	0	0	0
	Australia	2	0	0	2	0	0	0	0	0	2	0	0	0
	Singapore	0	0	0	0	0	0	0	0	0	0	0	0	0
	Spain	0	0	1	1	0	0	0	0	0	0	1	0	0
	Canada	1	0	0	1	1	0	0	0	0	0	0	0	0
	China	0	1	0	1	0	0	0	0	0	0	1	0	0
	France	1	0	0	1	0	0	0	0	0	0	0	1	0
	Germany	0	1	0	1	0	0	1	0	0	0	0	0	0
	Hong Kong	0	0	0	0	0	0	0	0	0	0	0	0	0
	Netherlands	0	0	0	0	0	0	0	0	0	0	0	0	0
	Switzerland	0	1	0	1	0	0	0	0	0	0	0	1	0
	TOTAL	24	6	1		7	6	3	3	2	3	3	2	2
Capital Value Observations	US	12	5	0	17	6	5	0	2	0	0	1	0	3
	UK	2	1	0	3	0	0	2	0	1	0	0	0	0
	Japan	0	3	0	3	0	0	0	0	0	3	0	0	0
	Sweden	1	2	0	3	0	0	3	0	0	0	0	0	0
	Australia	1	0	0	1	0	0	0	0	0	1	0	0	0
	Singapore	0	2	0	2	0	0	0	0	0	2	0	0	0
	Spain	0	1	0	1	0	0	1	0	0	0	0	0	0
	Canada	0	0	0	0	0	0	0	0	0	0	0	0	0
	China	0	1	0	1	0	0	0	0	0	0	1	0	0
	France	1	0	0	1	0	0	0	0	0	0	0	1	0
	Germany	0	1	0	1	0	0	1	0	0	0	0	0	0
	Hong Kong	0	1	0	1	0	0	0	0	0	0	0	0	1
	Netherlands	0	1	0	1	0	0	1	0	0	0	0	0	0
	Switzerland	0	0	0	0	0	0	0	0	0	0	0	0	0
	TOTAL	17	18	0		6	5	8	2	1	6	2	1	4

Figure 4: A heat map displaying the entire sample distribution by geography, property type and certification measure. 'Other certification schemes' include: Green Mark; Tokyo Green Building Program; International Energy Conservation Code (IECC); National Australian Built Environment Rating System (NABERS).

Results & Discussion

The primary analyses of rental and sales premiums produced weighted mean effects of 6.0% and 7.6% respectively, indicating positive price effects for energy-efficiency and environmental certification (*see* Table 4). However, the confidence intervals suggest that the true mean effects may be between 4.3%-7.8% and 5.9%-9.4% respectively, which are similar to the range anticipated by Morri and Soffietti (2013).

These estimates are highly statistically significant. The confidence intervals signify a range outside of which the true value is improbable ($p < 0.05$); and, in this case, the ranges have been estimated with high statistical power (p-values of < 0.0001) to be narrow and positive. This indicates a confident rejection of the null hypotheses of a zero mean.

Table 4: Summary statistics from the primary analysis of rental and capital value green premiums

	Magnitude and Significance				Heterogeneity		
	Effect size	Std. Error	k	Z-value	τ^2	Q	I^2
Sales	0.0761*** [0.0586; 0.0936]	0.0179	35	8.53	0.0017	1564.75***	97.8% [97.5; 98.1]
Rental	0.0602*** [0.0430; 0.0775]	0.0176	31	6.84	0.0017	574.05***	94.8% [93.5; 95.8]

95% confidence intervals are shown in brackets.
*** $p < 0.0001$

The results of the primary analyses of the rental and sales premiums are visualised as forest plots, *see* Figures 5 and 6 respectively. The horizontal lines depict the 95% confidence intervals for the observed effect sizes. The central point of each of these lines corresponds to the size of a respective study's observed effect, encompassed by a box providing a size-representation of its weighting in the analysis. The diamond represents the estimated overall effect size, and its width represents a confidence interval; the range outside of which the true value is improbable.

