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Abstract:

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The Price of Innovation: An Analysis of the Marginal Cost of Green Buildings

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More 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, Kok and Quigley, 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, McGraw and Quigley, 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 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, Kok and Pogue, 2015). McGraw-Hill Construction (2013) estimates that 38 percent of current construction is earmarked as green, but the number of green construction-related jobs is 611,000, which is just 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. This raises questions about the marginal costs and benefits of environmentally certified, green construction – perhaps these market trends simply reflect economic rationality.

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

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[1] This figure 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.)

to 30 percent for rents and from 8 to 21 percent for values (Eichholtz, Kok and Quigley, 2010; Fuerst and McAllister, 2011; Eichholtz, Kok and Quigley, 2013). For energy-efficient residential properties, transaction premiums have been documented to vary between 2 and 16 percent (Brounen and Kok, 2011; Deng, Li and Quigley, 2012). 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. 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 research are thus hard to interpret or generalize.[2] There has been no systematic research to assess the marginal cost of more efficient, green construction in an empirically rigorous manner. This hampers the understanding by policy makers, developers and real estate owners regarding the input and output costs of green construction, which may slow down the diffusion of energy efficient and sustainable building practices in the building stock, 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

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[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 costs 15.4 to 37.4 percent more.

the Royal Institution of Chartered Surveyors' Building Cost Information Services (BCIS) elemental construction cost database, which is to our knowledge the only large-scale, non-proprietary dataset that has project cost, project duration and contract data for construction projects. We link these data to the database of the Building Research Establishment (BRE), whose BREEAM label represents the oldest environmental certification system for buildings. We then assess the marginal construction cost for a set of nearly 200 BREEAM-certified buildings, matching projects on location, time and other project-level factors with about 300 non-certified construction projects between 2003 and 2014.

The analysis provides several findings that are important for policymakers, as well as for real estate developers who are bringing green buildings to market. In contrast to conventional wisdom, we do not document a statistically significant difference in total construction cost between green, BREEAM-certified buildings, and conventional, non-certified buildings. 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, and holds for the costs of new construction projects as well as for the costs of refurbishment of existing buildings.

However, there is significant heterogeneity in the estimated results. We document higher costs for more efficient, green buildings in some elements of construction. Univariate statistics point to higher design fees, and more costly building systems (services), building envelop (superstructure), and fittings. After controlling for building and contract characteristics, only design fees appear to be significantly correlated with the degree of a building's sustainability: green building design costs are over 65 percent higher than the costs of conventional building design. Design fees represent on average just three percent of the total construction costs, so the impact on overall costs is quite limited. We argue that these costs may nonetheless play a disproportional role in the decision-making process of developers, since they are largely paid up-front and financed from developer's equity.

Even though the average marginal costs of green construction are not significantly different from zero, we document a relationship between the level of environmental certification in new construction projects and the construction costs. The highest rated green buildings - those labeled BREEAM Excellent and Outstanding - are more costly to construct than non-certified projects, after controlling for a large set of building quality characteristics. This difference seems to be driven primarily by design fees and service costs. Employing a model with the most extensive set of control variables, we find that design fees for BREEAM Outstanding buildings are almost double the design fees for non-certified buildings, while service costs are 46 percent higher. Design fees for BREEAM Very Good and Excellent buildings are also significantly higher.

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 assess the duration of construction projects in our sample, and document 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 30 percent longer to complete as compared to conventional buildings, and construction time is much less predictable than it is for conventional buildings, which implies a substantial source of additional risk for the developer.

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. Contrasting the significant rent and value premiums documented in the literature (Eichholtz, Kok and Quigley, 2010; Fuerst and McAllister, 2011; Eichholtz, Kok and Quigley, 2013; Chegut, Eichholtz and

Kok, 2014), the main findings show that the marginal cost of more efficient, green construction is limited. However, the results also provide an indication as to why the diffusion of green technology is not more common in the building stock.

The results provide evidence of sizeable and significant cost premiums in design fees and a significantly longer duration of building projects that incorporate green features and technologies. Design fees are largely paid before construction is 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 that a developer has to pay for the option to develop a building. The fact that the results show design fees that are almost double for the most advanced green buildings reduces the likelihood that developers engage in the option to develop such projects. Moreover, the longer project lengths and higher variation in development duration for more efficient green buildings increase the uncertainty of total project costs and in turn of the developer's expected return on equity.

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

I. Innovation, Green Buildings, and Costs

A. *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, standards are set as organizations or ”committees” propose a mechanism towards a process of standardization (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 or other forms of physical capital, building construction also 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 (BIM), 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, Nobe and Dunbar, 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.

B. 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.[3]

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.

C. 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 (Chegut, Eichholtz and Kok, 2014).[4] 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 CO2 Emissions" to "Building Use Guides and Green Leases" and "Innovation." Importantly, buildings assessed by BREEAM are provided with

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

[4] 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.

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 just 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, fittings and finishes. 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.

II. Construction Cost Data

A. 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.[5] We manually extract data from the BCIS database, check it 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 public certification database of BREEAM (Green Book Live), as well as those buildings flagged as BREEAM-certified by clients of the BCIS.[6] To eliminate erroneous labeling of buildings as BREEAM-certified, we conduct an extensive manual verification of all 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, and that it is not in the process of being certified.

To identify cost differences between green and conventional construction techniques, we create a matched sample on the basis of construction vintage and location of BREEAM-certified buildings. For each BREEAM-certified building in the sample, we identify a random sample of conventional construction projects that have the same vintage and are located in the same county as a BREEAM-certified building. We select control projects in the same county, at least one of which was also constructed in the same year. This matching procedure results in a dataset of 487 construction projects, of which 181 are BREEAM-certified and 306 are non-certified.[7] The final 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

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[5] 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. Subscribers to the database are also the providers of the basic information, providing data on realized construction cost as experienced in the marketplace. According to the BCIS website, the database includes construction projects from public and private developers. Public developers represent 58 and 52 percent of the BREEAM-certified and non-certified sample respectively, and this pattern is similar by year of construction.

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

[7] We dropped a total of 383 observations: 2 projects have invalid construction years; 106 projects have incomplete tender information; 178 non-certified observations were not in BREEAM-certified counties, implying that we could not use them for our matched control sample; 50 projects had incomplete elemental cost numbers; after these deletions only one observation had erroneous elemental cost data.

construction.

The soft elemental costs that go into the development of the building include design fees, preliminaries, external works, and contingencies. The hard elemental costs of construction are broken down into five categories: substructure, superstructure, finishes, services, and fittings.[8] Design fees are the costs for designing the structure and systems. Preliminaries are for contractual negotiations prior to construction. External works involve the development of land and roads, and contingencies are for cost overruns. Substructure is construction below the lowest floor together with the foundation. 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 other variables used in the analysis, while Appendix Table A2 provides basic summary statistics for those variables, distinguishing more efficient, green-certified buildings from their conventional counterparts.

B. *Univariate Analysis*

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. Figure 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 grey 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 total cost per square meter for the complete sample period, as well as for each cost element and for each individual year.

The upper bar in Panel 1a shows a clear difference in average total costs

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[8] Some buildings, like refurbishments or renovations, do not face cost for the substructure. Within the analysis, these observations are controlled for and instead of log zero, a log of one is put into place.

per square meter between BREEAM-certified and non-certified construction projects. The mean difference is £171 per square meter, but it is statistically insignificant.

