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The price of innovation: An analysis of the marginal cost of green buildings☆

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ABSTRACT

Energy efficiency plays an important role in reducing the carbon externality from buildings, but economic analyses of more efficient, green building have thus far ignored input costs. This paper finds that the average marginal cost of green-labeled construction projects is smaller than the value premiums documented in the literature. However, design fees, representing just a fraction of development costs but paid largely up-front, are significantly higher for green construction projects. These projects also take longer to complete. The results provide some insight into the market barriers and market failures that may explain the relatively slow adoption of otherwise economically rational green construction practices.

Energy efficient, green construction practices can have a substantial impact on environmental outcomes: buildings represent 30 percent of global carbon emissions and 40 percent of raw materials and energy consumption (Kahn et al., 2014; Glaeser and Kahn, 2010). In general, the cost of switching to cleaner technologies is unclear, but it is predicted that such a switch is less costly in the long run than maintaining conventional technology (Acemoglu et al., 2012). Incentives for more efficient construction stem from government procurement policies in the US and EU (Simcoe and Toffel, 2012), increasingly strict building energy codes (Jacobsen and Kotchen, 2013), and popular demand for environmentally certified, green buildings (Kok et al., 2011).

The construction industry is making the transition to cleaner technology and building practices, but progress is slow. Recent market data from CBRE shows that environmentally certified buildings represent just 5.4 percent of the commercial office stock, and diffusion of such building practices is even more limited in other sectors, such as retail space and industrial warehouses (Holtermans et al., 2015). McGraw-Hill Construction (2013) estimates that 38 percent of current construction is earmarked as

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green, but the number of green construction-related jobs is 611,000, which is only 12.3 percent of total construction employment in 2011.[1] Even though green construction is gaining market share, new construction and building refurbishment are still mostly conventional. These market trends raise questions about the marginal costs and benefits of environmentally certified, green construction. Perhaps they simply reflect economic rationality, or rather point to an energy-efficiency gap (Gerarden et al., 2017) in commercial real estate construction.

The economic literature on more efficient, green building has thus far solely focused on the measurement of outputs, and generally documents rental, occupancy and value premiums for green commercial buildings, ranging from 13.3 to 36.5 percent for transaction prices (Eichholtz, Kok and Quigley, 2010, 2013; Fuerst and McAllister, 2011; Chegut et al., 2014). For energy efficient residential properties, transaction premiums have been documented to vary between 2 and 16 percent, relating to the level of the rating (Brounen and Kok, 2011; Deng et al., 2012; Walls et al., 2017). These marginal financial benefits reflect cost savings and risk perception, but perhaps also the higher input costs required to construct more efficient buildings. The relatively slow take-up of green construction practices could thus be due to construction costs that are higher than the marginal benefits. Indeed, the general perception in the construction and real estate development industry is that green construction is expensive, especially if it involves the refurbishment of existing buildings.

Given that green building is relatively novel in the construction industry, developers are understandably uncertain about the marginal cost of such building practices relative to traditional property development. As discussed by Matisoff et al. (2016), there is very limited rigorous empirical evidence regarding the cost and cost-effectiveness of investments to achieve green building certification. The existing research on input costs is limited to a handful of case studies, typically comparing a small number of green buildings to conventional counterfactuals, without properly controlling for other building characteristics and features of the construction process. The findings from this anecdotal evidence are thus hard to interpret or generalize.[2] To date, no systematic research has assessed the marginal cost of more efficient, green construction in an empirically rigorous manner. This lacuna hampers the understanding of developers and real estate owners regarding the input costs of green construction, and the understanding of policy makers as to which (potential) market failures to address. Combined, this may slow down the diffusion of energy efficient and sustainable building practices, and thus the necessary reduction of the carbon externality from the built environment.

Using a unique dataset, this paper identifies the marginal cost of green construction for the largest commercial property market in Europe, the UK. We use the Royal Institution of Chartered Surveyors' elemental construction cost database The Building Cost Information Services (BCIS), which is to our knowledge the only large-scale, non-proprietary dataset that has project cost, project duration and contract data for individual construction projects. We link these data to the database of the Building Research Establishment (BRE), whose BREEAM label represents the oldest and most widely adopted environmental certification system for buildings in the UK. Using propensity scoring, we then assess the marginal construction cost for a set of 336 BREEAM-certified buildings, matching projects on location and construction period with some 2000 non-certified construction projects built between 2003 and 2014.

In line with conventional wisdom, we document a statistically significant difference in total construction cost between green, BREEAM-certified buildings, and conventional, non-certified buildings. The average difference in total costs for the sample as a whole is 6.5 percent. This finding holds for simple univariate comparisons and more importantly, for cross-sectional regression analyses that control for property type, building owner category, and construction contract and tendering characteristics. The result is robust to various functional forms, the inclusion of propensity score weights and holds for the costs of new construction projects as well as for the costs of refurbishment of existing buildings.[3]

We find that the higher overall costs for more efficient, green buildings stem from a specific set of construction cost elements. Our dataset distinguishes eight specific construction cost elements - such as design, preliminaries, substructure, external work and finishings - which allows us to investigate the contribution of each of these elements to the total construction cost. Controlling for building and contract characteristics, only design fees and building fittings and finishes appear to be significantly correlated with the degree of a building's sustainability: green building design costs are 32 percent higher than the costs of conventional building design, and fittings and finishes costs are higher by 32 and 28 percent, on average, respectively.

Moreover, we document a strong positive relationship between the level of environmental certification in construction projects and the corresponding construction costs. The highest rated green buildings - those labeled BREEAM Very Good, Excellent and Outstanding - are up to 31 percent costlier to construct as compared to non-certified projects, after controlling for a large set of building quality characteristics. Construction cost elements also vary significantly with the "greenness" of buildings.

[1] This number includes designers, engineers, architects and construction workers in the green construction industry (See:http://www.carpetrecovery.org/pdf/annual_conference/2012_conference_pdfs/Presentations/USGreenMarketTrends.pdf, accessed June 14, 2013). The US Bureau of Labor Statistics registers only 487,709 green construction jobs, representing just 9.8 percent of total construction employment in 2011 (See:http://www.bls.gov/news.release/pdf/ggqcew.pdf, accessed June 25, 2014.).

[2] See Kats (2003); Matthiessen and Morris (2007). These reports compare green-certified buildings with conventional peer buildings and document an average cost premium of zero to three percent. In Europe, Atkinson (2010) studies three individual building sites that seek green certification for new construction. Results suggest that moving toward a high-performing building raises construction costs by 15.4–37.4 percent.

[3] Our results are contingent upon the assumption that green buildings do not sort into more valuable locations, or to the extent such sorting takes place, that our location controls pick up this effect. Beyond sorting on location, our analysis, as any cross-sectional study, also relies upon the assumption that there is no omitted variable bias – if green buildings would all have valuable but unobservable attributes or features (e.g. a fancy lobby or rooftop terrace), our results would merely reflect the value of those amenities, rather than the cost of "green" attributes.

Employing a model with the most extensive set of control variables, we find that design fees for BREEAM Outstanding buildings are 150 percent higher than the design fees for non-certified buildings.

For the key initiator of any construction project, the developer, the profitability of a project hinges not just on overall costs, but also on the development time - longer construction periods increase the burden of construction loans and reduce the return on the developer's equity investment. We therefore assess the duration of construction projects in our sample, documenting that more efficient, green buildings take significantly longer to complete, after controlling for project size and other variables that are likely to affect project duration. Specifically, green building projects take about 11 percent longer to complete as compared to conventional buildings, and that difference is higher for the most energy efficient buildings.

This paper provides the first systematic evidence on the cost of incorporating technological components in the construction of buildings that lead to enhanced environmental outcomes. The literature consistently documents significant demand-side effects of more efficient, green construction, leading to rent and transaction price premiums (Eichholtz et al., 2010, 2013; Chegut et al., 2014). Our findings show that these demand-side effects can be explained partially by the higher marginal cost of more efficient, green construction, but there is a positive gap between the average marginal transaction price found in the empirical literature and the average marginal cost we find in this paper. This suggests that the energy-efficiency gap in real estate may be due to both a market barrier and a market failure.

As for market failure, the results provide some indication as to why the diffusion of green technology is not more common in the building stock: the construction cost elements that are most strongly related to design, fittings, and finishes are more expensive. Even though these cost elements on aggregate represent a small proportion of total costs and are presumably capitalized into the price at which the developer can sell an asset, they accrue to a group of stakeholders making decisions that impact the lifecycle value of the entire building. Design fees are largely paid before construction has been started, and are mostly paid from the developer's equity (Geltner et al., 2013). Importantly, even though design fees are only three percent of overall costs, these fees are investments with a significant risk, since fees are paid during a phase when developers still face fundamental uncertainty regarding the success of their project. These fees can thus be regarded as the premium a developer has to incur for the option to develop a building. The fact that the results show design fees that are more than 150 percent higher for the most advanced green buildings reduces the likelihood that developers engage in the option to develop such projects. Fittings and finishes are implemented later in the development process, but if lenders are unwilling to provide additional financing for more sustainable, green buildings, these additional costs might prohibit green construction.