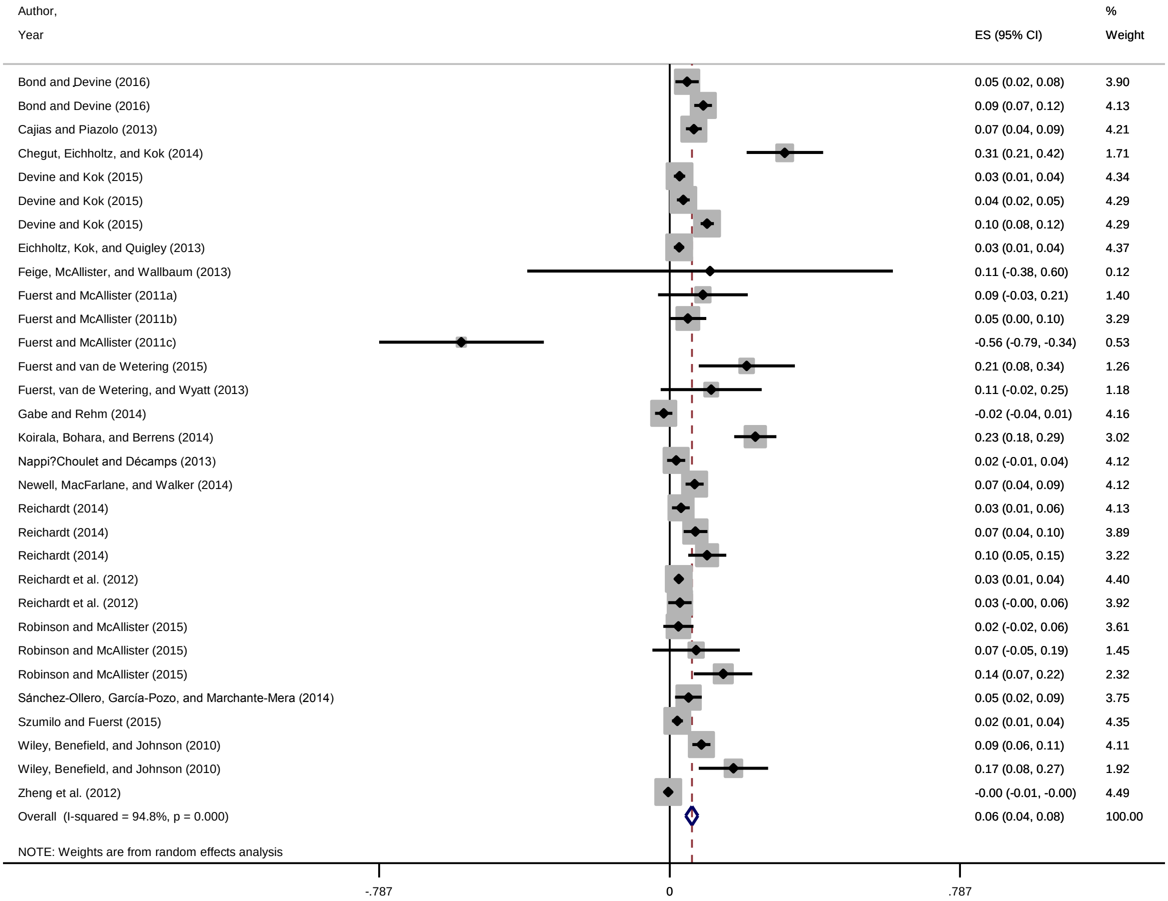
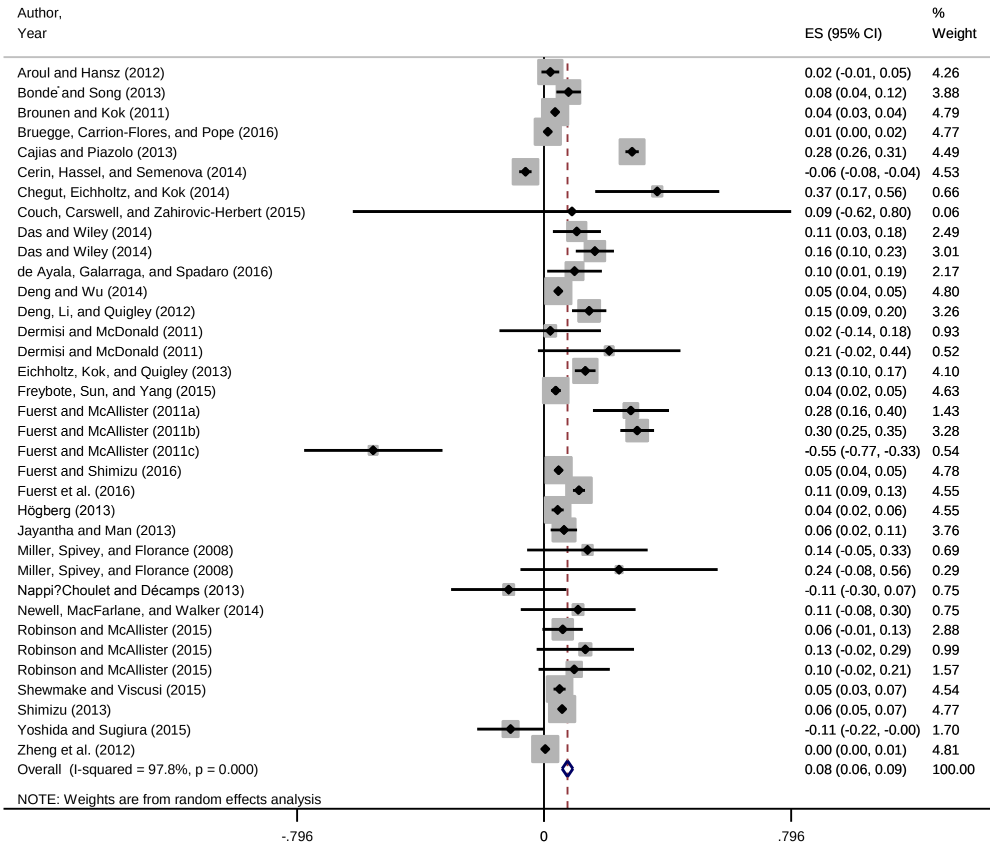


Figure 5: Primary rent premium forest plot



Rent Premium

Figure 6: Primary sales premium forest plot

Upon visual inspection, it is apparent that the majority of the studies included within the analyses observed a positive price effect, with the exception of three rental observations (Fuerst and McAllister, 2011c; Gabe and Rehm, 2014; Zheng et al., 2012) and four sales observations (Fuerst and McAllister, 2011c; Nappi-Choulet and Décamp,s 2013; Yoshida and Sugiura, 2015; Cerin, Hassel, and Semenova, 2014). As the confidence intervals are essentially normal distributions of where the true effect may lie, absence of overlapping intervals between studies, *ceteris paribus*, suggests a significant between-studies variance (τ^2) of the true effects (Borenstein et al., 2009; Cumming and Finch, 2005). A significant τ^2 illustrates statistical heterogeneity, and thus a rejection of the null hypothesis of homogeneity i.e. studies estimating the same effect. Whilst heterogeneity in a meta-analysis is inevitable, measuring the magnitude is of importance (Higgins, 2008). The *a priori* assumption of unexplained heterogeneity between the studies was a key reason for employing a random-effects model; thus, separating the total variance to also account for τ^2. The forest plots show little overlap between the studies, which prompts a further test for statistical heterogeneity.

As alluded to in the methodology section (Appendix A1), systematic reviews - and therefore meta-analyses - are prone to publication bias. We investigate publication bias using the Light and Pillemer (1984) 'funnel plots' (*see* Figures 7 and 8). The scatter plots of the observed effects are , with their size on the x-axis and their standard errors on the y-axis should show that the larger studies with lower standard errors appear towards the top in a narrow spread, and smaller studies at the bottom in a wider spread. The funnel plots for both the rental and sales premiums display asymmetry towards smaller studies on the x-axis where publications may be missing (Sterne et al., 2000). The lack of smaller studies estimating negative premiums is an indication, but not an accurate test (*see* Lau et al., 2006), of possible publication bias or studies that have not been undertaken. The widely-used test proposed by Egger et al. (1997) is used to test for funnel plot asymmetry, indicating significant bias at the 5% level (*see* Table 5); although this test is known to have low power (Sterne et al., 2011). Whilst the detection of bias prompts consideration, there is no set solution to the problem (Sterne et al., 2011).