The most important components contributing to overall construction costs are the superstructure and services costs. Superstructure and services together account for 52 and 49 percent of construction costs per square meter for BREEAM-certified and non-certified projects, respectively. External works and preliminaries also represent a considerable proportion of total costs, while finishes, fittings, contingencies and design fees make a far smaller contribution to total construction costs per square meter. Design fees are on average three percent for BREEAM-certified and only half a percent for non-certified projects.

The superstructure, fittings, services and design fees are significantly more expensive for more efficient, green construction projects, not controlling for building characteristics and aspects of the construction process. Relative to the cost of non-certified construction, BREEAM-certified design fees are larger by £45 per square meter. Given that design fees for non-certified buildings average £13 per square meter, this is a sizeable difference.

Figure 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 2008, 2009 and 2011 are on average more costly than conventional buildings constructed in these years. In 2004, by contrast, they were significantly less costly, while other years show no significant difference. From these univariate statistics, it is difficult to discern any systematic pattern in overall cost differences.

- Insert Figure 1 about here -

Figure 2 provides insight into the relative importance of each of the cost elements over time. Panel 2a depicts that the extent to which BREEAM-certified buildings cost more (less) than their conventional counterparts appears to differ quite substantially across cost elements and years. The cost of external works, for example, tends to be lower for BREEAM-certified buildings, while services, superstructure costs and design fees are almost always higher for these buildings. Especially in the case of design fees, the differences are relatively large, and statistically significant for most years in the sample period. However, the difference in design fees between BREEAM-certified buildings and non-certified buildings decreases and almost disappears in the last years of 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 do not have data regarding the cost of debt and equity capital employed by the developers in the projects we study. However, we do know project duration. We use project time as a proxy for the total capital costs 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 Figure 2 Panel 2b, 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 almost all years in the sample period. This may reflect the increased complexity of green building development, and it suggests that 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 take longer to complete, the increased project length may also be due to project size.

- Insert Figure 2 about here -

III. 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 II, 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.

Second, we employ a propensity score weighting of the control sample on the basis of observable characteristics, such as the number of stories, the size of the building and number of tenders. Conditional upon 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. Using the buildings with a common propensity for undergoing the certification treatment, we apply the resulting propensity score as a weight in the regression of Equation (1). This approach minimizes potential bias between the BREEAM-certified and non-certified sample (Rosenbaum and Rubin, 1983; Black and Smith, 2004).[9] Figure A1 in the Appendix displays the distribution of propensity score weights for the complete sample and the two subsamples, showing that there are indeed BREEAM-certified and non-certified construction projects with similar weights.

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

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[9] See for applications of the propensity score in commercial real estate Eichholtz, Kok and Quigley (2013); and Chegut, Eichholtz and Kok (2014).

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 costs.

Empirically, we operationalize our estimation strategy using a multivariate cost regression model:[10]

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

where C_i is construction cost or construction cost element per square meter for building i and α is a constant.[11] 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 dummy 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 in the construction process and represents a vector of control variables. It includes the building's characteristics, client characteristics, 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.

Our estimation procedure for Equation (1) employs OLS corrected for heteroskedasticity, with propensity score weighting to minimize observable differ-

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

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

ences between the BREEAM-certified and non-certified buildings in the estimation. 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 may bundle in potentially costly building attributes. In that case, we may overestimate 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 otherwise unrelated strategies or techniques that influence construction costs. One unique feature of the dataset is that it provides detailed information concerning the contract under which and 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″ consideration may affect construction costs.

IV. Results

A. Marginal Cost Analysis

Table 1 presents the regression results for Model (1), relating the logarithm of construction costs per gross square meter to the certification dummy and a set of building, client and contract characteristics with location and time-fixed effects. Results are propensity-score-weighted. The model explains up to 39 percent of the variation in the log construction cost per gross square meter.

Column (1) reports the results for the most parsimonious model, in which we include the certification dummy, location and construction year fixed effects. The results of this simple analysis suggest that BREEAM-certified buildings are not more costly to construct: we document a coefficient of 0.072, but it is statistically insignificant.

In Column (2), we add 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 the size and stories, are statistically significant in explaining construction costs. Doubling project size decreases costs per square meter by almost 17 percent. Relative to building out an extension, refurbishments reduce construction costs per square meter by 72 percent and new construction by 22 percent. Importantly, the green certification coefficient is hardly affected by this model extension, and it remains statistically insignificant.

In Column (3), we add further controls for building characteristics, such as primary materials. First, and most essential for this paper, this does not markedly affect the BREEAM certification coefficient, and its standard error. Second, relative to steel construction materials, concrete construction materials are 23 percent more costly, and other varied construction materials cost 25 percent less.

Column (4) provides results for the full model, which includes building use, client and contract characteristics. Adding additional covariates to the model does not notably reduce the coefficient of the BREEAM certification dummy, and it continues to be statistically insignificant. The regression results for the control variables show that relative to administrative building functions, university buildings are 32 percent more expensive. This is likely due to the extensive finishes and necessary attention to detail for educational structures. 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 have construction costs that are 48 percent higher than fixed costs contracts.

Incorporating green technology may be cost-effective when starting with a blank slate in new construction, but to do the same in the existing building stock, with its built-in legacy technology, is likely to be more expensive. To investigate this further, we include the interaction between green certification and the ″build-out″ dummy in the model. Results are presented in Column (5) of Table 1. The interaction terms with the dummies for new construction and refurbishment do not differ significantly from zero. Furthermore, when we test for the difference between the interaction term for green new construction and green refurbishment, we find a t-statistic of 0.19. F-tests of the specifications in Columns (4) and (5) show that the build-out interaction terms do not significantly improve the model's ability to explain variation in construction costs. This implies that the construction of more efficient, green buildings is not significantly more expensive than conventional construction, no matter whether it involves new buildings or the refurbishment of existing stock.

- Insert Table 1 about here -

B. Heterogeneous Effects

The key result reported in Table 1 is a statistically insignificant marginal cost for green construction projects. Of course, statistically insignificant results lead to the question whether the marginal effect is really nonexistent, whether the test does not have sufficient statistical power to detect an effect, or whether the average coefficient masks underlying heterogeneity in the effect. In parallel, our findings raise an important question regarding the prevalence of green construction. Buildings certified as green have been documented to command economically significant premiums in rents and sales prices (Eichholtz, Kok and Quigley, 2010; Fuerst and McAllister, 2011; Eichholtz, Kok and Quigley, 2013; Chegut, Eichholtz and Kok, 2014). Combined with our finding of a zero marginal cost premium, it seems that property developers forego an obvious profit opportunity. The question arises what explains this seeming market inefficiency, and we further analyze the marginal cost of green construction in three different ways.

First, we analyze the different elements of the total construction costs, focusing on the components for which we documented significant differences in the univariate analysis.[12] Table 2 presents the cross-sectional regression results for these elemental costs - design fees, services, superstructure, and fittings - over the 2003

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[12] We also analyze the other cost elements, but did not find any statistically significant results. These regression results are available upon request.