The longer average project length for more efficient green buildings rather constitute a market barrier. The project length increases the uncertainty of total project costs and in turn uncertainty around the developer's expected return on equity. Presumably, as developers and construction companies become more experienced in green building, the additional time required to developed green rather than conventional buildings will decrease.

The paper proceeds with Section 1, outlining the literature on the determinants of construction costs. Section 2 documents the data sources and summary statistics, followed by Section 3 where we describe the methodology and models. The empirical results are presented and discussed in Section 4, and the paper ends with a short discussion.

1. Innovation, green buildings, and costs

1.1. Innovation and buildings

Capital innovation stems from augmenting the existing quality of a product or process, which requires an effort cost incurred by the innovator who brings the product to market (Aghion and Griffith, 2005). Technology improves through these efforts. In turn, the quality of the product in the previous period forms the basis of learning, development and cost for the current period (Baltagi and Griffin, 1988). Over time, a process of standardization sets in on the basis of a given state of technology (Farrell and Saloner, 1985). In this way, there is a continued tension between technological progress and standards for the production of goods and services.

Like in manufacturing, construction undergoes a cycle of invention, innovation, technological change and standardization. Additional effort and potential costs can come from invention and process innovations in construction (Slaughter, 1998), such as the recent efforts in Building Information Modeling, which fundamentally alters building design and processes.

Designing, constructing and delivering efficient, green buildings is a relatively recent innovation in the real estate sector, but this type of innovation has been shown to impact costs in different ways. Energy efficiency has already been documented as requiring changes in the design methods (Mapp et al., 2011), contracting (Fisher and Bradshaw, 2010) and construction materials (Tatari and Kucukvar, 2011). Product innovations like triple-glazed windows, building monitoring systems and embodied carbon-free insulation may have increased material and labor costs in construction over the last decade, and even more sophisticated innovations like photovoltaic roof coverage or window panes may require additional reconfiguration of a building's systems infrastructure and in turn further increase costs, as well as planning and contracting time.

1.2. Building codes

Over time, technical change leads to new construction methods and/or standards established by governments or committees – building codes. These codes have a larger mandate than energy efficiency or the use of environmentally responsible materials; codes are designed for improving structural integrity and to protect public health, safety and general welfare in construction and occupancy. Changes in building codes are fairly gradual (Gann, 2000). For example, the UK's Building Act of 1984 has been adjusted in 1991, 2000 and 2010 to guide design, construction, demolition and services for buildings, and between 2003 and 2014, there have been 22 minor amendments to the building codes.[4]

However, for this paper, the most salient changes in UK building codes occurred in 2006, when UK building codes began to incorporate requirements towards decreased energy consumption of newly constructed buildings, with the aim to decrease energy consumption by identifying baseline buildings and then lowering energy consumption relative to these buildings. This change in the UK building code was partly in response to the EU's Energy Performance Building Directive that mandates measurement of projected energy consumption in new construction.

1.3. Green buildings and certification

Green construction involves innovation beyond building code standards (Lam et al., 2010) and to measure the greenness of buildings, both governments and the building industry have established certification systems. Within the UK, our market of interest, the two main private certification and environmental information schemes are BREEAM and LEED, and BREEAM certification is by far the dominant scheme in that country (Chegut et al., 2014).[5] BREEAM provides certification for buildings based on a detailed points system during the design and construction phase of a building. These points are based on various issues corresponding to the environmental performance of a building, from the "Reduction of CO_2 Emissions" to "Building Use Guides and Green Leases" and "Innovation." Importantly, buildings assessed by BREEAM are provided with an absolute score. Final scores range from Unclassified with a score of less than 30, increasing stepwise to Pass, Good, Very Good, Excellent and Outstanding (buildings with a score greater than 85). Theoretically, a building can receive a maximum score of 100 points.

Green building standards change over time, and BREEAM standards are set and revisited periodically. Since 1999 the BREEAM assessment has been expanded three times, in 2006, 2008 and 2011. With each subsequent shift, the standards require more effort to achieve points on the same aspect, which makes achieving the next rating level more challenging.

The shift towards green construction represents an innovation in the construction process that started over a decade ago. The effort to augment conventional construction processes to meet energy efficiency demands may increase the cost of producing buildings in general, and for those innovators who move beyond minimal required standards, the effort cost could result in higher marginal costs to incorporate additional green building technologies and features.

To assess the marginal cost of green construction, we identify the extent of innovation in green buildings in two ways. First, we use the fact that a building has received BREEAM certification in the first place as a measure of technological progress beyond buildings codes. Second, we assess a building's level of BREEAM certification, which serves as a proxy for progressively advanced technology. Especially higher graded projects, such as BREEAM Outstanding and Excellent buildings, are likely to cost more than non-certified construction projects due to the advanced level of innovation and required technology in their construction.

2. Construction cost data

2.1. Identifying green buildings

Access to a comprehensive and consistent set of data on building construction cost is surprisingly hard to obtain. The one exception is the UK, where such information is collected on a reasonably large scale. The Royal Institution of Chartered Surveyor's BCIS database provides a comprehensive resource of construction cost. The BCIS Online tool includes over 18,000 projects spanning the last 50 years. The database includes cost breakdowns for projects, indices and location-adjustment factors. Clients who subscribe to the database who are also the providers of the basic information, submitting data on their construction costs as experienced in the marketplace. According to the BCIS website, the database includes construction projects from public and private clients. The information in the BCIS database is based on reports from the design and construction companies' clients, including commercial developers, non-profit building owners, and corporate building owners.[6]

We extract all data from the BCIS database, check the data against the construction progress reports by municipalities and further manually verify it for integrity. Second, to identify BREEAM-certified buildings in the BCIS database, we use the certi-

[4] For a comprehensive guide to the regulatory changes, see http://www.planningportal.gov.uk/buildingregulations/buildingpolicyandlegislation/previous, last accessed September 10, 2015.

[5] BRE was originally founded in 1917 by the Department of Scientific and Industrial Research as a research and development program to investigate construction materials and methods for use in housing after World War I. For a look at the 90 year history of BRE see: http://www.bre.co.uk/page.jsp?id=1712. The agency has grown and become a global certification scheme for the design and procurement of sustainable and energy-efficient commercial and residential real estate projects.

[6] Databases relying on self-reported data may suffer from reporting bias. Indeed, the BCIS is a database that has historically been based on an exchange system, where firms provide data on their construction projects in exchange for information on the full dataset of other construction projects. We analyzed the BCIS for reporting bias in a number of ways. First we looked at the extent to which the reporting of individual firms dominate the database. In our sample there are 796 unique providers of data, and the average amount of data submitted by a single provider is 0.12 percent, with no single data submission source contributing more than five percent of the overall dataset. While this does not rule out reporting bias per se, it is clear that the BCIS database includes a wide variety of companies, and is not dominated by the reporting of just a handful of firms. Second, we looked for any evidence regarding systematic differences in reporting between green and conventional building projects, and found none. Third, we have scanned BICS message boards to look for reports or discussions pertaining to a potential self-reporting bias, and again found none.

fication database of BREEAM (Green Book Live), as well as those buildings flagged as BREEAM-certified by clients of the BCIS.[7] To eliminate erroneous labeling of buildings as BREEAM-certified, we conduct an extensive manual verification of the buildings from the BCIS dataset to confirm that they are indeed BREEAM-certified. Last, we verify for each non-certified building that it is not employing green technology and construction methods, as witnessed by BREEAM, and that it is not in the process of being certified.

To identify cost differences between green and conventional construction techniques, we start with the full BCIS database over the 2003 to 2014 period, some 4080 buildings. We then eliminate observations with incomplete information[8] and match BREEAM-certified and non-certified buildings on the basis of being in the same county, in the spirit of the real estate maxim "location, location, location." We require that at least one non-certified observation in the county is constructed in the same year as the BREEAM-certified observation, to control for temporal variation in construction technology. This matching procedure results in a dataset of 2396 construction projects covering the period from 2003 to 2014. Of these, 336 are BREEAM-certified and 2060 are non-certified. The dataset includes complete information on BREEAM rating, elemental costs, contract length, building, client and contract characteristics, tender and procurement strategy, as well as location and year of construction.