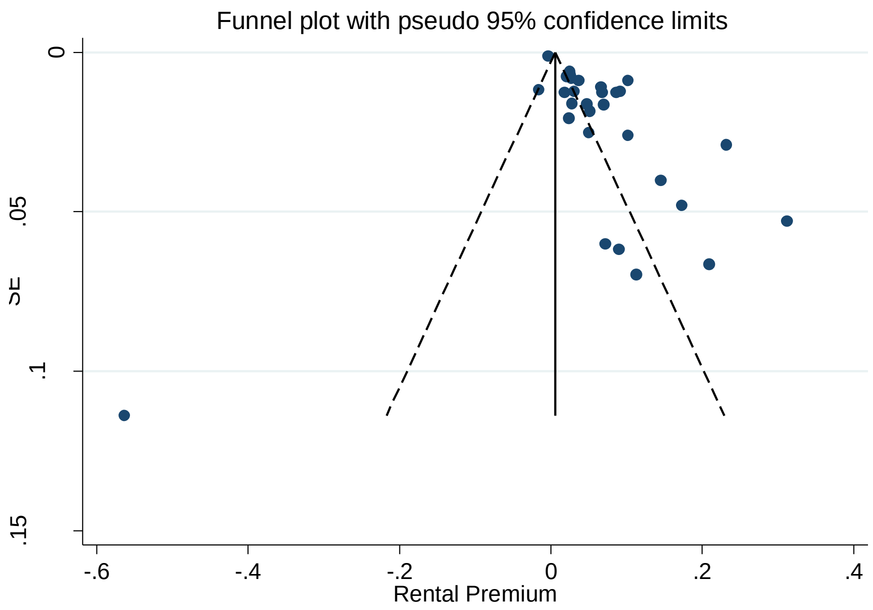


Figure 7: Funnel plot of the rental premium observations

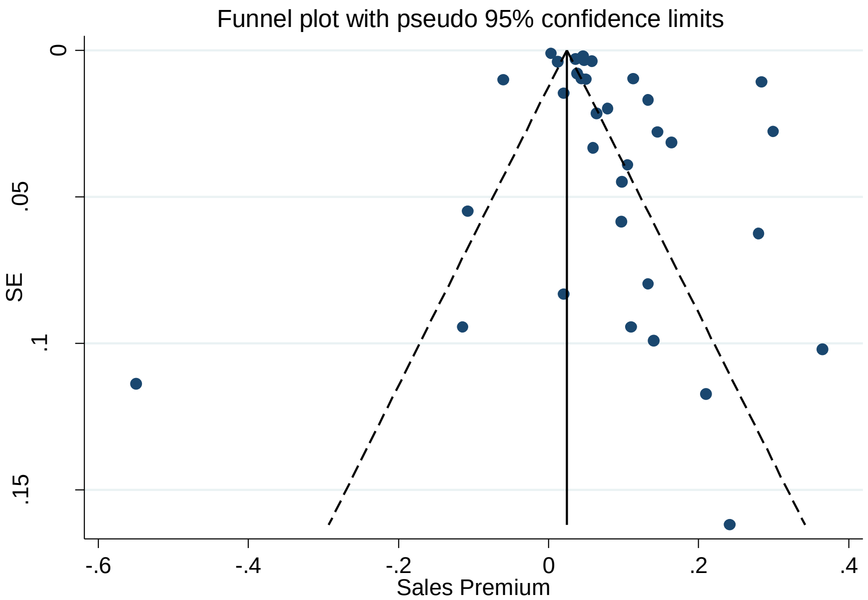


Figure 8: Funnel plot of the sales premium observations

Table 5: Results from the Egger et al. (1997) test

	t	p	95% CI
Sales	2.58	0.015	0.6779; 5.7723
Rental	5.53	0.000	2.2871; 4.9694

4.2 Heterogeneity and Subgroup Analysis

τ^2 is an absolute measure dependent on the scale of effect sizes (Borenstein et al., 2009). The magnitude of heterogeneity in the random-effects model can be quantified independent of scale using the I^2 index; a descriptive statistic proposed by Higgins et al. (2003):

$$I^2 = \left(\frac{Q - df}{Q}\right) \times 100\% \tag{11}$$

Where: Q is Cochran's Q as estimated in the Methodology section; and df is the degrees of freedom $(k - 1)$. Thus, I^2 is a percentage estimate of the total variance $\left(\tau^2 + v_{y_i}\right)$ that is attributable to the between-studies variance (τ^2).

Higgins et al. (2003) categorise, albeit tentatively, the I^2 index percentages of 25%, 50%, and 75% as low, moderate and high levels of heterogeneity respectively. However, it must be stressed that a high level of heterogeneity does not indicate a wrong result; if that was the case, real estate meta-analyses, such as this one, which are *a priori* heterogeneous would be redundant. A later commentary on the I^2 index by Higgins (2008), emphasised that a high level of heterogeneity warrants exploration.

As a function of Cochran's Q, the power to predict a reliable I^2 is dependent on the number of studies included within the analysis; thus, a small number of studies will estimate heterogeneity with low power and often underestimate I^2 (Thorlund et al., 2012), providing an erroneous sense of precision (von Hippel, 2015). In this case, the I^2 is estimated with high statistical power due to the large number of observations attributing to a significant Q ($p<0.0001$).

As expected, the primary analyses for the sales premium and rental premium exhibit high levels of heterogeneity at an I^2 of 97.9% and 95.1% respectively. Subgroup analysis may present further explanation for the magnitude of the heterogeneity. The selection of the subgroups for further analysis should be made a priori; in this case, the groups are categorical discrete study-level variables of market (geography), measure of energy efficiency, and property type.

The heterogeneity between groups is analysed through conducting separate meta-analyses for each group (forest plots available upon request from author), and testing the null hypothesis that the effect size is not dependent on inclusion within a subgroup (Borenstein et al., 2009). Testing heterogeneity between the subgroups follows the same logic as that in the primary analysis; however, the total variance is partitioned into within-subgroup variance and between-subgroup variance (Borenstein et al., 2009). The variance between subgroups is then tested for statistical significance:

$$Q_b = Q - \sum_{j=1}^{k} Q_j \tag{12}$$

Where: Q_b is the weighted between-subgroups variance around the overall effect; Q is the total weighted variance around the overall effect; for k subgroups, Q_j is the weighted variance of the subgroup j around the effect of subgroup j.