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 and changes in building codes and regulation. The model explains up to 50 percent of the variation in the logarithm of elemental costs per gross square meter. The control variables provide an interesting insight into the cost effects of scale. Overall costs are negatively related to building size, but design fees are not: larger buildings cost more to design per square meter than small buildings.

Of the four cost elements addressed in the analysis, only design fees are significantly associated with green building techniques. This association is economically quite large: it costs 65.4 percent per gross square meter more to design a green building than an otherwise comparable conventional building. For the three other cost elements, the effect is insignificant.

As shown in Appendix Table A2 and Figure 1, design fees represent a very small part of overall construction costs. However, design fees are likely to influence the decision making of developers in a way that is disproportional to their absolute level: such 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 to 40 percent of the overall design fee is needed to get planning permission, 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, Schwartz and Salinas (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. Therefore, the 65 percent higher design fees for green construction documented in Table 2 may partially explain why green construction is still a relatively rare occurrence, even in the existence of an output premium and an insignificantly higher cost.

- Insert Table 2 about here -

Second, we address the heterogeneity in the degree of ”greenness” and its effect on the marginal costs of green construction. Table 3 reports the regression coefficients for the BREEAM-certified projects by quality rating. For reasons of brevity, we do not explicitly report the regression results for the control variables, since they do not differ markedly from the control variables reported in Table 1. Column (1) shows results for the model that includes just the dummies for certification level and the time and location-fixed effects. In this specification, we document that buildings with the ”Outstanding” mark cost about 26 percent more per gross square meter as compared to conventional buildings. However, the results show that Pass, Good, Very Good, and Excellent buildings are not more costly to construct as compared to their non-certified peers. In Column (2), control variables for building quality and the extent of build-out are added to the model. In this specification, the regression results suggests that buildings labeled as Outstanding are 35.3 percent more expensive, whereas buildings labeled as Excellent are 17.3 percent more costly as compared to non-certified buildings. In Column (3) primary materials, building use and client are added to the model. This reduces the coefficient for Outstanding buildings to 28.8 percent, while Excellent buildings remain 15.2 percent more expensive. Finally, in Column (4) contract characteristics for competition and project delivery are added. This further reduces the certification coefficients, leaving no statistically significant effects.

- Insert Table 3 about here -

To further analyze the effect of increasing degrees of greenness on construction costs, we include the logarithm of the elemental costs per square meter as the dependent variable in the regression. Table 4 reports the coefficients for the BREEAM-certified projects by quality rating, using the full set of control variables, and focusing only on the cost elements that we found to be significant in the univariate analysis.[13] The table does not provide regression results for the individual control variables – these are comparable to those reported in Table 2.

The table shows a notable increase in design fees for increasing levels of environmental performance. The construction costs of buildings marked as Outstanding are a remarkable 187 percent higher than those of non-certified projects; Excellent projects cost 77 percent more; and Very Good projects are 51 percent more expensive. Construction projects marked as Outstanding are also documented to have higher Services costs, which suggests more attention to facilities and systems in the structure. Marginal superstructure and fittings costs are insignificant for any level of certification. So, for a developer constructing environmentally Excellent or Outstanding buildings, the costs are indeed higher as compared to constructing a non-certified building or a building that is merely rated as Pass or Good.

- Insert Table 4 about here -

Third, we address the time variation in construction costs, and whether the cost dynamics of green and conventional construction are different. We estimate

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[13] As before, we also analyzed the other cost elements, but did not find a significant association between varying degrees of greenness and construction cost levels. Results are available upon request.

two construction cost indices: one for BREEAM-certified buildings and one for conventional buildings. The aggregate BREEAM-certified and non-certified parameter estimates from Equation (1) are re-estimated by interacting $Z_i \cdot T_t$, which can be transformed into an ex-post construction cost index representing the development of green and conventional construction costs. Figure 3 shows the construction cost indices for the BREEAM-certified and non-certified samples over the 2004 to 2013 period, adjusted for general price inflation. The left axis depicts real index values, with 2004 as the base year.

Figure 3 shows two important trends. First, there seems to be no systematic difference between the two indices, confirming our previous findings that the average costs per square meter of sustainable and conventional construction do not significantly differ from each other. Second, building codes in the UK first implemented energy efficiency requirements in 2006, and the graph suggests that this has not led to an increase in construction costs. In real terms, building costs per square meter are about as high in 2013 as they were in 2004.[14]

- Insert Figure 3 here -

C. Development Duration

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 wait until a project's cash flow turns positive. And if the duration of a project is harder to predict, this adds additional uncertainty to the project. We therefore investigate the role of green construction in determining building project duration.

Table 5 provides regression results. The model we use is similar to in Equation (1), but we employ the logarithm of project duration as the dependent variable. Column (1) shows results for project length and BREEAM certification. The reported certification coefficient implies that green-certified buildings take about

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[14] Of course, a simple event study would further address this issue more thoroughly, but that would require a longer time series to measure construction costs before and after the implementation of this building code change.

30 percent longer to complete, after controlling for factors like project size, build-out extent and building use, which also significantly affect project duration.

We then study the predictability of project duration, which we estimate by calculating the residuals from the project length regression, using the squared residuals as the dependent variable in the regression model. The results are reported in Column (2). The positive and significant regression coefficients show that the time it takes to complete a BREEAM-certified building is significantly less predictable than the time needed for the construction of a conventional building, after controlling for other factors likely to increase project complexity.

In Columns (3) and (4), we report the results of similar analyses, but instead of using certification as the independent covariate, we study the effect of different levels of BREEAM certification on project duration and variation. The documented results provide evidence that buildings designated as Very Good and Excellent take longer to complete, and that Excellent buildings are associated with lower predictability of project duration length. Results for buildings labeled as Outstanding are inconclusive.

Summarizing, developers have to wait longer for the cash flows resulting from green building construction, and are less certain about the exact timing of such cash flows. This outcome adds to the capital costs involved in the development of green projects (on top of the higher up-front design fees), and creates a disincentive to start such construction projects. So, 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.

- Insert Table 5 about here -

V. 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 labels, 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 more efficient, green construction. This is contrasting the literature on the marginal financial implications of green building, which documents significant rent and value premiums associated with green building construction and redevelopment (Eichholtz, Kok and Quigley, 2013; Eichholtz et al., 2015).

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 switching to more efficient, green construction is 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 181 green buildings and 306 matched conventional buildings. The main findings show no significant marginal cost for more efficient, green construction and refurbishment practices. However, we document some evidence on an economically and statistically significant difference between buildings having the highest environmental ratings – BREEAM Excellent and Outstanding – and conventional construction projects.

In addition, we document an economically and statistically significant premium in the design costs for green buildings, which is robust to different model specifications. Overall, environmentally certified buildings have 65 percent higher design costs as compared to conventional buildings. BREEAM Excellent and Outstanding buildings are, on average, 77 and 187 percent more expensive to design as compared to 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 these fees represent a considerable risk to developers. Although design fees represent 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 typically tend to have rather small balance sheets relative to the size of their activities, so even the relatively limited capital outlay that these higher design fees represent a notable financial risk. This may partially explain why green construction and refurbishment practices are not prevalent, even though overall marginal costs are zero and green buildings command a price premium in the market, suggesting a market inefficiency.