The construction cost data include all the costs that the construction company and the design firm charge, so representing the costs as negotiated between the developer/client on the one hand and the construction company and the architect on the other. That means the costs do not include any profit margin for the developer/client. They do, however, include the budgeted profit margin for the designer, the construction company and the suppliers of building materials, etc. The soft elemental costs that go into the development of the building include design fees, preliminaries, contingencies, and external works. Preliminaries concern costs relating to the preparation, management, and cleaning of the building site, and contingencies are for cost overruns. External works involve the development of land and roads. Substructure is construction below the lowest floor together with the foundation. Design fees are the costs for designing the structure and systems. The hard elemental costs of construction are broken down into five categories: substructure, superstructure, finishes, services, and fittings.[9] Superstructure represents the frame, floors, roof, stairs, external walls, windows and doors. Services include sanitary, kitchen, plumbing, disposal, water, heat sources, air treatment, electrical wiring, lifts and protective systems costs. Finishes are for the wall, floor, and ceiling enhancements, and fittings are items such as installed furniture, flooring and equipment. Appendix Table A1 provides detailed definitions of all variables used in the analysis.

2.2. Univariate analysis

Table 1 provides sample statistics for the BREEAM-certified sample, as well as for the unweighted non-certified sample, and the propensity-weighted control sample. It also shows significance levels of tests for the equality of means between the certified sample, and the unweighted and weighted control sample, respectively. As for the certified buildings, the table shows that BREEAM Very Good and Excellent are the dominant certification levels, together good for 82 percent of all environmentally certified buildings. The mean building cost for a certified building is £6.8 mln. This is more than twice as high as in the unweighted non-certified sample and also higher than in the propensity weighted control sample. However, building size is partly to blame for this difference. Both in terms of floor area and in terms of stories, certified buildings are relatively large. When we look at building cost per square foot, the cost differences between the certified and non-certified samples are much smaller.

The table shows that Superstructure and Services Costs together contribute almost half of the total construction bill. External works and preliminaries also represent a considerable proportion of total costs at 13 and 12 percent, respectively, while finishes, fittings, contingencies and design fees have a much smaller contribution to total construction costs per square meter. Design fees are on average three percent for BREEAM-certified projects and only two percent for non-certified projects. This holds for the certified sample, as well as for the control samples. Steel is the most frequently observed construction material overall, but it seems that buildings in the non-certified samples tend to use brick more than certified ones. As for clients: public sector clients are more frequent in the certified sample than in the non-certified ones. In terms of tender process and contractual cost sharing, there is not much difference between the sample: Selected Competition and Design and Build are always the two most important processes, and Firm and Fixed cost the dominant cost sharing methods.

As a first analysis of the overall cost differences between green-certified buildings and their conventional peers, we compare the two samples using a simple univariate analysis. In addition to Table 1 Columns 5 and 6, Fig. 1 provides the average costs for the BREEAM-certified and non-certified samples. The light gray bars depict the average costs for the non-certified sample and the dark gray bars depict the BREEAM-certified sample's mean additional costs. The figure also shows the results of a two sample *t*-test with equal variances for the equality of means of the total cost per square meter for the complete sample period, as well as for each cost element and for each individual year.

[7] See http://www.greenbooklive.com/search/scheme.jsp?id=202.

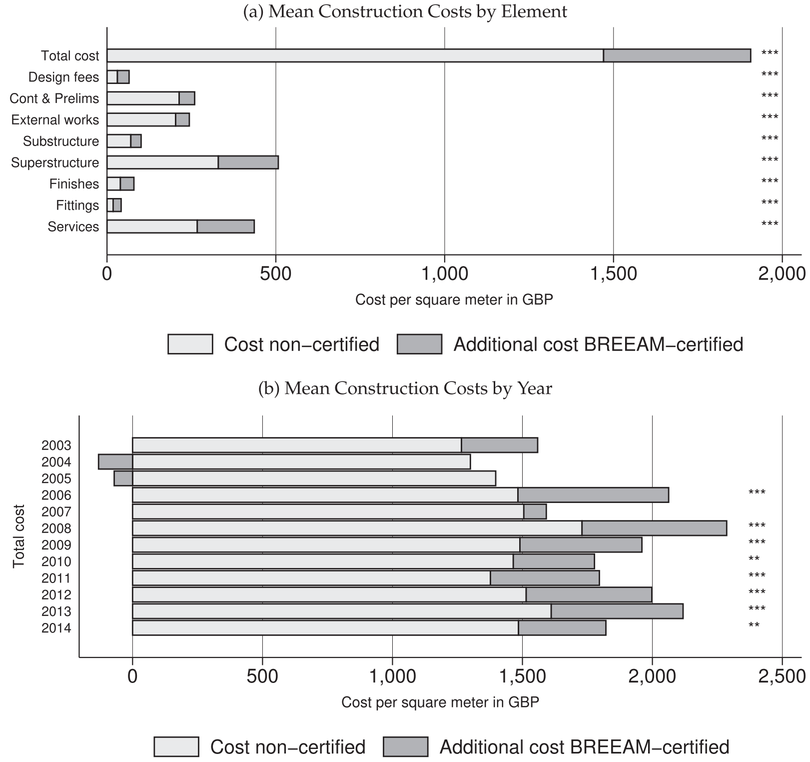
[8] We drop a total of 786 incomplete observations: 2 projects have invalid construction years; 106 projects have incomplete tender information; 664 projects have size irregularities, implying that we could not use them for our matched control sample; 16 projects have elemental cost data missing; after these deletions only one observation had erroneous elemental cost data.

[9] Some building projects, like refurbishments or renovations, do not include costs for the substructure. Within the analysis, these observations are controlled for and instead of log zero, a log of one is included.

Table 1
Comparison of BREEAM-certified and non-certified samples.

Variable	BREEAM-Certified Sample Size (336 observations)		Non-Certified Sample Size (2060 observations)				T-Test For Equality of Means	
			No Weights		PS Weights		Certified-Non-Certified	
	Mean (1)	(Std. D.) (2)	Mean (3)	(Std. D.) (4)	Mean (5)	(Std. D.) (6)	No Weights (7)	(PS Weights) (8)
BREEAM rating								
Outstanding	0.01	(0.11)						
Excellent	0.36	(0.48)						
Very good	0.46	(0.50)						
Good	0.04	(0.19)						
Pass	0.02	(0.13)						
Elemental costs (GBP/sqm ths.)								
Total Building Cost	6799	(8345)	3235	(5800)	5512	(11,232)	−3,563***	−1,287***
Total Building Cost/sqm	1.90	(0.85)	1.47	(0.78)	1.63	(0.84)	−0.43***	−0.27***
Substructure Cost	0.10	(0.07)	0.07	(0.07)	0.08	(0.08)	−0.03***	−0.02***
Superstructure Cost	0.51	(0.29)	0.33	(0.26)	0.39	(0.27)	−0.17***	−0.12***
Finishes Cost	0.08	(0.07)	0.04	(0.06)	0.04	(0.06)	−0.03***	−0.04***
Fittings Cost	0.04	(0.05)	0.02	(0.04)	0.02	(0.04)	−0.02***	−0.02***
Services Cost	0.43	(0.28)	0.27	(0.27)	0.33	(0.29)	−0.16***	−0.10***
Contingencies Cost	0.05	(0.05)	0.04	(0.07)	0.05	(0.08)	−0.004	−0.001
Preliminaries Cost	0.21	(0.12)	0.17	(0.12)	0.19	(0.13)	−0.04***	−0.02***
External Works Cost	0.24	(0.21)	0.20	(0.19)	0.22	(0.21)	−0.04***	−0.02***
Design Fees Cost	0.07	(0.11)	0.03	(0.09)	0.04	(0.11)	−0.03***	−0.03***
Contracting period								
Contract length	8.65	(18.14)	5.21	(10.69)	7.62	(15.12)	−3.43***	−1.03***
Building size								
Gross internal floor area	3617	(3870)	2207	(3088)	3261	(5313)	−1,410***	−356***
Stories	2.74	(1.97)	2.12	(1.60)	2.56	(2.30)	−0.62***	−0.18***
Contract competition								
Number of tenders	2.57	(2.29)	2.41	(2.31)	2.56	(2.32)	−0.15	−0.01
Build-out extent - by percent								
New construction	0.81	(0.39)	0.67	(0.47)	0.69	(0.46)		
Other	0.19	(0.09)	0.33	(0.18)	0.31	(0.18)		
Primary materials - by percent								
Brick	0.12	(0.32)	0.27	(0.45)	0.20	(0.40)		
Concrete	0.11	(0.31)	0.06	(0.23)	0.10	(0.30)		
Steel	0.66	(0.47)	0.40	(0.49)	0.50	(0.50)		
Timber	0.04	(0.19)	0.12	(0.32)	0.08	(0.27)		
Other	0.01	(0.11)	0.01	(0.08)	0.01	(0.09)		
Unknown	0.06	(0.24)	0.05	(0.07)	0.06	(0.08)		
Client - by percent								
Developer	0.03	(0.18)	0.03	(0.17)	0.01	(0.10)		
Private	0.26	(0.44)	0.47	(0.50)	0.33	(0.47)		
Public	0.71	(0.45)	0.49	(0.50)	0.66	(0.47)		
Tender process - by percent								
Competitive	0.07	(0.25)	0.04	(0.20)	0.04	(0.19)		
Design and build	0.21	(0.41)	0.21	(0.41)	0.24	(0.43)		
Negotiated	0.17	(0.38)	0.12	(0.33)	0.15	(0.36)		
Open competition	0.04	(0.19)	0.04	(0.19)	0.04	(0.21)		
Selected competition	0.31	(0.46)	0.36	(0.48)	0.38	(0.48)		
Two stage tendering	0.05	(0.22)	0.03	(0.17)	0.04	(0.21)		
Unknown	0.13	(0.33)	0.16	(0.37)	0.14	(0.34)		
Contractual cost sharing - by percent								
Other Sharing	0.005	(0.05)	0.005	(0.06)	0.005	(0.05)		
Pain gain cost share	0.13	(0.33)	0.07	(0.25)	0.09	(0.29)		
Firm costs	0.37	(0.48)	0.51	(0.50)	0.51	(0.50)		
Fixed costs	0.50	(0.50)	0.42	(0.49)	0.39	(0.49)		