Due to the small sample sizes within the studies, it is difficult to make accurate inferences from subgroups with a small number of studies. As alluded to above, the number of studies must also be taken into consideration when estimating Q as a test for heterogeneity; subgroups with few studies will estimate Q_j with low power, and subgroups in which there is only one study will estimate Q_j as 0 as there will be 0 degrees of freedom.

The market, property type and energy-efficiency measure groups for both the sales and rental premiums exhibited highly significant Q_b values ($p < 0.001$ as a chi-square distribution) (*see* Tables 6 and 7); a rejection of the null hypothesis that all subgroups observe the same effect size. Thus, all groups are heterogeneous and attribute to the statistical heterogeneity of the primary analysis. Although, as noted above, subgroups with only few observations will significantly limit the power of Q_b.

For both the sales and rental premiums, the US market subgroup has a sufficient number of observations (19 and 17) to make significant inferences. The US sales premiums produced a weighted mean average of 10.5%, which is markedly higher than the overall average premium of 7.6% estimated in the primary analysis. This is estimated with a confidence interval (CI) of 7-14%, which is a significant rejection of the null hypothesis of a zero mean. The US rental premiums produced an average of 5.9% (CI 4.3;7.5%), which is similar in size and precision to the overall average premium of 6% (CI 4.3;7.8%). This is not surprising, as 61% of the observations for the rental premium are from the US market.

Table 6: Sales premium subgroup heterogeneity

Sales
(Q=1564.75)

Subgroup	Q_b	n	ES	95% CI	Q_j
Market	1225.31***				
US		17	0.105	0.070; 0.140	202.85
Sweden		3	0.020	-0.063; 0.103	70.94
Netherlands		1	0.036	0.030; 0.042	0
Germany		1	0.284	0.263; 0.305	0
UK		3	-0.016	-0.406; 0.378	39.92
Spain		1	0.098	0.010; 0.186	0
Singapore		2	0.092	-0.005; 0.189	12.42
Japan		3	0.049	0.032; 0.066	13.31
Hong Kong		1	0.064	0.022; 0.106	0
France		1	-0.114	0.299; 0.071	0
Australia		1	0.110	0.295; 0.750	0
China		1	0.004	0.001; 0.006	0
Property	132.02***				
Commercial		17	0.115	0.058; 0.173	106.25
Residential		18	0.055	0.036; 0.075	1326.48
Energy Measure	741.98***				
Marketing		2	0.005	-0.005; 0.015	1.25
EPC		8	0.047	-0.025; 0.118	673.1
Energy Star		5	0.075	-0.002; 0.151	26.23
BREEAM		1	0.365	0.165; 0.565	0
LEED		6	0.083	0.026; 0.141	7.78
Other Cert. Schemes		6	0.053	0.041; 0.065	29
Mixed		4	0.134	0.045; 0.223	80.85
Dual: LEED & ES		2	0.187	0.008; 0.367	4.56
Energy Consumption		1	-0.114	-0.299; 0.071	0

Table 7: Rental premium subgroup heterogeneity

Rental
(Q=574.05)

Subgroup	Q_b	n	ES	95% CI	Q_j
Market	381.28***				
US		19	0.059	0.0430; 0.0750	119.84
Germany		1	0.066	0.0450; 0.0870	0
UK		4	0.033	-0.2500; 0.3160	49.55
Canada		1	0.102	0.0840; 0.1200	0
Switzerland		1	0.110	-0.3850; 0.6050	0
Australia		2	0.026	-0.0560; 0.1080	23.38
France		1	0.018	-0.0070; 0.0430	0
Spain		1	0.052	0.0150; 0.0880	0
China		1	-0.004	-0.0060; -0.0010	0
Property	204.13***				
Commercial		24	0.054	0.0370; 0.0720	197.87
Residential		6	0.082	0.0240; 0.1410	172.05
Hotels		1	0.052	0.0150; 0.0880	0
Energy Measure	357.92***				
Marketing		3	0.029	-0.0140; 0.0720	18.6
LEED		7	0.073	0.0400; 0.1050	71.52
EPC		3	-0.104	-0.3760; 0.1680	30.81
BREEAM		2	0.268	0.1690; 0.3680	1.47
Energy Star		6	0.036	0.0170; 0.0550	20.97
Mixed		2	0.028	0.0140; 0.0410	0.84
Energy Consumption		2	0.018	-0.0060; 0.0430	0.13
Dual: LEED & ES		3	0.112	0.0720; 0.1530	0.95
Other Cert. Schemes		3	0.091	-0.0140; 0.1960	70.84

*** $p < 0.001$, as a chi-square distribution with $j-1$ degrees of freedom, for j number of subgroups. Q_b is the weighted between-subgroup variance around the overall effect; n is number of studies within subgroup; Q_j is the weighted variance of the subgroup around its effect.

The residential and commercial property type subgroups also have sufficient observations to make inferences. The commercial property subgroups produced an average sales premium of 11.5% (CI 5.8;17.3%), and rental premium of 5.4% (CI 3.7;7.2%). The premiums are similar in size to those from the US market subgroup as there is a considerable overlap between the observations as 71% of commercial sales premiums and 60% of commercial rental premiums are observed in the US market. Interestingly, the residential sales premiums which are less biased towards the US market (only 27% of observations), average at 5.5% (CI 3.6;7.5%). This may either suggest that the green premium is generally lower for residential capital values or, because this subgroup primarily captures the effects of different markets, the premium for capital values may actually be less in countries outside of the US. This would explain why the average sales premium for the US market was substantially higher than the overall average from the primary analysis. The residential rental premium is estimated at 8.2% (CI 2.4;14%), which is higher than both the commercial property rental premium (above) and the overall rental premium of 6% from the primary analysis. However, this is estimated with only 6 observations, which is reflected in the wide confidence interval; thus, it may not be appropriate to infer that a higher rental premium is obtained for residential property.