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 30 percent longer to complete, after controlling for building size and other factors influencing construction project duration. The development time for green buildings is also less predictable. These findings imply that developers have to wait longer to recoup their initial investment, adding significantly to the risk exposure of developers engaging in environmentally certified building projects.

Our findings have some important practical and policy implications. 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 of market frictions that may explain the limited uptake of more efficient building practices. Relatively high design fees are one factor influencing more efficient, green construction and refurbishment projects, while the duration of such construction projects represents another factor influencing the diffusion of technologically advanced construction practices. However, our results also show that the share of design fees is relatively small within construction budgets, and that marginal design fees have decreased in recent years. Considering the lifecycle of a building and the total development costs, the marginal cost of enabling more efficient, green building practices seems quite limited. However, it is important to consider that the initial decision maker and investor – the developer – faces the greatest uncertainty in the returns to its product. More attention should therefore be paid to identifying commercially scalable green building services, solutions, and technologies. This trend may already be under way, as design fees for green construction projects are decreasing in recent years, perhaps reflecting increased architectural experience in designing more efficient, green buildings. Such lower fees reduce the upfront risk for developers, and are likely to stimulate future growth of the market for more energy efficient, green buildings.

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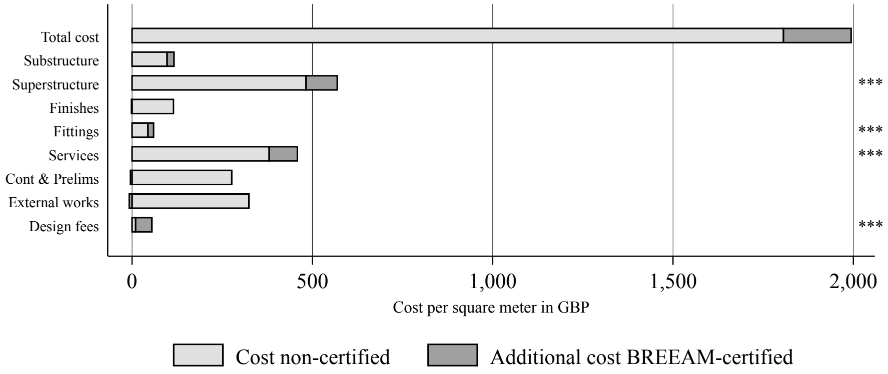
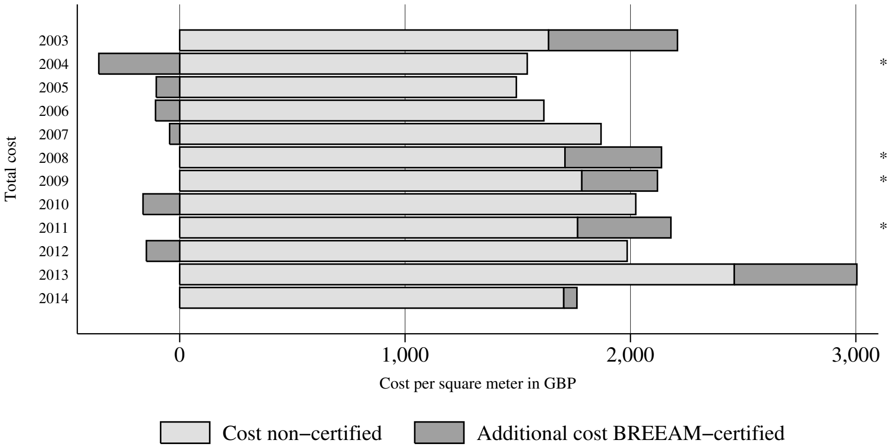
Figure 1. Mean Total Construction Costs by Element and Time

(a) Mean Construction Costs by Element



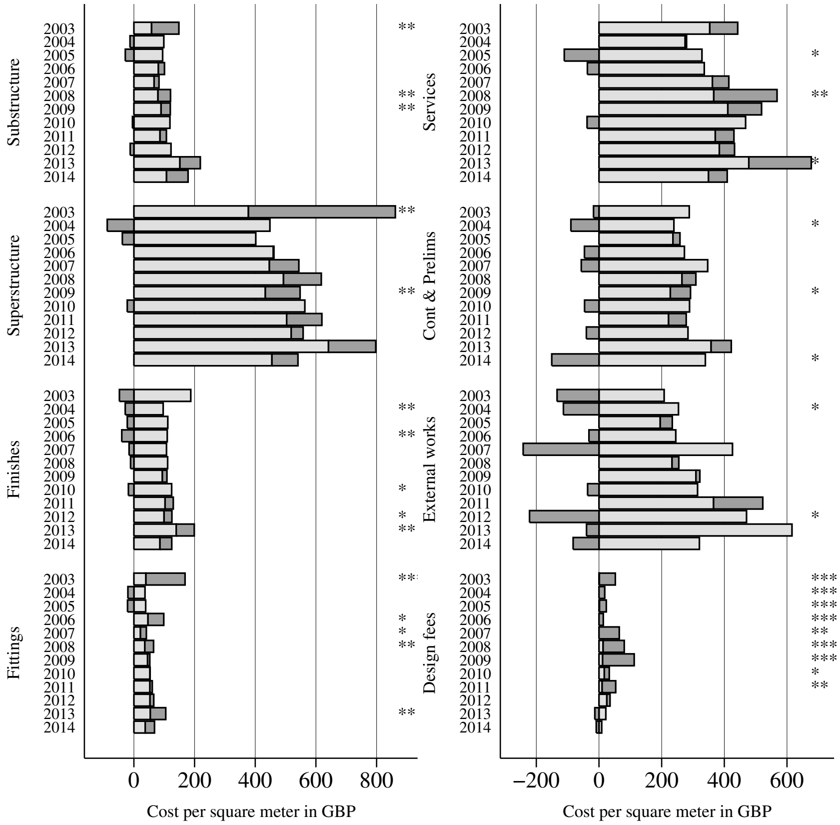
(b) Mean Construction Costs by Year



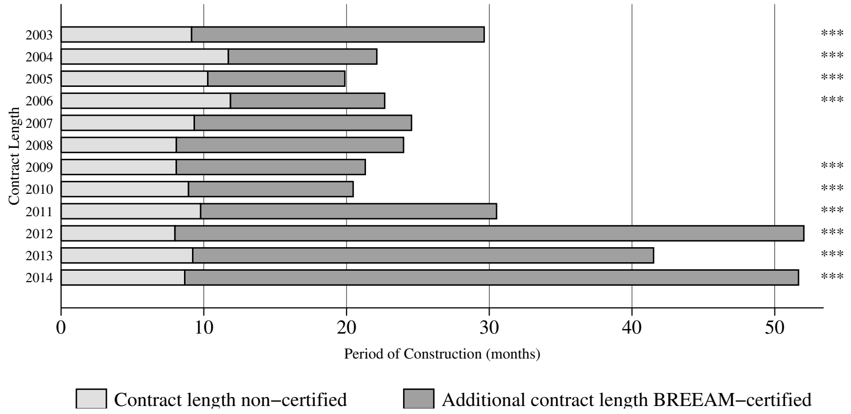
Notes: Figure 1 reports the total mean construction and elemental costs per gross square meter for the BREEAM-certified and non-certified samples over the 2003 to 2014 (Q2) period. The light gray bars depict the non-certified samples' mean costs and the dark grey bars depict the BREEAM-certified samples'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

