



Energy Performance Certificates and House Prices: a Quantile Regression approach

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Abstract

Purpose: A number of studies have investigated the relationship between energy performance certificates (EPCs) and house prices. The majority of studies have tended to model energy performance pricing effects within a traditional hedonic conditional mean estimate model. There has been limited analysis which has accounted for the relationship between EPCs and the effects across the pricing distribution. Moreover, there has been limited research examining the ‘standard cost improvements EPC score, or ‘potential score’. Therefore, this paper attempts to quantify and measure the dynamic effects of EPCs on house prices across the price spectrum and account for standardised cost-effective retrofit improvements.

Methodology: Existing EPC studies produce one coefficient for the entirety of the pricing distribution, culminating in a single marginal implicit price effect. The approach within this study applies a quantile regression approach in order to empirically estimate how quantiles of house prices respond differently to unitary changes in the proximal effects of EPCs and structural property characteristics across the conditional distribution of house prices. Using a dataset of 1,476 achieved transaction prices, the quantile regression models apply both assessed EPC score and bands and further examine the *potential* EPC rating for improved energy performance based on an average energy cost improvement.

Findings: The findings show that EPCs are valued differently across the quantiles and that conditional quantiles are asymmetrical. Only property prices in the upper quantiles of the price distribution show significant capitalisation effects with energy performance and only properties with higher EPC scores display positive significant effects at the higher end of the price distribution. There are also brown discount effects evident for lower rated properties within F and G rated EPC properties at the higher end of the pricing distribution. Moreover, the potential energy efficiency rating (score) also shows increased effects with sales prices and appears to minimise any brown discount effects. The findings imply that energy performance is a complex feature that is not easily ‘averaged’ for valuation effect purposes.

Originality: Whilst numerous studies have investigated the pricing effects of EPCs, they have tended to provide a single estimate to determine the relationship with price. This paper extends the traditional analytical insights beyond the conditional mean estimate by examining the quantiles of the relationship between EPCs and house prices to enhance the understanding of this esoteric and complex issue. In addition, this research applies the assessed energy efficiency potential to establish whether effective cost improvements enhance the relationship with sales price and capitalisation effects.

Key Words: Energy Performance Certificates, quantile regression, hedonic pricing model, house prices, energy efficiency.

Introduction

The housing sector constitutes approximately 75% of the 25 billion m² of total building stock within EU member states and is responsible for approximately 22% of total energy consumption (Gynther *et al.*, 2015; Loga *et al.*, 2016). The renovation and retrofit of dwellings to reduce the energy intensity of existing housing stock is a key strategy for EU

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3 member states (Ballarini *et al.*, 2014). Indeed, as much as 80% of existing housing stock within
4 Europe is expected to be renovated to achieve the 2°C target requested by the Paris Agreement
5 by 2050 over the course of the next two decades. The attainment of Paris Goals will require
6 product and process innovation as well as a pronounced upscaling in energy efficient
7 retrofitting. In the UK for example, between 3% and 5% of housing stock is retrofitted annually
8 (Gleeson *et al.* 2011). Nonetheless, this needs to more than double over the course of the next
9 decade in tandem with investment of £200bn-£400bn if Paris Goals are to be attained
10 (Technology Strategy Board, 2013).
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18 Given the high levels of energy consumption and carbon intensity – buildings account for
19 almost 40% of CO₂ emissions across Europe – upscaling the retrofitting of existing building
20 stock represents an impactful means of reducing carbon consumption levels in line with the
21 Paris Agreement. However, as identified by Bahareh *et al.* (2018) there remain a number of
22 economic, technical and social barriers to green retrofitting within the housing sector. From a
23 policy perspective there is a requirement for more effective communication and understanding
24 of scale and nature of retrofit solutions and their impacts (on energy and carbon intensity),
25 associated costs and benefits, payback periods and the extent to which intervention measures
26 can be capitalised in terms of added economic value, liveability, health and wellbeing.
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34 In this context, one of the most important policy instruments implemented across the European
35 Union has been Energy Performance Certificates (EPCs). While EPCs aim to improve the
36 awareness of the energy performance of buildings and to improve transparency and
37 understanding of the energy intensity profile of a building, they also contain recommendations
38 which if properly understood, and effectively communicated, influence future investments by
39 defining the most attractive cost-effective measures to reduce energy intensity. An extensive
40 body of empirical evidence from European residential markets assembled over the course of
41 the last decade generally confirms that energy efficiency is capitalised into property prices
42 (Brounen and Kok, 2010; Cajias and Piazzolo, 2013; Fuerst *et al.*, 2016; Kholodilin and
43 Michelsen, 2014). Despite this, the impact of EPCs on property prices is not conclusive. A
44 number investigations have failed to establish any form of price premium predicated on EPC
45 scores (Murphy, 2014; Laine, 2011; Amecke, 2012) and infer that EPCs have a modest or
46 negligible impact on price negotiations and the purchaser decisions. Moreover, based on in-
47 depth interviews with homeowners in ten European countries, as well as a large survey among
48 homeowners in five European countries, Backhaus *et al.* (2011) concluded that the EPCs have
49 a small or negligible impact on homeowners' investment decisions.
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3 From a practical viewpoint, and in order for EPCs to serve as a valuable evidence base to
4 inform and support green retrofit decision making going forward, Ramón *et al.* (2017) detail
5 the need for EPC's to be properly used, not only to compare the energy efficiency of different
6 buildings, but also to communicate suggestions on energy improvement measures able to
7 increase the energy savings and reduce consumption costs. This later dimension of the EPC
8 process - in essence the 'efficiency potential' and how to optimise that potential - seem to be
9 downplayed or overlooked entirely in EPC evaluations. Indeed, there has been limited analysis
10 which has accounted the 'standard cost improvements EPC score, or 'potential score' and how
11 for example this data could be used more effectively within the confines of the 2015 Paris
12 Goals. Accordingly, this paper attempts to quantify and measure the dynamic effects of EPCs
13 on house prices across the price spectrum as well as improving understanding of the potential
14 contribution of EPCs in the mobilisation of cost effective retrofit improvements which enable
15 householders to optimise energy efficiency within clearly defined financial frameworks.
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28 **Literature**