Notes: Table 1 highlights the mean and standard deviation of construction cost characteristics for the BREEAM-certified and non-certified samples over the 2003 to 2014 period. Descriptives for the non-certified sample are presented both unweighted as well as weighted by propensity scores. The difference results and statistical significance of two-sided t-tests for equality of means are presented in columns seven and eight, with the exception of categorical variables. Statistical significance at the 1, 5 and 10 percent levels denoted by ***,**,*, respectively.



Notes: Figure 1 reports the total mean construction and elemental costs per gross square meter for the BREEAM-certified and non-certified samples over the 2003 to 2014 (Q2) period. The light gray bars depict the non-certified samples' mean costs and the dark grey bars depict the BREEAM-certified samples' additional mean costs. Statistical significance at the 1, 5 and 10 percent levels denoted by ***,**,*, respectively.

Fig. 1. Mean total construction costs by element and time.

The upper bar in Panel 2 shows a clear difference in average total costs per square meter between BREEAM-certified and non-certified construction projects. The mean difference is £431 per square meter, and it is statistically significant.

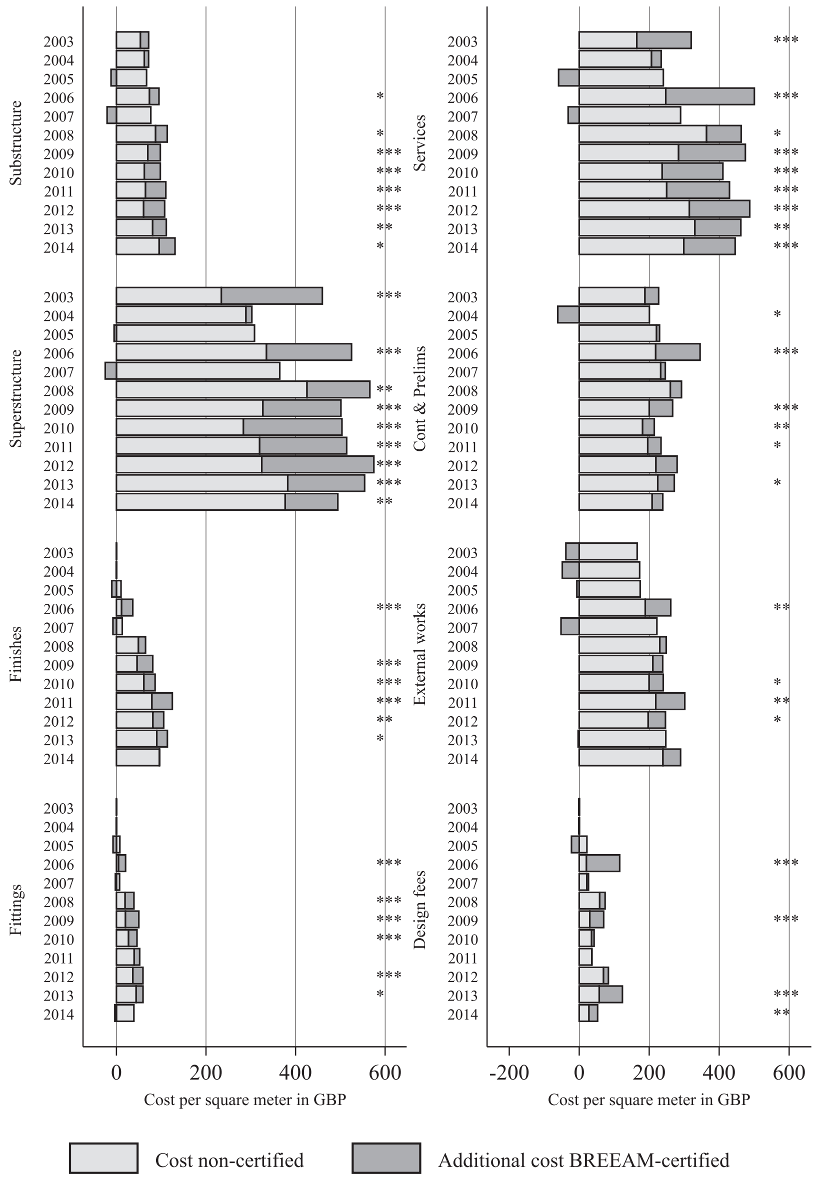
All elements of construction costs are significantly higher for more efficient, green construction projects, not controlling for building characteristics and other aspects of the construction process. For example, relative to the cost of non-certified construction, BREEAM-certified design fees are larger by £64 per square meter. Given that design fees for non-certified buildings average £30 per square meter, this is a sizeable difference.

Fig. 1 Panel 1b provides insight into total building costs over time, reporting average construction costs per gross square meter for each year of the sample period. The graph suggests that certified buildings constructed in all years but 2003, 2004, 2005 and 2007 are on average more costly than conventional buildings constructed in these years.

Fig. 2 provides insight into the relative importance of each of the cost elements over time. The graph shows that the extent to which BREEAM-certified buildings cost more (less) than their conventional counterparts appears to differ across cost elements and years. The cost of external works, for example, tends to be lower for BREEAM-certified buildings for a few years, while services, superstructure costs and design fees are almost always higher for these buildings. Especially in the case of services, the differences are relatively large, and statistically significant for most years in the sample period.

The cost elements do not include the capital costs that a developer incurs in order to realize a project. We cannot observe these capital costs directly, as we have no data regarding the cost of debt and equity capital employed by the developers for the construction projects that we analyze. However, we have information on project duration. Since project time determines the time period during which the developers capital is employed, we use it as a proxy for the total capital costs that a developer has to pay. The time it takes to realize a project is likely to be driven by project complexity and innovativeness, and green development may therefore take longer.

In Fig. 3, we compare contract length for green buildings and conventional buildings for each year from 2003 to 2014. Green buildings take consistently longer to finish than conventional buildings and the difference is statistically significant for all years in the sample period. This may reflect the increased complexity of green building development, and it suggests that a developer's capital needs to be employed longer in green construction projects than in conventional projects. However, green buildings tend to be relatively large, and since larger buildings typically take longer to complete, the increased project length may also be due to project size.



Notes: Figure 2 reports the elemental costs per gross square meter for the BREEAM-certified and non-certified samples over the 2003 to 2014 (Q2) period. Statistical significance at the 1, 5 and 10 percent levels denoted by *, **, ***, respectively.

Fig. 2. Elemental construction costs by year.

3. Method

There is no natural experiment that allows us to directly identify cost differences between “green” and conventional construction techniques, and our identification strategy therefore relies on documenting cost differences based on regression analyses, controlling for observable differences between more efficient, green buildings and conventional construction projects. To ensure comparability between green buildings and the control group, we employ two additional strategies.

First, we create a matched sample on the basis of construction vintage and location. As described in Section 2, we first collect a sample of construction projects with a BREEAM rating and then select control projects in the same county, at least one of which is also constructed in the same year. In addition, we remove any building type that is not in the BREEAM-certified sample. This mechanical matching procedure reflects the reality that real estate development costs, and subsequently property values, strongly differ over time, across space, and across property types.

Notes: Figure 3 depicts the average contract lengths of the two samples. The light gray bars show the non-certified samples' mean costs (contract length) and the dark grey bars show the BREEAM-certified samples' additional mean costs (contract length). Statistical significance at the 1, 5 and 10 percent levels denoted by ***,**,*, respectively.

Fig. 3. Mean contract length by year.