Figure 2. Mean Construction Costs by Element and Time

(a) Elemental Costs by Year

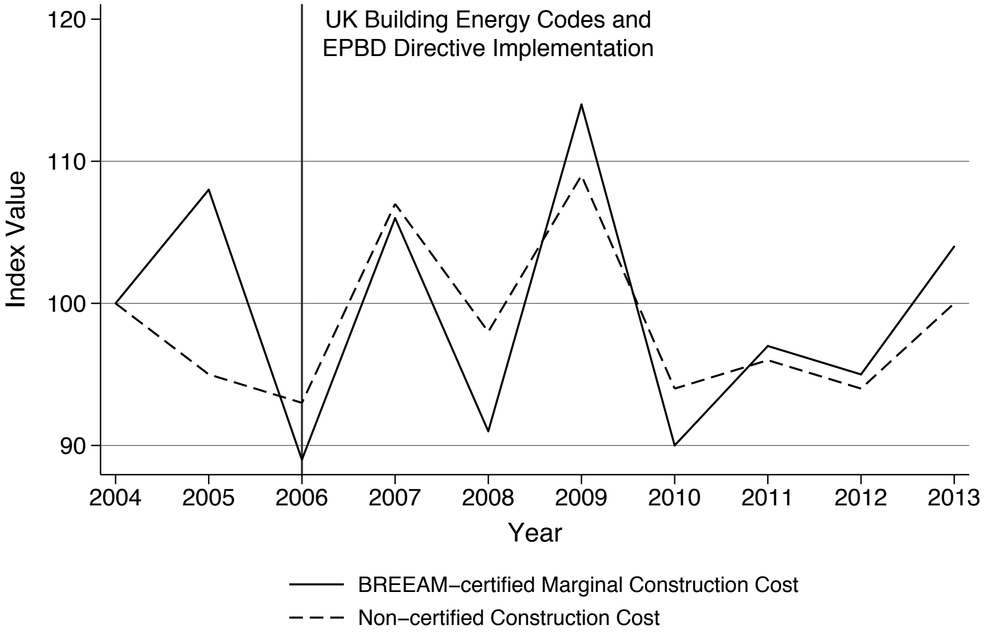


(b) Contract Length by Year



Notes: Figure 2 Panel 2a reports the elemental costs per gross square meter for the BREEAM-certified and non-certified samples over the 2003 to 2014 (Q2) period. Panel 2b depicts the average contract lengths of the two samples. The light gray bars depict the non-certified samples' mean costs (contract length) and the dark grey bars depict the BREEAM-certified samples' additional mean costs (contract length). Statistical significance at the 1, 5 and 10 percent levels denoted by *, **, ***, respectively.

Figure 3. Green Construction Cost Index



Notes: Figure 3 displays the BREEAM-certified and non-certified samples' construction cost indices over the 2004 to 2013 period. Index values are deflated by the UK Consumer Price Index. Year 2004 is the index base period.

Table 1 — Construction Costs for BREEAM-certified & Non-certified Buildings
(Dependent Variable: Logarithm of Construction Cost per Gross Square Meter)

	(1)	(2)	(3)	(4)	(5)
Certification					
BREEAM-certified	0.072	0.098	0.080	0.057	0.136
	[0.068]	[0.070]	[0.073]	[0.075]	[0.158]
Building size					
Log size		-0.174***	-0.187***	-0.192***	-0.193***
		[0.030]	[0.033]	[0.037]	[0.038]
Stories		0.038*	0.034*	0.036*	0.038*
		[0.019]	[0.020]	[0.020]	[0.021]
Build-out extent					
New construction		-0.227**	-0.238**	-0.191*	-0.175
		[0.109]	[0.107]	[0.107]	[0.134]
Refurbishment		-0.724***	-0.625***	-0.528***	-0.495***
		[0.119]	[0.129]	[0.122]	[0.155]
Certified*New construction					-0.066
					[0.166]
Certified*Refurbishment					-0.137
					[0.287]
Primary materials					
Brick			-0.107	-0.115*	-0.118*
			[0.073]	[0.069]	[0.069]
Concrete			0.230*	0.209*	0.206*
			[0.133]	[0.115]	[0.116]
Timber			-0.142	-0.234*	-0.234
			[0.131]	[0.141]	[0.143]
Other			-0.253**	-0.228*	-0.227*
			[0.126]	[0.120]	[0.119]
Unknown			-0.210	-0.414**	-0.428**
			[0.158]	[0.171]	[0.178]
Building use					
Industrial				-0.156	-0.155
				[0.235]	[0.237]
Office				-0.094	-0.095
				[0.151]	[0.151]
Other				0.036	0.036
				[0.180]	[0.181]
Residential				0.086	0.087
				[0.181]	[0.181]
Retail				-0.195	-0.194
				[0.193]	[0.193]
School				0.200	0.199
				[0.141]	[0.142]
University				0.327**	0.330**
				[0.147]	[0.146]
Client					
Private				-0.215*	-0.209
				[0.129]	[0.128]
Public				-0.136	-0.132
				[0.135]	[0.136]
Contract competition					
Number of tenders				0.031	0.032
				[0.043]	[0.044]

Continued on next page ...

Table 1 —- (Continued from previous page)

	(1)	(2)	(3)	(4)	(5)
Number of tenders[2]				-0.004	-0.004
				[0.006]	[0.006]
Tender process					
Competitive				0.052	0.054
				[0.253]	[0.254]
Design and build				-0.095	-0.091
				[0.240]	[0.241]
Negotiated				0.220	0.227
				[0.257]	[0.258]
Open competition				0.095	0.101
				[0.273]	[0.272]
Selected competition				-0.091	-0.088
				[0.241]	[0.240]
Two stage tendering				0.149	0.156
				[0.264]	[0.264]
Other				0.160	0.170
				[0.278]	[0.279]
Unknown				-0.073	-0.078
				[0.253]	[0.253]
Contractual cost sharing					
Fluctuating costs				0.251	0.248
				[0.199]	[0.198]
Pain gain cost share				0.484***	0.471**
				[0.183]	[0.188]
Firm costs				0.099	0.101
				[0.061]	[0.061]
Year fixed effects	Yes	Yes	Yes	Yes	Yes
County fixed effects	Yes	Yes	Yes	Yes	Yes
Constant	7.725***	8.835***	8.969***	9.036***	9.323***
	[0.196]	[0.222]	[0.234]	[0.384]	[0.496]
Observations	487	487	487	487	487
Adj R2	0.082	0.26	0.28	0.39	0.38

Notes: Table 1 reports the results of Equation (1) via 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.