LEED and Energy Star had the most observations for the rental premium. The subgroup analysis of the rental premium by energy-efficiency measure, estimates a significant positive premium for LEED at 7.3% (CI 4;10.5%) and Energy Star at 3.6% (CI 1.7;5.5%). With a similar number of observations, both primarily in the US, the evidence suggests that LEED certification provides the optimal rent premium. It is worth noting that 69% of the US commercial rental premiums were estimated using LEED and Energy Star ratings, a further 19% was estimated from dual LEED and Energy Star certification at 11.2% (CI 7.2;15.3%). With only 3 observations for dual certification, it is difficult to draw any conclusions in regards to its influence on the overall premium; however, inferences can be made about the US rental market premium, given that it is primarily based on commercial observations (84%), 88% of which are LEED, Energy Star or dual certified. The US market rental premium is a lower 5.9% (CI 4.3;7.5%), in comparison to the LEED and dual certification, which suggests that the Energy Star rating may be lowering the overall US rental premium.

Whilst LEED and Energy Star attribute to the most observations for rental premiums, the sales premium is also largely influenced by EPCs and other certification schemes, such as Green Mark and NABERS. The subgroup analysis of the sales premium by energy-efficiency measure, estimates a significant positive premium for LEED at 8.3% (CI 2.6;14%) and other certification schemes at 5.3% (CI 4.1;6.5%); however, the confidence intervals for EPCs (CI -2.5;11.8%) and Energy Star (CI -0.2;15.1%) include zero, indicating that their estimates are not a significant rejection of the null hypothesis of zero means. Whilst the EPC subgroup exhibits high heterogeneity, which may suggest that the premium varies throughout Europe, the Energy Star subgroup was observed entirely in the US and does not exhibit as much heterogeneity. As such, Energy Star certification may not result in a sales price premium; although, the confidence interval is largely positive. Again, this signifies that LEED is the optimal choice of certification.

Implications for Investments in Sustainable Real Estate

The evidence of positive price premia reflects a consumer WTP for green real estate; and, perhaps the ability to convey its energy-efficiency. Subject to this study's limitations, the significant premiums obtained from the primary and subgroup meta-analyses may be directly input into cash-flow analyses to inform investment and policy-making decisions. The estimations within Table 8, with positive confidence intervals and sufficient observations, may be employed.

	Overall	US	Commercial	Residential	LEED	Energy Star
Rental	6	5.9	5.4	8.2	7.3	3.6
Premium	[4.3-7.5]	[4.3-7.5]	[3.7;7.2]	[2.4-14]	[4;10.5]	[1.7;5.5]
Sales	7.6	10.5	11.5	5.5	8.3	NS
Premium	[5.9;9.4]	[7-14]	[5.8;17.3]	[3.6-7.5]	[2.6;14]	

Table 8: Significant positive rental premiums

NS = not significant to reject the null hypothesis of a zero mean.

A discernible application of the green premium would be within real estate valuation. Usually, the value of a real estate asset is based on what an investor would expect to pay for its projected net operating income in perpetuity:

$$CV_0 = \frac{NOI_1}{k} \tag{13}$$

Where: CV is the capital value; NOI is the net operating income, whereby operating expenses, fees, taxes and other costs have been deducted from the gross rental income; and k is the capitalisation rate, given by

$$r - g \tag{14}$$

Where: r is the required rate of return, and g is a constant growth rate. The viability of an investment over a given time period can be modelled using a discounted cash flow (DCF) - the present value of future cash flows plus initial investment:

$$NPV = \sum_{t=0}^{n} \frac{NOI^t \times (1+g)^t}{(1+r)^t} \tag{15}$$

Where: NPV is the asset's net present value; and t is the holding period. The rate of return at which the NPV is 0, is the internal rate of return (IRR). The rental premium and reduced operating costs should increase NOI during the entire holding period, and the sales premium should also increase the NOI at its sale. The NOI would also be higher with reduced vacancies.

To illustrate, a hypothetical yearly DCF model is constructed for a 15,000sf office building in Chicago, US assuming: no depreciation; a holding period of 10 years; Chicago office capitalisation rates of 4.5% with constant 2% rental growth, totalling in a 6.5% discount rate; acquisition and sales fees of 3.5% and 2.5% respectively; acquisition and sales yields of 5.5% and 4.5% respectively; Real Property Transfer Tax at 0.75% of capital value; 11% capital gains tax; $37.00psf rent, with 5 year upwards-only rental reviews; void charge per annum of $300,000; and construction costs of $200.00psf. Variable parameters are also included within the model: construction cost premium (%); operating expenses as a percentage of net rental income; vacancy rate (%); rental green premium (%); and sales green premium (%).

Following a similar approach to the DCF analysis undertaken by Vimpari and Junnila (2014), two cases are made - A and B - whereby the building is non-certified in case A, and is LEED certified in case B. Both cases can be analysed from a development perspective, and from an investment/asset management perspective whereby the building is to be acquired.

Three scenarios are presented for case B to provide a more effective comparison with case A: a base, downside and upside scenario (*see* Table 9). The variable parameters are adjusted accordingly in each scenario. The base rental and sales premiums are taken as the weighted mean effect size from the LEED subgroup meta-analysis, and the upside and downside premiums are taken as its respective confidence interval bounds. The base operating expenses, excluding tax, are also expected to be 5.4% less in case B compared to case A, employing figures from Reichardt (2014) (*see* preliminary literature review). Vacancy rates are believed to be less in LEED properties, although further study is required. The base construction premium in case A is taken from Kats (2003) (*see* preliminary literature review).

From the standpoint of an investor acquiring the building, the higher IRR and NPV yielded in the case B scenarios supports LEED certification. In fact, in this example, it is the rental and sales premium that make the investment feasible, with case A producing a negative NPV, and the downside of case B producing an NPV of $268,879. Whilst developing the building is feasible in both cases, LEED certification is still superior in all scenarios.

This example demonstrates a case where investment in LEED certification produces higher returns for owners and developers. The differences between the upside and downside scenarios was used to perform a sensitivity analysis on the IRR. In an acquisition, the IRR is most sensitive to the sales and rental premiums; however, in a development, the IRR becomes less sensitive to the sales premium and more sensitive to the rental premium and the vacancy rate (*see* Table 9).