Second, we use a propensity score weighting of the control sample where the propensity score is estimated based on observable characteristics, such as the number of stories, the size of the building, number of tenders, the client type, construction material, contract length and building function. Conditional upon such observable characteristics, we thus eliminate differences between green construction projects and conventional control buildings by estimating the propensity of undergoing the design and procurement process for BREEAM certification for all buildings in the construction cost sample. We apply the resulting propensity score as a weight in the regression of Equation (1). This approach minimizes the potential bias between the BREEAM-certified and non-certified sample (Rosenbaum and Rubin, 1983; Black and Smith, 2004).[10] Fig. A1 in the Appendix displays the distribution of propensity score weights for the complete sample and the two subsamples, showing that all projects included in the sample of BREEAM-certified and non-certified construction projects have weights assigned, with a large area of common support. Table 1 shows that observable differences between the treated and control sample are much smaller when the propensity weight is applied.

In estimating construction cost differences between green projects and their conventional peers, it is important to realize that incorporating advanced technology and modern techniques into the construction process is in part just complying with existing building codes, which, in turn, reflect changes in technological possibilities. Our marginal cost identification strategy must thus take stock of general technological progress in the built environment and of changing building codes. We therefore include time-fixed effects in the analysis (Baltagi and Griffin, 1988). We also include county-fixed effects to attribute geographical differences in construction costs as well as fixed effects for building use.

Empirically, we operationalize our estimation strategy using a multivariate cost regression model[11]:

$$\log C_i = \alpha + \phi Z_i + \theta K_i + \delta T_i + \lambda R_i + \epsilon_i, \tag{1}$$

where C_i is construction cost or construction cost element per square meter for building i and α is a constant.[12] In an alternative specification, we employ this model to investigate construction duration for green and conventional construction projects. Our principal variable of interest is a binary variable for green certification Z_i, which equals one if building i is certified by BREEAM, and zero otherwise. We also investigate the cost effects of different certification levels, in which case Z_i represents a vector of dummies for each level of BREEAM certification, ranging from Pass to Outstanding. K_i captures the key components determining the construction process and represents a vector of control variables. It includes the building, client, and contract characteristics, as well as procurement and tendering processes. K_i also captures the building's property type, owner group and hedonic characteristics relevant for construction, such as number of stories and new construction (refurbishment) status. T_i is a vector of time dummies, with a value of one in the year of construction of building i and zero otherwise. R_i is a vector of county-fixed effects, representing the region of construction for building i. The estimated parameters are ϕ, θ, δ, and λ. ϵ_i is a vector of regression disturbances.[13]

[10] Applications of propensity score weighting in commercial real estate include Eichholtz et al. (2013); and Chegut et al. (2014).

[11] For the development of hedonic-based ex-post construction cost models see Runeson (2010); Wheaton and Simonton (2007); Lowe et al. (2006); Somerville (1999).

[12] We use the log of cost per square meter to control for size differences. Results are quantitatively similar if we include the log of construction cost and control for the size of a building on the right-hand side of the equation.

[13] As suggested by one of the referees, we would ideally control for more granular location-fixed effects, for example at the postcode level. However, there are many instances with very few observations per postcode, rendering this analysis not meaningful. An alternative approach might be to include commercial real estate price indices that are spatially highly granular. But for this approach we are confronted with the limitations of data in commercial real estate: such price indices are available for large metropolitan areas only, which does not add to the existing analysis.

Our estimation procedure for Equation (1) employs OLS corrected for heteroskedasticity, with propensity score weighting to minimize observable differences between the BREEAM-certified and non-certified buildings included in the analysis. While this approach reduces possible omitted variable bias in comparing treated, "green" construction projects and non-treated, "conventional" projects, we acknowledge that more efficient, green construction projects may bundle in potentially costly building attributes. In that case, we may overestimate the cost of green construction. Equally, green building projects may skimp on expensive, non-green attributes, reducing the cost of such projects. In that case, we underestimate the cost of green construction.

In addition, the choice to construct green is endogenous, as some developers or client types may bundle the choice for green certification with other construction elements or techniques that influence construction costs, such as higher-quality finishings or fittings (Flowers et al., 2018). One unique feature of the dataset is that it provides contract information as well as information on the client for whom the building was constructed. We can thus include a large set of controls for developer, contract and client characteristics, which alleviates concerns that issues other than "green" considerations may affect construction costs.

4. Results

4.1. Marginal cost analysis

The first four columns of Table 2 present the regression results for Model (1), relating the logarithm of construction costs per gross square meter to the green certification dummy and a set of building, client and contract characteristics with location and time-fixed effects. Results are weighted by propensity score. The model explains up to 47 percent of the variation in the log construction cost per gross square meter. The last column of the table provides results for the contract length regression.

Column (1) reports the results for the most parsimonious model, in which we include the certification dummy, location and construction year fixed effects, as well as control variables for building characteristics, such as size and the scope of construction (i.e., refurbishment, new construction, or building extensions). We document that building characteristics relating to the scale of the building, like size and the number of stories, are statistically significant in explaining construction costs. Relative to building extensions and refurbishments, new construction increases costs by 28 percent. The results of this analysis suggest that BREEAM certified buildings are costlier to construct than conventional buildings: we document a statistically significant coefficient for green certification of 12.6 percent.

In Column (2), we add further controls for building characteristics, such as primary materials. This does not markedly affect the BREEAM certification coefficient, or its standard error, but these do change when we employ the full model specification. Column (3) provides results for this specification, including building use and client and contract characteristics. Adding these additional covariates to the model reduces the coefficient of the BREEAM certification dummy to 6.5 percent.

The regression results for the control variables show that buildings developed for private entities are 21 percent less expensive as compared to developer clients in the database. Furthermore, contract competition as measured by the number of tenders has limited impact on the construction cost per gross square meter. Contracts that share in the "pain and gain" of cost differences result in construction costs that are 37 percent higher than fixed cost contracts.

The key result reported in Table 2 is a statistically significant cost premium for green construction projects, where the fully specified model in Column (3) results in a coefficient for BREEAM certification of 6.5 percent. This finding raises an important question regarding the prevalence of green construction. Commercial buildings certified as green have been documented to command economically significant premiums in rents and sales prices (Eichholtz, Kok and Quigley, 2010, 2013; Fuerst and McAllister, 2011; Chegut et al., 2014), where transaction premiums range from 13.3 percent to 36.5 percent. The 6.5 percent construction cost premium resulting from our analysis suggests that high costs per se are thus not necessarily an impediment to more energy efficient construction. Moreover, the 6.5 percent cost premium we find relates to the building and not to the land, while the value premiums found in the literature relate to the combined value of building and land. Bokhari and Geltner (2017) find that building value is approximately 25 percent of total value for new and renovated buildings, which would imply a cost premium of 4.9 percent of total value. The question arises what then explains the dearth of green building in the real estate sector. We therefore analyze further the different aspects of green construction.

First, an important source of developer risk is project duration. The longer it takes for a construction project to be completed, the longer a developer has to pay for construction labor and equipment. In addition the developer will need to wait longer to either occupy, lease or sell the project before cash flows can turn positive, which implies a longer need for working capital, increasing the capital costs of the project. We therefore investigate the role of green construction in determining building development project duration. Column (4) of Table 2 provides regression results explaining project duration, employing the most extensive set of control variables. The reported certification coefficient implies that green-certified buildings take almost 11 percent longer to complete, after controlling for factors like project size, buildout extent and building use, which also significantly affect project duration. At the point of means (i.e., a construction period of 7.6 months), clients have to wait about one month longer for the cash flows resulting from green building construction, implying that their capital is locked up" for a longer

Table 2
Construction costs for BREEAM-certified & non-certified buildings (Dependent variable: Logarithm of construction cost per gross square meter & contract length).