Table 2 — Elemental Costs for BREEAM-certified & Non-certified Buildings (Dependent Variable: Logarithm of Elemental Cost per Gross Square Meter)

	(Design fees)	(Services)	(Superstructure)	(Fittings)
Certification				
BREEAM-certified	0.654***	0.098	-0.030	0.189
	[0.170]	[0.110]	[0.090]	[0.170]
Building size				
Log size	0.091	-0.176***	-0.126**	-0.058
	[0.070]	[0.054]	[0.052]	[0.079]
Stories	-0.079**	0.063**	0.064**	0.118***
	[0.036]	[0.031]	[0.025]	[0.042]
Build-out extent				
New construction	-0.482	-0.186	0.051	-0.114
	[0.380]	[0.131]	[0.126]	[0.354]
Refurbishment	-0.322	-0.305*	-0.435***	-0.125
	[0.402]	[0.160]	[0.161]	[0.374]
Primary materials				
Brick	-0.394**	0.001	-0.354***	-0.037
	[0.187]	[0.121]	[0.130]	[0.187]
Concrete	0.393	0.242	0.135	0.376
	[0.333]	[0.179]	[0.124]	[0.296]
Timber	-0.198	-0.181	-0.151	-0.053
	[0.382]	[0.149]	[0.223]	[0.327]
Other	-0.602***	0.078	-0.621***	0.366
	[0.193]	[0.151]	[0.175]	[0.252]
Unknown	-0.178	0.061	-0.842***	-0.310
	[0.427]	[0.253]	[0.275]	[0.481]
Building use				
Industrial	0.014	-0.245	-0.448*	-1.323**
	[0.544]	[0.331]	[0.246]	[0.571]
Office	-0.012	-0.218	-0.280*	-0.639**
	[0.247]	[0.222]	[0.150]	[0.314]
Other	0.089	0.301	-0.209	0.454
	[0.377]	[0.269]	[0.205]	[0.422]
Residential	1.290***	-0.199	0.126	0.400
	[0.403]	[0.266]	[0.219]	[0.420]
Retail	0.766**	-2.091***	-0.234	-1.277***
	[0.373]	[0.478]	[0.260]	[0.456]
School	0.046	0.081	-0.021	0.318
	[0.243]	[0.171]	[0.151]	[0.270]
University	0.234	0.303	0.113	0.110
	[0.314]	[0.204]	[0.165]	[0.322]
Client				
Private	0.269	0.028	-0.237	0.478
	[0.308]	[0.194]	[0.189]	[0.327]
Public	0.431	0.086	-0.104	0.640**
	[0.317]	[0.182]	[0.200]	[0.320]
Contract competition				
Number of tenders	0.155	0.061	0.068	-0.035
	[0.111]	[0.064]	[0.054]	[0.102]
Number of tenders^2	-0.026	-0.010	-0.008	0.011
	[0.017]	[0.009]	[0.008]	[0.015]
Tender process				

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Table 2 —- (Continued from previous page)

	(Design fees)	(Services)	(Superstructure)	(Fittings)
Competitive	-0.659	0.049	0.585	0.269
	[0.544]	[0.468]	[0.407]	[0.557]
Design and build	-0.309	0.070	0.376	0.068
	[0.497]	[0.454]	[0.368]	[0.520]
Negotiated	-0.081	0.271	0.562	0.227
	[0.550]	[0.451]	[0.408]	[0.593]
Open competition	-1.328**	0.252	0.500	-0.004
	[0.575]	[0.467]	[0.427]	[0.651]
Other	-0.578	0.146	0.393	0.763
	[0.534]	[0.489]	[0.445]	[0.609]
Selected competition	-1.231**	0.089	0.380	-0.031
	[0.487]	[0.439]	[0.385]	[0.514]
Two stage tendering	-1.021*	0.475	0.477	0.065
	[0.611]	[0.465]	[0.426]	[0.601]
Unknown	-0.528	0.019	0.315	0.002
	[0.697]	[0.464]	[0.434]	[0.636]
Contractual cost sharing				
Fluctuating costs	1.928***	0.316	0.191	0.577
	[0.530]	[0.283]	[0.325]	[0.636]
Pain gain cost share	2.317***	0.439	0.852***	0.038
	[0.617]	[0.323]	[0.319]	[0.560]
Firm costs	-0.229	0.134	0.076	0.131
	[0.147]	[0.104]	[0.076]	[0.157]
Year fixed effects	Yes	Yes	Yes	Yes
County fixed effects	Yes	Yes	Yes	Yes
Constant	0.711	6.724***	6.468***	3.574***
	[0.741]	[0.586]	[0.715]	[0.788]
Observations	487	487	487	487
Adj R2	0.50	0.38	0.31	0.24

Notes: Table 3 reports the results of Equation (1) via 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 3 — Construction Costs by BREEAM-quality & Non-certified Buildings (Dependent Variable: Logarithm of Construction Cost per Gross Square Meter)

	(1)	(2)	(3)	(4)
Certification				
Outstanding	0.258**	0.353**	0.288*	0.186
	[0.129]	[0.167]	[0.163]	[0.159]
Excellent	0.119	0.173**	0.152*	0.076
	[0.083]	[0.081]	[0.083]	[0.086]
Very good	0.033	0.041	0.036	0.062
	[0.089]	[0.093]	[0.095]	[0.092]
Good	0.211	0.123	0.065	0.106
	[0.182]	[0.146]	[0.161]	[0.147]
Pass	-0.072	0.004	-0.043	-0.091
	[0.165]	[0.162]	[0.151]	[0.139]
Building size		Yes	Yes	Yes
Build-out extent		Yes	Yes	Yes
Primary materials			Yes	Yes
Building use			Yes	Yes
Client			Yes	Yes
Contract competition				Yes
Tender process				Yes
Contractual cost sharing				Yes
Year fixed effects	Yes	Yes	Yes	Yes
County fixed effects	Yes	Yes	Yes	Yes
Constant	7.780***	8.934***	9.055***	9.061***
	[0.210]	[0.235]	[0.249]	[0.405]
Observations	487	487	487	487
Adj R2	0.077	0.26	0.28	0.38

Notes: Table 3 reports the results of equation (1) via OLS corrected for heteroskedasticity with robust standard errors (White, 1980). Statistical significance at the 1, 5 and 10 percent levels denoted by *, **, ***, respectively.

Table 4 — Elemental Costs by BREEAM-quality & Non-certified Buildings (Dependent Variable: Logarithm of Elemental Cost per Gross Square Meter)

	(Design fees)	(Services)	(Superstructure)	(Fittings)
Certification				
Outstanding	1.870***	0.461**	-0.075	-0.077
	[0.458]	[0.182]	[0.223]	[0.508]
Excellent	0.774***	0.142	-0.007	0.327
	[0.246]	[0.119]	[0.117]	[0.216]
Very good	0.515**	0.104	-0.014	0.134
	[0.200]	[0.150]	[0.107]	[0.206]
Good	0.386	0.130	0.067	0.325
	[0.587]	[0.381]	[0.218]	[0.818]
Pass	0.748	-0.197	-0.230	-0.029
	[0.618]	[0.171]	[0.254]	[0.423]
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	1.074	6.795***	6.465***	3.685***
	[0.757]	[0.618]	[0.736]	[0.826]
Observations	487	487	487	487
Adj R2	0.50	0.38	0.31	0.23

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

Table 5 — Contract Length by BREEAM-quality & Non-certified Buildings (Dependent Variable: Logarithm of Contract Length and Residuals^2)