The IRR in case B is clearly sensitive to the rental premium. However, previous studies addressed in the preliminary literature review, such as Morri and Soffietti (2013) and Zalejska-Jonsson (2014), have indicated that the tenant's WTP such premiums is related to perceived savings from reduced operating expenses. Figure 9 displays the savings available to the tenant in the case B LEED building at different rental premiums and operating expenses, compared with an uncertified case A building. Interestingly, this investment would not be feasible for the tenant based on the expected rental premiums and operating expenses. The downside case of a 4% rental premium for investors, would require a reduction of approximately 20% in operating expenses to produce savings for tenants, which is far greater than the 5.4% reduction estimated by Reichardt (2014).

Although this is a hypothetical investment case, the findings are interesting. The DCF model rejects the split-incentives problem which agency theorists such as Jaffe and Stavins (1994) posit; the owners benefit from investing in energy-efficiency in each scenario. However, it does prompt further research into the tenant's WTP for energy-efficiency and whether they are overpaying - perhaps the savings do not actually justify the premium. If the rental premiums are not outweighed by savings to the tenant, if may also be the case that there is no 'vicious circle of blame'; in fact, the developers' perception of insufficient demand for energy-efficient properties may hold some truth if a large number of buyers and tenants are unconvinced of the savings. Prior research has focussed mostly on the premiums available to owners, rather than the net savings available to tenants. Exploring this area is a

Table 9: DCF scenarios and output

Parameter	B - Normal	A - Green			
		Downside	Base	Upside	IRR Difference
Acquisition					
Operating expenses	25.00%	25.00%	23.65%	22.37%	0.13%
Rental Premium	0.00%	4.00%	7.30%	10.50%	0.81%
Sales Premium	0.00%	2.60%	8.30%	14.00%	1.00%
Vacancy Rate	10.00%	10.00%	7.50%	5.00%	0.18%
IRR	6.05%	6.81%	7.89%	8.92%	
NPV	-$384,990	$268,879	$1,256,818	$2,261,225	
Development					
Operating expenses	25.00%	25.00%	23.65%	22.37%	0.30%
Rental Premium	0.00%	4.00%	7.30%	10.50%	1.09%
Sales Premium	0.00%	2.60%	8.30%	14.00%	0.47%
Vacancy Rate	10.00%	10.00%	7.50%	5.00%	0.83%
Construction Premium	0.00%	4.00%	2.00%	0.00%	0.66%
IRR	23.33%	24.53%	26.43%	28.36%	
NPV	$7,134,782	$8,442,809	$9,487,232	$10,548,123	

recommendation for future research.

Limitations of the Meta-Analysis

Although the price premiums reported above are highly statistically significant, the limitations in the estimation must be realised before informing investment or policy decisions. One of the limitations of the underlying studies, as raised by Das and Wiley (2014), is that the estimated green premium coefficients are stationary; most of the studies do not report how the premium is changing over time and may omit an 'attrition effect'.

Tenant Savings ($)	Operating Expenses							
Rent Premium	25.00%	24.00%	23.00%	22.00%	21.00%	20.00%	19.00%	18.00%
2.00%	- 13,875	- 8,214	- 2,553	3,108	8,769	14,430	20,091	25,752
3.00%	- 20,813	- 15,096	- 9,380	- 3,663	2,054	7,770	13,487	19,203
4.00%	- 27,750	- 21,978	- 16,206	- 10,434	- 4,662	1,110	6,882	12,654
5.00%	- 34,688	- 28,860	- 23,033	- 17,205	- 11,378	- 5,550	278	6,105
6.00%	- 41,625	- 35,742	- 29,859	- 23,976	- 18,093	- 12,210	- 6,327	- 444
7.00%	- 48,563	- 42,624	- 36,686	- 30,747	- 24,809	- 18,870	- 12,932	- 6,993
8.00%	- 55,500	- 49,506	- 43,512	- 37,518	- 31,524	- 25,530	- 19,536	- 13,542
9.00%	- 62,438	- 56,388	- 50,339	- 44,289	- 38,240	- 32,190	- 26,141	- 20,091
10.00%	- 69,375	- 63,270	- 57,165	- 51,060	- 44,955	- 38,850	- 32,745	- 26,640

Figure 9: Savings available to the tenant in the case B LEED building at different rental premiums and operating expenses

Indeed, in one of the few studies that has provided coefficients over time, Reichardt et al. (2012), did find a that the Energy Star premium has been decreasing over time; albeit a short time series.

Figure 10 plots the variance-weighted averages of the premiums by their year of publication, but no clear trend is visible. The time series is too short and the observations too few to draw any conclusions on whether there is an underlying attrition effect. However, if an attrition effect does exist, later publications which have employed a greater time series would be prone to overestimating the green premium due to the bias caused by the inclusion of earlier studies. This prompts an investigation for future studies.

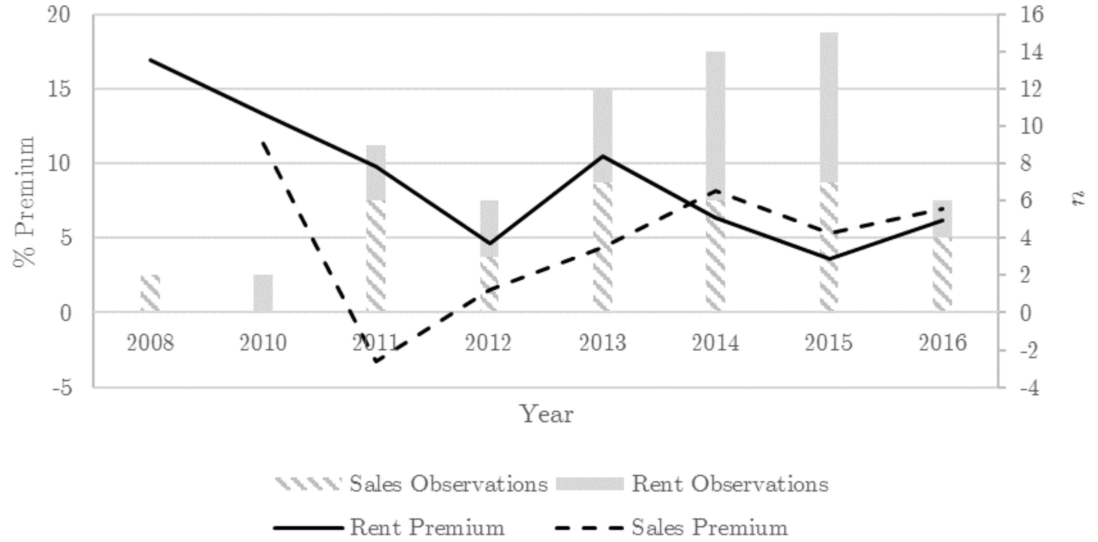


Figure 10: A variance-weighted average of observed premiums by year of publication

This chapter examines the premium for energy-efficiency, on the premise that WTP for environmental certification is related to reduced operating expenses; however, only three observations directly measured energy-consumption. As the majority of observations were premiums for environmental certification, there are undoubtedly other factors besides energy efficiency which influence WTP.