	(Cost)	(Cost)	(Cost)	(Cost)	(Length)
Certification					
BREEAM Certified	0.183***	0.126***	0.109***	0.065**	0.110*
	[0.030]	[0.030]	[0.030]	[0.028]	[0.064]
Building size					
Size		−0.015**	−0.019**	−0.024***	0.078***
		[0.007]	[0.008]	[0.007]	[0.013]
$Size^2$		0.000	0.000*	0.000**	−0.000**
		[0.000]	[0.000]	[0.000]	[0.000]
Stories		0.022***	0.011	0.018**	0.008
		[0.008]	[0.008]	[0.008]	[0.018]
Build-out extent					
New construction		0.276***	0.201***	0.204***	0.154***
		[0.028]	[0.030]	[0.028]	[0.043]
Primary materials					
Brick			−0.154***	−0.111***	−0.025
			[0.030]	[0.028]	[0.057]
Concrete			0.097**	0.076*	−0.021
			[0.048]	[0.045]	[0.096]
Timber			−0.126***	−0.104***	−0.109
			[0.040]	[0.037]	[0.070]
Other			0.087	−0.076	−0.243
			[0.106]	[0.107]	[0.336]
Unknown			−0.321***	−0.354***	−0.320***
			[0.045]	[0.043]	[0.068]
Client					
Private				−0.214***	0.100
				[0.067]	[0.119]
Public				−0.134*	−0.068
				[0.072]	[0.129]
Contract competition					
Number of tenders				0.011	−0.084**
				[0.017]	[0.036]
Number of $tenders^2$				−0.003	0.007*
				[0.002]	[0.004]
Tender process					
Competitive				−0.170**	−0.053
				[0.072]	[0.188]
Design and build				−0.163***	−0.244
				[0.062]	[0.169]
Negotiated				−0.014	−0.224
				[0.069]	
					[0.162]
Selected competition				−0.121**	−0.159
				[0.058]	[0.159]
Two stage tendering				−0.065	−0.072
				[0.054]	[0.175]
Unknown				−0.282***	−0.713**
				[0.066]	[0.282]
Contractual cost sharing					
Other sharing				−0.037	0.280**
				[0.091]	[0.121]
Pain gain cost share				0.366***	0.303**
				[0.056]	[0.130]
Firm costs				0.045**	0.012
				[0.022]	[0.038]
Building function fixed effects	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes
County fixed effects	Yes	Yes	Yes	Yes	Yes
Constant	7.258***	6.873***	6.973***	7.214***	0.209
	[0.108]	[0.110]	[0.111]	[0.146]	[0.236]
Observations	2379	2379	2379	2379	825
R-squared	0.325	0.374	0.408	0.470	0.768
Adj R2	0.29	0.34	0.38	0.44	0.73

Notes: Table 2 reports the results of Equation (1) estimated by OLS corrected for heteroskedasticity with robust standard errors (White, 1980). Dummies are relative to items in parentheses: New construction, Refurbishment (Extension); Brick, Concrete, Timber, Other and Unknown (Steel); Industrial, Office, Other types, Residential, Retail, School and University (Administration); Private, Public (Developer); Competitive, Design and Build, Negotiated, Selected competition, Traditional, Two stage tendering, Other, Unknown (Open competition); Fluctuating costs, Pain or gain cost share, Firm costs (Fixed costs). Statistical significance at the 1, 5 and 10 percent levels denoted by ***,**,*, respectively.

time period. This adds to the capital costs involved in the development of green projects (on top of the higher construction costs), and creates a financial disincentive to initiate such construction projects.

Employing the framework outlined by Geltner and De Neufville (2018), a simple calculation shows the effect of longer project duration on the internal rate of return (IRR) for the developer: at the point of means, the average construction project requires an outlay of £5512 million. Assuming the developer finances the construction project through a construction loan, at a loan-to-value ratio of 90 percent, and assuming an interest rate of 10 percent on that loan, the average project IRR, or return on equity for the developer, is 17.12 percent. Ceteris paribus, so ignoring the higher construction costs for green-certified projects, an increase in project duration of 11 percent reduces the project IRR by 2.6 percentage points. While the size of this effect is not as large as the impact of a 6.5 percent increase in construction costs, it may lead to some projects no longer passing the return hurdle of the developer.

4.2. Heterogeneous effects

We then analyze the different elements of total construction costs, presenting results for the elements for which we document significant certification effects.[14] Table 3 presents the cross-sectional regression results for these elemental costs - design fees, fittings, finishes and preliminaries - during the 2003 to 2014 period, relating the logarithm of these elemental costs per gross square meter to the most extensive set of building, client and contract characteristics. We also include location and time-fixed effects to control for general technical change, building codes and regulation.

Table 3 shows that it costs almost 32 percent per gross square meter more to design a green building than an otherwise comparable, conventional building. Preliminaries and contingencies together are almost 12 percent more expensive for green construction projects, whereas fittings and finishes are more expensive by approximately 32 and 28 percent, respectively.

As shown in Table 1 and Fig. 1, design fees and fittings represent a very small part of overall construction costs. For the total sample, these amount to 2.1 and 1.2 percent, respectively. However, both design fees and fittings are likely to influence the decision making of developers in a way that is disproportional to their absolute level. First, design fees are largely paid up front, and are paid through equity financing by developers, which are market participants with relatively small balance sheets (Geltner et al., 2013). Typically, about 20–40 percent of the overall design fee is needed to get planning permissions, and such permission represents a major and risky hurdle for a developer. The design fees pay for the architectural work on a building's overall concept and the so-called full design. An additional 50 to 75 percent of the design fees are paid to architects and engineering consultants to generate the detailed specifications and conditions needed to contract with the construction company. The remaining 5 to 10 percent of design fees are paid during the construction phase. Developers typically aim to minimize design changes after signing with the contractor. Therefore, almost the entire design budget is spent before construction starts, in a phase when developers are fundamentally unsure about buyers and/or tenants for their project, and when external debt financing is still largely unavailable.

Cortazar et al. (1998) propose a real options model to evaluate environmental investments. Using that theoretical framework, one can regard the design fee as the premium of the option to develop a building, since a building's design creates the possibility to construct the asset. An increase in the option premium will reduce the likelihood that developers create the development option in the first place. So, design fees may be small and insignificant ex-post, but they are economically important ex-ante and buffered by a time window of uncertainty. Therefore, the 32 percent higher design fees for green construction documented in Table 3 may partially explain why green construction is still a relatively rare occurrence, even in the presence of an average output premium that is more than double the average marginal construction cost.

For finishes and fitting costs, upfront financing is not an issue, given that such costs are bundled in with the total development costs and are paid over the course of the development period. However, developers may pay more up-front attention to the marginal costs of finishings and fittings in green buildings. As discussed by Flowers et al. (2018), such finishes and fittings include measures with both clear private benefits (e.g. water-use reduction technologies, on-site renewable energy, and more efficient lightbulbs), but also measures with mostly public returns (e.g. certified wood, renewable materials, and habitat protection), or returns to the ultimate end-user of the building (e.g. high-quality air filters, low-emitting materials, etc). In either case, the decision to develop a green building creates an up-front commitment for higher quality design and therefore more extensive finishes and fittings, even when tenants and(or) buyers of the property have not yet been secured. This creates an additional financial risk for the developer, as the signaling value of higher-quality finishes or fittings may not be equally important to all market participants (Flowers et al., 2018), and the financial return to these marginal investments through higher rents and/or sales prices are uncertain.

We also address the heterogeneity in the degree of "greenness" and its effect on the marginal costs of green construction, as well as the time it takes to finish a project. Table 4 reports the regression coefficients for the BREEAM-certified projects for the five different levels of BREEAM rating: Outstanding, Excellent, Very Good, Good, and Pass. Column (1) shows results for the model including the dummies for certification level and the time, building function and location-fixed effects. For reasons of brevity, we do not explicitly report the regression results for the control variables, since they

[14] The regression results for the other cost elements are available upon request.

Table 3
Elemental costs for BREEAM-certified & non-certified buildings (Dependent variable: Logarithm of elemental cost per gross square meter).

	(Design Fees)	(Fittings)	(Finishes)	(Preliminaries)
Certification				
BREEAM Certified	0.316***	0.316***	0.282***	0.126***
	[0.091]	[0.088]	[0.095]	[0.038]
Building size				
Size	0.005	0.004	−0.004	−0.045***
	[0.017]	[0.019]	[0.021]	[0.008]
Size^2	−0.000	0.000	0.000	0.000***
	[0.000]	[0.000]	[0.000]	[0.000]
Stories	−0.038*	0.046**	0.041*	0.034***
	[0.022]	[0.021]	[0.023]	[0.011]
Build-out extent				
New construction	0.136**	0.252***	0.331***	0.264***
	[0.062]	[0.068]	[0.078]	[0.040]
Primary materials				
Brick	−0.021	−0.004	0.064	−0.113***
	[0.079]	[0.073]	[0.084]	[0.039]
Concrete	0.274**	−0.024	0.123	0.080
	[0.132]	[0.139]	[0.151]	[0.062]
Timber	0.010	0.066	0.301**	−0.212***
	[0.115]	[0.111]	[0.124]	[0.067]
Other	−0.488*	−0.319	−0.402	−0.453**
	[0.254]	[0.484]	[0.498]	[0.184]
Unknown	−0.275***	0.066	0.050	−0.397***
	[0.087]	[0.098]	[0.111]	[0.058]
Client				
Private	0.185	−0.221	−0.003	−0.199**
	[0.133]	[0.160]	[0.179]	[0.080]
Public	0.112	−0.290*	−0.147	−0.089
	[0.145]	[0.173]	[0.196]	[0.087]
Contract competition				
Number of tenders	0.152***	0.025	0.100*	0.071***
	[0.045]	[0.047]	[0.054]	[0.024]
Number of tenders^2	−0.022***	−0.006	−0.017**	−0.013***
	[0.006]	[0.007]	[0.008]	[0.003]
Tender process				
Competitive	0.374**	0.409**	0.715***	−0.161*
	[0.188]	[0.184]	[0.198]	[0.088]
Design and build	0.731***	0.200	0.367**	−0.077
	[0.133]	[0.135]	[0.160]	[0.062]
Negotiated	0.626***	0.037	0.362*	0.164**
	[0.215]	[0.172]	[0.213]	[0.082]
Selected competition	−0.108	0.061	0.194	−0.134**
	[0.109]	[0.123]	[0.147]	[0.055]
Two stage tendering	0.086	−0.002	0.154	−0.064
	[0.166]	[0.190]	[0.219]	[0.085]
Unknown	0.548***	0.036	0.270	−0.254***
	[0.150]	[0.152]	[0.178]	[0.077]
Contractual cost sharing				
Other sharing	1.376***	−0.739	−0.679	−0.130
	[0.401]	[0.555]	[0.662]	[0.311]
Pain gain cost share	3.175***	1.516***	1.884***	0.365***
	[0.238]	[0.191]	[0.211]	[0.084]
Firm costs	−0.273***	−0.154**	−0.231***	0.041
	[0.064]	[0.060]	[0.068]	[0.032]
Building function fixed effects	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes
County fixed effects	Yes	Yes	Yes	Yes
Constant	0.057	−0.435	0.715	4.414***
	[0.335]	[0.421]	[0.490]	[0.196]
Observations	2379	2379	2379	2379
R-squared	0.664	0.531	0.602	0.407
Adj R2	0.64	0.50	0.58	0.37