	(Contract Length)	(Residuals^2)	(Contract Length)	(Residuals^2)
Certification				
BREEAM-certified	0.294***	0.088**		
	[0.073]	[0.036]		
Outstanding			0.046	0.018
			[0.191]	[0.072]
Excellent			0.333***	0.140***
			[0.109]	[0.053]
Very good			0.386***	0.044
			[0.079]	[0.042]
Good			0.159	0.080
			[0.196]	[0.089]
Pass			-0.155	0.016
			[0.140]	[0.088]
Building size				
Log size	0.215***	-0.033	0.203***	-0.029
	[0.034]	[0.022]	[0.033]	[0.022]
Stories	-0.003	-0.010	0.002	-0.010
	[0.019]	[0.010]	[0.016]	[0.009]
Build-out extent				
New construction	0.269*	0.225***	0.273**	0.212***
	[0.139]	[0.062]	[0.136]	[0.060]
Refurbishment	0.107	0.323***	0.151	0.307***
	[0.158]	[0.081]	[0.156]	[0.080]
Primary materials				
Brick	0.085	0.098*	0.070	0.097*
	[0.086]	[0.059]	[0.086]	[0.058]
Concrete	0.065	0.095	0.046	0.092
	[0.112]	[0.060]	[0.113]	[0.059]
Timber	0.025	0.114	0.045	0.086
	[0.175]	[0.106]	[0.167]	[0.108]
Other	-0.181*	0.027	-0.213**	0.029
	[0.097]	[0.050]	[0.096]	[0.049]
Unknown	-0.322*	-0.122	-0.368*	-0.104
	[0.195]	[0.102]	[0.197]	[0.098]
Building use				
Industrial	0.031	0.116	0.018	0.089
	[0.263]	[0.116]	[0.260]	[0.111]
Office	-0.111	-0.014	-0.122	-0.030
	[0.101]	[0.065]	[0.102]	[0.063]
Residential	0.393**	-0.023	0.383**	-0.018
	[0.183]	[0.122]	[0.182]	[0.116]
Retail	-0.218	0.227	-0.241	0.221
	[0.234]	[0.217]	[0.236]	[0.214]
School	0.234**	0.033	0.229**	0.023
	[0.091]	[0.059]	[0.090]	[0.057]
University	0.183	-0.017	0.182	-0.028
	[0.112]	[0.075]	[0.116]	[0.074]
Other	-0.033	0.078	-0.036	0.069
	[0.196]	[0.100]	[0.195]	[0.099]
Client				
Private	-0.269*	-0.077	-0.242	-0.079

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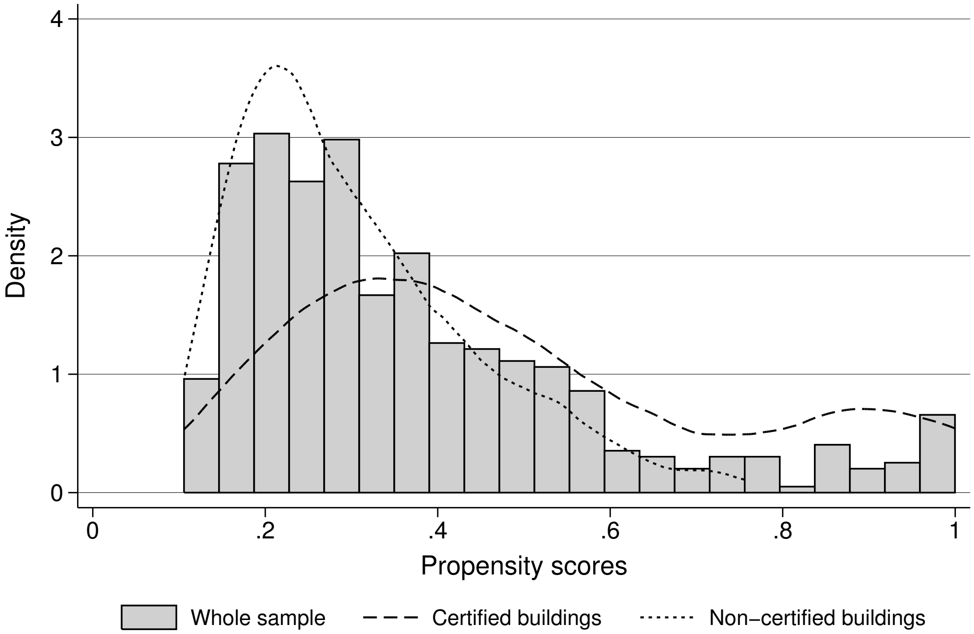
Table 5 —- : (Continued from previous page)

	(Contract Length)	(Residuals^2)	(Contract Length)	(Residuals^2)
	[0.157]	[0.076]	[0.154]	[0.076]
Public	-0.319**	-0.026	-0.298*	-0.033
	[0.161]	[0.079]	[0.158]	[0.078]
Contract competition				
Number of tenders	-0.019	0.010	-0.006	0.009
	[0.042]	[0.028]	[0.042]	[0.027]
Number of tenders^2	0.003	-0.003	0.001	-0.003
	[0.006]	[0.004]	[0.006]	[0.004]
Tender process				
Competitive	0.361	0.162	0.365	0.143
	[0.248]	[0.139]	[0.246]	[0.135]
Design and build	0.272	0.037	0.302	0.033
	[0.208]	[0.123]	[0.204]	[0.119]
Negotiated	0.284	-0.094	0.357	-0.069
	[0.219]	[0.125]	[0.219]	[0.122]
Open competition	0.579**	-0.006	0.587**	-0.003
	[0.260]	[0.152]	[0.259]	[0.143]
Selected competition	0.322	0.000	0.332	0.005
	[0.209]	[0.121]	[0.205]	[0.117]
Two stage tendering	0.222	0.004	0.228	0.013
	[0.241]	[0.140]	[0.239]	[0.136]
Other	0.338	-0.048	0.356*	-0.050
	[0.213]	[0.116]	[0.210]	[0.112]
Unknown	0.198	0.234	0.182	0.234
	[0.353]	[0.218]	[0.347]	[0.218]
Contractual cost sharing				
Fluctuating costs	-0.239	-0.127	-0.223	-0.121
	[0.241]	[0.130]	[0.245]	[0.127]
Pain gain cost share	0.100	0.030	0.021	-0.005
	[0.259]	[0.146]	[0.269]	[0.146]
Firm costs	0.025	-0.024	0.036	-0.019
	[0.062]	[0.048]	[0.061]	[0.047]
Year fixed effects	Yes	Yes	Yes	Yes
County fixed effects	Yes	Yes	Yes	Yes
Constant	0.394	-0.171	0.449	-0.119
	[0.529]	[0.267]	[0.523]	[0.258]
Observations	469	469	469	469
Adj R2	0.48	0.12	0.49	0.11

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

APPENDIX A

Figure A1. Propensity Score Distribution and Area of Common Support



Notes: Figure A1 displays the distribution of propensity score weights for the whole sample, BREEAM-certified and non-certified samples. The region of common support is [.00, .80], which is distributed amongst 5 blocks. The mean weight is 37 percent and the standard deviation is 20 percent. The propensity score density is positively skewed, with a measure of 1.59. In addition, the dashed and the dotted lines indicate the area of common support for the samples. The overlap indicates that there are BREEAM-certified and non-certified construction projects with similar weights. Economically, this suggests that both forms of construction do have areas of commonality, but distinct differences remain at the margins.