The WTP for energy efficiency may not be financially-driven, as this chapter has assumed. For example, corporate tenants may also be seeking to satisfy corporate social responsibility (CSR) requirements, which have received increased attention and response in the past two decades. There is also a bias towards the US market, particularly LEED and Energy Star commercial properties.

Conclusions

The random-effects meta-analysis aggregated 42 studies that examine the relationship between energy-efficiency and property prices. The studies were identified through a systematic review, searching two general databases and six academic databases. The primary analysis included all observations to estimate an overall weighted mean premium for rental and sales values. The rental premium was estimated as 6.02% (CI 4.30;7.75%), and the sales premium as 7.61% (CI 5.86;9.36%). Although the estimates were both highly significant, the analyses revealed considerable statistical heterogeneity and potential publication bias.

Further subgroup analyses were conducted as a means of explaining the high degree of heterogeneity. This comprised of analysing the effect sizes and between-subgroup variances of different markets, energy-efficiency measures, and property types. All were found to significantly contribute to heterogeneity. From the subgroup analyses, it was also determined that the US market, commercial property, residential property, LEED and Energy Star subgroups contained a sufficient number of studies to estimate significant premiums. The Energy Star rating appears inferior to the LEED rating, particularly the sales premium which was not significantly positive. As such, the Energy Star rating is believed to be reducing the estimated premia for the US market, due to the large number of Energy Star observations underlying the subgroup.

The potential publication bias was identified by using the Egger et al. (1997) test to measure funnel plot asymmetry. The test indicated significant bias, most likely attributable to the exclusion of smaller studies estimating negative premiums that may or may not exist.

A hypothetical DCF mode was constructed to demonstrate the application of the green premium within an investment scenario, and the implications for stakeholders. A comparison of scenarios in which a building is LEED-certified and non-certified indicated a that the former yields a higher IRR and NPV for both investors and developers. However, based on previous studies such as Morri and Soffietti (2013) and Zalejska-Jonsson (2014), the tenant's WTP for energy-efficient property primarily related to a perceived reduction in operating expenses. A sensitivity analysis of a tenant's savings in comparison to the rental premium produced negative values in each scenario, indicating that the investment would not be feasible for the tenant. Although this case is hypothetical, it prompts an interesting discussion about the tenant's WTP, and whether they are overpaying for energy savings. A widespread tenant and buyer scepticism of the savings may also provide an alternative to the 'vicious circle of blame' as an explanation for the low development of green properties (*see* Andelin et al., 2015).

This chapter contributes towards the body of evidence on real estate 'green' premiums to inform policy-making and investment decisions. There has been little prior research on the green premium from the tenant's perspective, and on the net savings available to them. The majority of studies also report a 'static' premium, which has been identified as a limitation due to a potential underlying attrition effect. These are both areas for future research.

Appendix: Methodology

This chapter contains a meta-analysis of the overall rental and sales value green premiums and includes all observations recorded in the dataset besides those that are considered 'supplementary' to the another effect reported within the same study e.g. the LEED and ES estimates in Eichholtz, Kok, and Quigley (2013) when a LEED and/or ES estimate is also provided. The primary analysis is expected to exhibit large heterogeneity due to the variety of the studies, in terms of the property type, country, and energy-efficiency measure analysed; although, it will be biased towards the US commercial market and LEED/ES certification (*see* Figure 4). Further estimations of market, property type and certification subset effect sizes will be undertaken to explain heterogeneity between studies. For the purpose of this meta-analysis, the single study on hotel green premiums is included as a rental green premium; although the short-term nature of a hotel stay will invariably have an impact on consumer WTP.

All but one of the selected studies (Freybote et al., 2015) estimate the price effect of the green premium through a hedonic log-linear model, which originates from the work Rosen (1974). The model assumes that the price of a good is a function of its attributes (*see* Equation 1). In this case, the rental or sales price (P) of a building is a function of energy-efficiency φ, and other attributes - commonly those concerned with its physical ζ, locational ψ, and sales/lease characteristics η.

$$P = f(\varphi, \zeta, \psi, \eta) \tag{1}$$

Thus, the regression is can be notated in log-linear form as:

$$\ln P = X\beta + \varepsilon \tag{2}$$

Where: $\ln P$ is the natural log of rental/sales price; X is a matrix of attribute vectors (e.g. $\varphi, \zeta, \psi, \eta$); β is a matrix of respective vectors to be estimated; ε is the stochastic error term. As such, the result is reported as an elasticity coefficient ($\%\Delta P/\%\Delta\varphi$); an intuitive ratio that represents the price differential, *ceteris paribus*, between a 'treatment' sample of energy-efficient properties, and a non-energy-efficient 'control' sample. This ratio is taken to directly represent the green premium as a percentage, and will serve as the observed effect size for each study. In the case of Freybote, Sun, and Yang (2015), which employed a second-order parsimonious spatio-temporal autoregressive (2PSTAR) model, the estimate was still provided as an elasticity coefficient. Within each study, there are usually multiple model iterations that estimate the green premium, usually controlling for different factors or interaction terms. It is important to acknowledge that the green premium may not be solely attributable to energy efficiency and the variables denoted in Equation 1; rather, it may be dependent on an interaction between energy efficiency and another variable (e.g. age), or confounded by selection bias from uncontrolled systematic differences between the treatment and control samples.