Notes: Table 3 reports the results of Equation (1) estimated by OLS corrected for heteroskedasticity with robust standard errors (White, 1980). Dummies are relative to items in parentheses: New construction, Refurbishment (Extension); Brick, Concrete, Timber, Other, Unknown (Steel); Industrial, Office, Other types, Residential, Retail, School, University (Administration); Private, Public (Developer); Competitive, Design and Build, Negotiated, Selected competition, Traditional, Two stage tendering, Other, Unknown (Open competition); Fluctuating costs, Pain or gain cost share, Firm costs (Fixed costs). Statistical significance at the 1, 5 and 10 percent levels denoted by ***,**,*, respectively.

Table 4
Construction costs by BREEAM rating (Dependent variable: Logarithm of construction cost per gross square meter & contract length).

	(Cost)	(Cost)	(Cost)	(Cost)	(Length)
Certification					
Outstanding	0.380*	0.307	0.347*	0.305*	
	[0.220]	[0.210]	[0.191]	[0.183]	
Excellent	0.189***	0.101***	0.078**	0.047	
	[0.034]	[0.033]	[0.034]	[0.036]	
Very Good	0.185***	0.136***	0.132***	0.099**	
	[0.047]	[0.046]	[0.046]	[0.041]	
Good	−0.008	−0.052	−0.076	−0.070	
	[0.107]	[0.090]	[0.089]	[0.076]	
Pass	0.120	0.060	0.069	0.051	
	[0.221]	[0.187]	[0.182]	[0.175]	
Outstanding/Excellent/Very Good					0.130*
					[0.067]
Good/Pass					−0.056
					[0.105]
Building size		Yes	Yes	Yes	Yes
Build-out extent		Yes	Yes	Yes	Yes
Primary materials			Yes	Yes	Yes
Building use			Yes	Yes	Yes
Client			Yes	Yes	Yes
Contract competition				Yes	Yes
Tender process				Yes	Yes
Contractual cost sharing				Yes	Yes
Building function fixed effects	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes
County fixed effects	Yes	Yes	Yes	Yes	Yes
Constant	7.256***	6.871***	6.974***	7.105***	−0.838***
	[0.108]	[0.109]	[0.111]	[0.139]	[0.302]
Observations	2379	2379	2379	2379	825
R-squared	0.324	0.374	0.408	0.472	0.693
Adj R2	0.29	0.34	0.38	0.44	0.64

Notes: Table 4 reports the results of equation (1) estimated by OLS corrected for heteroskedasticity with robust standard errors (White, 1980). Statistical significance at the 1, 5 and 10 percent levels denoted by ***,**,*, respectively.

do not differ markedly from the control variables reported in Table 2. Overall, the results reported in Table 4 show that the marginal costs of green buildings increase with the certification level, and that the cost differences between certification levels are substantial. Across the four model specifications we employ, buildings certified as Outstanding are 30–38 percent more expensive to construct. For buildings rated as Excellent and Very Good, we find construction cost premiums ranging between 5 and 19 percent, and for the lowest two levels of green certification, we do not find statistically significant green cost premiums at all, irrespective of the model specification. These results suggest that the overall green construction cost effects reported in Table 2 are mostly determined by the costs of the greenest buildings in the sample.

Next, we investigate whether the degree of “greenness” is also related to project duration. We do not have enough contract length observations to investigate the effects for all five BREEAM certification levels, so we cluster the observations in each of these categories into two groups, with the “deep green” group consisting of Outstanding, Excellent and Very Good buildings, and the “light green” group consisting of Good and Pass buildings. The regression results in Column (5) show that only the “deep green” construction projects that aim for high levels of efficiency take significantly longer to finish, with a 13 percent longer contract length, on average. This finding implies that these buildings need longer capital commitments as compared to conventional buildings or construction projects with limited energy efficiency sustainability attributes. On contract length, we therefore also conclude that the result provided in Table 2 seems to be attributable to the most sustainable, greenest buildings.

To further analyze the effect of relative greenness on construction costs, we estimate a model using the elemental construction costs as explained by BREEAM ratings. Table 5 reports the coefficients for the five levels of BREEAM certification, using the full set of control variables, and focusing only on the four cost elements that we analyzed previously. The table does not report results for the individual control variables – these are comparable to the results reported in Table 3.

The findings show a notable increase in design fees for increasing levels of environmental performance. The design costs of buildings marked as Outstanding are 150 percent higher as compared to those of non-certified projects; Excellent projects cost about 40 percent more to design, whereas lower levels of building energy efficiency and sustainability are not associated with higher design fees. Preliminaries, Finishes and Fittings costs are not significantly higher for Outstanding buildings, but higher for Excellent and Very Good buildings. It is possible that the small sample size for Outstanding buildings affects significance levels here.

Table 5
Elemental costs by BREEAM-quality (Dependent variable: Logarithm of elemental cost per gross square meter).

	(Design Fees)	(Fittings)	(Finishes)	(Preliminaries)
Certification				
Outstanding	1.501***	0.698	0.894	0.142
	[0.571]	[0.559]	[0.734]	[0.269]
Excellent	0.401***	0.384***	0.217	0.101*
	[0.147]	[0.127]	[0.132]	[0.056]
Very Good	0.166	0.361***	0.362***	0.179***
	[0.120]	[0.124]	[0.123]	[0.051]
Good	0.526	−0.654	−0.481	−0.164
	[0.387]	[0.465]	[0.664]	[0.131]
Pass	0.476	1.175*	1.247**	−0.288**
	[0.567]	[0.623]	[0.564]	[0.138]
Building size	Yes	Yes	Yes	Yes
Build-out extent	Yes	Yes	Yes	Yes
Primary materials	Yes	Yes	Yes	Yes
Building use	Yes	Yes	Yes	Yes
Client	Yes	Yes	Yes	Yes
Contract competition	Yes	Yes	Yes	Yes
Tender process	Yes	Yes	Yes	Yes
Contracting period	Yes	Yes	Yes	Yes
Contractual cost sharing	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes
County fixed effects	Yes	Yes	Yes	Yes
Constant	0.106	−0.454	0.695	4.402***
	[0.333]	[0.421]	[0.483]	[0.195]
Observations	2379	2379	2379	2379
R-squared	0.665	0.535	0.605	0.409
Adj R2	0.65	0.51	0.58	0.37

Notes: Table 5 reports the results of equation (1) estimated by OLS corrected for heteroskedasticity with robust standard errors (White, 1980). Statistical significance at the 1, 5 and 10 percent levels denoted by ***,**,*, respectively.

5. Conclusion

Buildings represent an important input for the modern economy, and the building stock is a large and growing consumer of electricity, gas and other resources, leading to significant environmental externalities. Green building certification, regulation towards sustainability performance measurement, and building codes for energy efficiency are gaining in importance, all with the aim of transforming the built environment towards more efficient, greener construction and operations. However, a large share of new construction has yet to switch to such efficient, green construction. This is contrasting the literature on the marginal financial implications of green building, which documents significant value premiums associated with green commercial real estate ranging between 13.3 and 36.5 percent (Eichholtz, Kok and Quigley, 2010, 2013; Fuerst and McAllister, 2011; Chegut et al., 2014).