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.
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.
Finishes cost	Preparatory work and finishes to surfaces of walls and other vertical surfaces internally.
Fittings cost	Fittings, fixtures, furniture; works of art, and non-mechanical and electrical equipment. Note: Includes domestic kitchen equipment supplied with kitchen fittings.
Services cost	The installation and equipment for sanitary, mechanical, electrical, disposal, water, heat, air, ventilation, fuel, lift and conveyor, fire and lightening, communication, security and central systems.
Contingencies cost	Allowance for client's risks of unforeseen costs.
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.
External works cost	Covers the road works, ground and air related infrastructure of the building(s).
Design fees cost	Cost of design including consultant's fees and contractor's design fees.
Contract length (months)	Stipulated by client, offered by builder (if different), agreed.
Control variables	

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Table A1 (Continued from previous page)

Variable	**Description**
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.

Table A2 — Comparison of BREEAM-certified and Non-certified Samples

(a) BREEAM-certified sample (181 observations)

Variable	Mean	(Std. Dev.)	Min.	Max.
BREEAM rating				
Outstanding	0.02	(0.14)	0	1
Excellent	0.39	(0.49)	0	1
Very good	0.54	(0.50)	0	1
Good	0.02	(0.15)	0	1
Pass	0.02	(0.15)	0	1
Elemental costs (GBP/sqm ths.)				
Total building cost	8,797	(11,617)	228	69,674
Total building cost/sqm	2.06	(0.90)	0.10	5.54
Substructure cost/sqm	0.12	(0.08)	0	0.67
Superstructure cost/sqm	0.59	(0.29)	0.01	1.55
Finishes cost/sqm	0.12	(0.07)	0	0.55
Fittings cost/sqm	0.06	(0.06)	0	0.40
Services cost/sqm	0.47	(0.28)	0	2.63
Contingencies cost/sqm	0.05	(0.06)	0	0.31
Preliminaries cost/sqm	0.22	(0.13)	0.01	0.92
External works cost/sqm	0.32	(0.34)	0	2.40
Design fees cost/sqm	0.06	(0.10)	0	0.50
Contracting period				
Contract length (months)	24.58	(20.73)	0	102
Building size				
Gross internal floor area (sqm)	4,465	(5,071)	117	30,464
Stories	3.03	(2.54)	1	17
Build-out extent - by percent				
Extension	0.03	(0.17)	0	1
New construction	0.90	(0.30)	0	1
Refurbishment	0.07	(0.26)	0	1
Primary materials - by percent				
Brick	0.12	(0.33)	0	1
Concrete	0.13	(0.34)	0	1
Steel	0.66	(0.47)	0	1
Timber	0.05	(0.21)	0	1
Other	0.04	(0.20)	0	1
Building use - by percent				
Administration	0.13	(0.33)	0	1
Industrial	0.04	(0.19)	0	1
Office	0.19	(0.40)	0	1
Residential	0.06	(0.23)	0	1
Retail	0.03	(0.16)	0	1
School	0.32	(0.47)	0	1
University	0.11	(0.32)	0	1
Other types	0.13	(0.34)	0	1
Client - by percent				
Developer	0.06	(0.23)	0	1
Private	0.38	(0.49)	0	1
Public	0.56	(0.50)	0	1

(b) Non-certified sample (306 observations)

Variable	Mean	(Std. Dev.)	Min.	Max.
Elemental costs (GBP/sqm ths.)				
Total building cost	3,542	(4,302)	118	27,010
Total building cost/sqm	1.79	(0.99)	0.23	8.16
Substructure cost/sqm	0.09	(0.08)	0	0.55
Superstructure cost/sqm	0.49	(0.27)	0	1.79
Finishes cost/sqm	0.12	(0.12)	0	2.03
Fittings cost/sqm	0.04	(0.05)	0	0.32
Services cost/sqm	0.38	(0.25)	0	2.82
Contingencies cost/sqm	0.06	(0.08)	0	0.79
Preliminaries cost/sqm	0.21	(0.15)	0	1.54
External works cost/sqm	0.31	(0.40)	0	4.76
Design fees cost/sqm	0.01	(0.03)	0	0.22
Contracting period				
Contract length (months)	10.75	(4.97)	0	25
Building size				
Gross internal floor area (sqm)	2,307	(2,585)	45	14,100
Stories	2.42	(1.71)	1	12
Build-out extent - by percent				
Extension	0.04	(0.18)	0	1
New construction	0.65	(0.48)	0	1
Refurbishment	0.31	(0.46)	0	1
Primary materials - by percent				
Brick	0.19	(0.39)	0	1
Concrete	0.05	(0.21)	0	1
Steel	0.56	(0.50)	0	1
Timber	0.05	(0.22)	0	1
Other	0.15	(0.36)	0	1
Building use - by percent				
Administration	0.08	(0.27)	0	1
Industrial	0.02	(0.12)	0	1
Office	0.30	(0.46)	0	1
Residential	0.04	(0.19)	0	1
Retail	0.07	(0.25)	0	1
School	0.36	(0.48)	0	1
University	0.09	(0.29)	0	1
Other Types	0.04	(0.21)	0	1
Client - by percent				
Developer	0.06	(0.24)	0	1
Private	0.36	(0.48)	0	1
Public	0.58	(0.49)	0	1

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Table A2 — (Continued from previous page)

(c) BREEAM-certified sample (181 observations)

Variable	Mean	(Std. Dev.)	Min.	Max.
Contract competition				
Number of tenders (# of contracts)	2.28	(2.28)	0	8
Tender process - by percent				
Competitive	0.09	(0.28)	0	1
Design and build	0.29	(0.46)	0	1
Negotiated	0.11	(0.32)	0	1
Open competition	0.03	(0.16)	0	1
Selected competition	0.30	(0.46)	0	1
Traditional	0.01	(0.10)	0	1
Two stage tendering	0.08	(0.27)	0	1
Unknown	0.06	(0.23)	0	1
Other	0.04	(0.19)	0	1
Contractual cost sharing - by percent				
Fluctuating costs	0.00	(0.00)	0	0
Pain gain cost share	0.06	(0.24)	0	1
Firm costs	0.30	(0.46)	0	1
Fixed costs	0.64	(0.48)	0	1

(d) Non-certified sample (306 observations)

Variable	Mean	(Std. Dev.)	Min.	Max.
Contract competition				
Number of tenders (# of contracts)	2.97	(2.33)	0	8
Tender process - by percent				
Competitive	0.05	(0.22)	0	1
Design and build	0.21	(0.41)	0	1
Negotiated	0.06	(0.23)	0	1
Open competition	0.03	(0.17)	0	1
Selected competition	0.55	(0.50)	0	1
Traditional	0.03	(0.18)	0	1
Two stage tendering	0.02	(0.15)	0	1
Unknown	0.00	(0.00)	0	0
Other	0.05	(0.22)	0	1
Contractual cost sharing - by percent				
Fluctuating costs	0.01	(0.09)	0	1
Pain gain cost share	0.00	(0.06)	0	1
Firm costs	0.51	(0.50)	0	1
Fixed costs	0.48	(0.50)	0	1

Notes: Table A2 highlights the mean and variation of construction cost characteristics for the BREEAM-certified and non-certified samples over the 2003 to 2014 (Q2) period, by BREEAM status, elemental construction cost £ thousands, building, build-out, material, building type, client, contract, cost layout, cost sharing, tender process and contract type characteristics.