Whilst a few studies have introduced instrumental variables to mitigate selection bias from unobservables (e.g. Wiley, Benefield, and Johnson 2010; Szumilo and Fuerst 2015; Brounen and Kok 2011), the studies have more commonly addressed selection bias from observables - through the Rosenbaum and Rubin (1983) propensity score matching methods (*see* Reichardt, 2014; Chegut, Eichholtz, and Kok, 2014; Yoshida and Sugiura, 2015). More often than not, the studies will explore various interactions between energy efficiency and other variables through the inclusion of interaction terms e.g. $\delta E_{it} \cdot \delta AGE_{it}$; by doing so, this can identify more precise and informative effect sizes for different subgroups (e.g. the green premium for energy efficient buildings in different age categories). However, the terms are inconsistent throughout the selected studies. Therefore, to ensure consistency and simplicity, the green premium will be taken from the most statistically robust model estimates that exclude interaction terms, as suggested by Stanley and Doucouliagos (2012), but control for the most factors. In cases where the authors only provided models interaction terms, a 'crude' summary effect size was estimated by adding an equal-weighted average of the subgroup coefficient estimates.

As the intention of this research is to inform policy and investment decisions, it is of upmost importance that a suitable model is used to estimate the overall effect, and to alleviate publication bias which can lead to its overestimation (van Assen et al., 2015). Whilst the inclusion of grey literature within the systematic review has sought to mitigate bias at the editorial level, it is equally important to include observed effect sizes from all studies that met the inclusion criteria; this is regardless of the direction of the effect and its statistical significance (*see* Hedges and Olkin, 1985 for a discussion on the importance of including non-significant results).

A common issue within meta-analyses is missing standard errors within studies (Higgins et al., 2011). Whilst it is common practice for medical journals to report standard errors, the real estate literature is inconsistent in its reporting; 25 of the studies did not directly report standard errors. Algebraic and approximate algebraic recalculation of the standard errors from other statistical information provided, such as exact p-values and t-statistics, was used in 22 of the studies (*see* Stevens, 2011). In the remaining 3 studies where this was not possible, values were imputed from other studies within the meta-analysis - a technique which Furukawa et al. (2006) demonstrated to yield accurate results.

Step 6: In estimating an overall effect, a meta-analysis should address the weighting of significance that it assigns to the results of its underlying studies. There are predominantly two meta-analytic models - 'fixed effect' and 'random effect'. A fixed effect model assigns weighting based on the inverse variance within the studies (similar to the size of the studies), assuming a common effect size (Borenstein et al., 2007); therefore the methodology followed by each study should be identical. However, as Hedges and Vevea (1998) note, model selection is not only a question of study homogeneity; rather, it is also the inferences that can be made. In the case of the fixed effects model, limiting the analysis to assign weights based solely upon the variance within studies, inference is also limited to the observed studies (conditional inference - *see* Hedges and Vevea, 1998). This model does not lend itself to the heterogeneity of the studies selected for the meta-analysis, which exhibit variation in their samples, methodologies and control factors; this is expected due to the inherent heterogeneity of real estate. Furthermore, a conditional inference is only pertinent to those studies analysed; therefore, in order to apply the estimated effect to other transactions or cash flows, it is imperative that unconditional inferences - those which make generalised observations that can extend beyond the observed studies - can be made (Hedges and Vevea, 1998). Unconditional inferences can be made through the application of the random effects model. This is because the model does not assume a common effect size, accounts for variance between studies (tau-squared), as well as the variance within studies

(Borenstein et al., 2007) (*see* Equation 4). Incorporating the variance between studies also accounts for heterogeneity e.g. different market conditions between studies.

As noted above, the random effects model does not assume a common effect size; rather, it seeks to estimate a distribution of true effects, y_i, to estimate an overall mean effect, μ (Borenstein et al., 2007). The true effect size of a study is essentially a projection of its observed effect θ_i for an infinite sample; thus, sampling error is inevitably present (Borenstein et al., 2009). With this in mind, a study's observed effect should be equal to the deviation of its true effect from the overall mean effect, δ_i, adjusted for sampling error ε_i (Borenstein et al., 2009):

$$y_i = \mu + \delta_i + \varepsilon_i \tag{3}$$

δ_i is derived from the standard deviation of the true effects distribution, τ^2, which is essentially the 'between-studies' variance; its estimation can be observed in Equation 5.

However, a meta-analysis must start with the observed effects in order to arrive at an estimation of μ. Considering k number of studies with index i $(i = 1, 2, \ldots, k)$, the random effects model assigns weights to studies based on both within-study and between-study variance:

$$w_i^* = \frac{1}{\tau^2 + v_{y_i}} \tag{4}$$

Where: w_i^* is the inverse of the sample variance in the ith study (σ_i^{-2}); τ^2 is the variance of parameter effect size between studies; and v_{y_i} is the variance within study i. Whilst v_{y_i} is observable, τ^2 is estimated following the DerSimonian-Laird (1986) non-iterative method-of-moments estimator:

$$\tau^2 = max\left(0, \frac{Q - (k - 1)}{\sum w_i - \frac{\sum {w_i}^2}{\sum w_i}}\right) \tag{5}$$

Where: Q is Cochran's Q, the observed weighted sum of squares, estimated by:

$$Q = \sum_{i=1}^{k} w_i (y_i - \bar{y}_w)^2 \tag{6}$$

Where: $\bar{y}_w$ is the weighted mean effect estimator $\left(\sum_{i=1}^{k} w_i y_i / \sum_{i=1}^{k} w_i\right)$; and y_i is the estimated effect of the ith study.

The weighted mean (summary) effect, $\hat{\mu}$, can then be estimated:

$$\hat{\mu} = \frac{\sum_{i=1}^{k} w_i^* y_i}{\sum_{i=1}^{k} w_i^*} \tag{7}$$

Following Borenstein et al. (2009, p.74), the estimated summary effect is then used to calculate the variance, standard error and a 95% confidence interval of the summary effect:

$$v_{\hat{\mu}} = \frac{1}{\sum_{i=1}^{k} w_i^*} \tag{8}$$

$$SE_{\hat{\mu}} = \sqrt{v_{\hat{\mu}}} \tag{9}$$

$$Lower_{\hat{\mu}} = \hat{\mu} - 1.96 \times SE_{\hat{\mu}}, \quad Upper_{\hat{\mu}} = \hat{\mu} + 1.96 \times SE_{\hat{\mu}} \tag{10}$$

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