Of course, the positive marginal output effects of more efficient, environmentally certified construction practices may simply reflect higher construction costs for these buildings. Currently, there is no systematic evidence addressing differences in input costs between green and conventional construction, but the general perception of developers and investors seems to be that converting to more efficient, green construction is substantially more costly, especially when it involves refurbishment of existing buildings.

Using a unique, manually constructed dataset, this paper assesses the magnitude, heterogeneity and temporal dynamics of green construction costs between 2003 and 2014 for a sample of 336 green buildings and 2060 matched conventional buildings. The main findings show higher marginal costs for more efficient, green construction and refurbishment projects. On average, costs are higher by 6.5 percent, but we document significant variation in the marginal cost of green construction based on the extent of environmental performance. Buildings that achieve the highest environmental ratings, BREEAM Very Good, Excellent and Outstanding, are constructed at a higher cost as compared to conventional construction projects, whereas efficient buildings that obtain Pass or Good ratings are not more expensive. As clients move up the technology curve, more efficient construction becomes more expensive in the design and implementation of such technology.

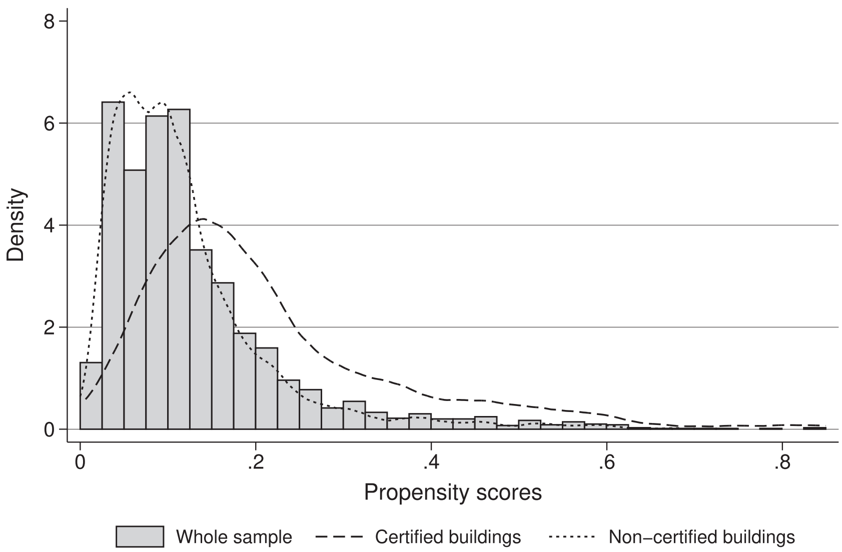
Analyzing the composition of construction costs, we find an economically and statistically significant premium in design costs and preliminaries, as well as in finishes and fitting costs for green buildings, which is robust to different model specifications. Overall, environmentally certified buildings have 31 percent higher design costs as compared to conventional buildings. BREEAM Excellent and Outstanding buildings are, on average, 40 and 150 percent more expensive to design than their conventional and otherwise comparable peers. These higher design fees are likely to reduce the willingness of property developers to engage in green building practices, since design fees represent a considerable risk to developers. Although design fees are less than three percent of overall construction costs, these expenditures have to be paid up-front, at a time when the developer faces fundamental uncertainty over building permits and market take-up of the project. Moreover, these fees are typically fully paid by the developer, since external equity or debt is not available at this stage of the development process. Developers tend to have rather small balance sheets relative to the size of their activities, so even the relatively limited capital outlay through these higher design fees poses a notable financial risk. This may partially explain why green construction and refurbishment practices are not more prevalent, even though overall marginal costs are lower than the price premium commanded by green buildings in the market, suggesting a market failure.

The higher finishes and fitting costs are financed during the project development, but can have other behavioral implications: developers may be uncertain about the willingness of market participants to pay for more expensive finishes, such as cradle-to-cradle carpets, low-VOC paint, and other sustainable materials. Whereas a more efficient heating, cooling and ventilation system probably provides a clear payback to potential buyers, other green attributes may have softer benefits. Developers may be hesitant to invest in those soft attributes in the absence of a certain pay-off, even though academic evidence shows a clear willingness to pay for green attributes, both in the real estate sector as well as for consumer goods, automobiles, solar panels, etc. (see, for example, Dastrup et al. (2012); Kahn (2007)). This market failure may be resolved relatively easily through provision of additional debt financing by construction lenders, which means developers do not have to invest their valuable equity to pay for additional green features. Anecdotally, we observe that some banks have started to provide such green loans, which have lower rates and higher LTVs than conventional loans.

Analysis of the duration of construction projects provides an additional explanation for the slow uptake of more efficient, green building practices: buildings certified as green take on average almost 11 percent longer to complete, after controlling for building size and other factors influencing construction project duration. This finding implies that there is a market barrier to the adoption of green buildings: developers have to wait longer to recoup their initial investment, adding significantly to the risk exposure of developers engaging in certified green construction projects. Potentially, this market barrier will reduce over time if developers and construction companies make advances in green building practices and innovation through the adoption of digital technology for improved cooperation (Boland et al., 2007; Barlow, 2000).

Results from this paper show that even if the long-term benefits of a switch to green production processes outweigh the costs (Acemoglu et al., 2012, 2014), the short-term incentives in the real estate development industry may prevent this switch from happening at the pace that would otherwise be economically rational. Policymakers increasingly rely on certification programs providing transparency on the efficiency and sustainability of buildings to stimulate market efficiency and the uptake and diffusion of more efficient building practices. While there is evidence that these certification programs have the desired demand-side implications, resulting in marginal outputs that differ based on environmental certification, the results in this paper provide some evidence that may explain the limited uptake of more efficient building practices, and the well-documented energy-efficiency gap.

Appendix A



Notes: Figure A1 displays the distribution of propensity score weights for the full sample, BREEAM-certified and non-certified samples.

Fig. A1 Propensity score distribution and area of common support.

Table A1
Data sources, variable list and description.

Variable	Description
Building Research Establishment Environmental Assessment Method (BREEAM) - Green Book Live	
Certification	
BREEAM-certified	Dummy variable indicating BREEAM certification
Outstanding	Indicates BREEAM certification score greater than or equal to 85
Excellent	Indicates BREEAM certification score greater than or equal to 70
Very Good	Indicates BREEAM certification score greater than or equal to 55
Good	Indicates BREEAM certification score greater than or equal to 45
Pass	Indicates BREEAM certification score greater than or equal to 30
Building Cost Information Service - BCIS	
Cost and cost elements	
Total building cost	Inclusion of substructure, superstructure, finishes, fittings, services, contingencies, preliminaries, external works and design fees.
Design fees cost	Cost of design including consultant's fees and contractor's design fees.
Fittings cost	Fittings, fixtures, furniture; works of art, and non-mechanical and electrical equipment. Note: Includes domestic kitchen equipment supplied with kitchen fittings.
Finishes cost	Preparatory work and finishes to surfaces of walls and other vertical surfaces internally.
Preliminaries cost	Priced items in Preliminaries and Summary but excluding contractor's price adjustments, profit and overheads, and can include: management and staff, site establishment, temporary services, security, safety and environmental protection, control and protection, mechanical plant, temporary works, site records and cleaning.
Contingencies cost	Allowance for client's risks of unforeseen costs.
External works cost	Covers the road works, ground and air related infrastructure of the building(s).
Substructure cost	All work below underside of screed or, where no screed exists, to underside of lowest floor finishes including damp-proof membrane, together with relevant excavations and foundations (includes walls to basements designed as retaining walls).
Superstructure cost	Load bearing framework. Main floor and roof beams, ties and roof trusses of framed buildings; casing to 42,000 stanchions and beams for structural or protective purposes.
Services cost	The installation and equipment for sanitary, mechanical, electrical, disposal, water, heat, air, ventilation, fuel, lift and conveyor, fire and lightning, communication, security and central systems.
Contract length (months)	Stipulated by client, offered by builder (if different), agreed.
Control variables	
Gross internal floor area (sqm)	Area of a building measured to the internal face of the perimeter walls at each floor level.
Stories	Total number of floors including basement floors.
Extension	A horizontal extension of an existing structure(s).
New construction	New building project or structure.
Refurbishment	A reconstruction of an existing structure.
Primary building material	Brick, concrete, steel, timber, offsite construction or undisclosed.
Future building use	Administration, industrial production, offices, residential, retail, school, university or other types of space.
Client characteristics	Developer, private firm, public or municipal client contract.
Number of tenders	Number of tenders received.
Cost sharing characteristics	Costs vary across fluctuate, pain/gain, firm and fixed. Fluctuate allows costs to vary across the contract, pain/gain stipulates sharing in cost increases or decreases, firm costs allow for some variation and fixed costs allow for no changes in costs.
Selection of contractor	Competitive, design and build, negotiated, open competition, selected competition, traditional, two stage tendering, other and unknown.

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