29 There has been a voluminous number of studies investigating EPCs. The primary focus of the majority
30 of this research has tended to investigate the role and pricing of energy efficiency within residential
31 property using a hedonic methodology with the findings revealing varying degrees of premium effects
32 (Brounen and Kok, 2011; Hoberg, 2013; Kahn and Kok, 2014; Cerin *et al.*, 2014; Fuerst *et al.*, 2015;
33 Fuerst *et al.*, 2016; Fregonara *et al.*, 2014; Davis *et al.*, 2015; Olaussen, Oust and Solstad, 2017; Aroul
34 and Rodriguez, 2017). Indeed, some pertinent meta-analysis reviews have emerged examining the
35 premium effects of EPCs. Cespedes-Lopez (2019) in a systematic review, meta-analysis, and meta-
36 regression of 66 prior studies indicate that, at a global level EPCs comprise an overall price premium
37 of 4.2%. On a continent level they show average premiums of 5.36% are observed for North America,
38 with 4.8% in Asia, and 2.3% in Europe, the latter of which the authors contend are more inconclusive
39 due to the qualification criteria given limited consensus to the banded reference for comparison
40 purposes which generate small comparable samples.
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49 Equally, and complimenting the inconclusive findings of Cespedes-Lopez *et al.* (2019), Wilkinson and
50 Sayce (2019) reviewed academic literature and quantitative studies conducted within a European
51 context between EPCs and capital (or rental) values. Their meta-analysis indicated that a positive
52 relationship between observed market price and EPCs however noted these are variable concluding that
53 whilst there is some evidence that energy efficiency is beginning to impact on value, this is relatively
54 small in comparison to other value drivers. Moreover, and in line with Davis *et al.* (2015), they indicate
55 that the findings point more towards the emergence of a 'brown' discount being more plausible in the
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3 long-term trend than a 'green' premium. Interestingly, the authors also affirm that energy upgrades may
4 increase value, but suggest that this is not to the point where costs outweigh the value gain.
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7 Pasichnyi *et al.* (2019) examine EPCs from a data perspective, illustrating that whilst EPCs have
8 become a core source of information about building energy, the domains of its applications have not
9 been studied systematically, which they contend partially explains the limitation of conventional EPC
10 data quality studies. Reviewing existing applications of EPC data within 79 papers the authors propose
11 a new 'quality assurance' method for assessing the quality of EPCs - identifying thirteen application
12 domains based on six validation levels which they tested using four samples of EPC dataset for the case
13 of Sweden. Their findings showed that EPC data can be improved through adding or revising the EPC
14 features and specifically assuring interoperability of EPC datasets.
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21 This analysis has evolved with advancements in methodological approaches and insights of energy
22 efficiency to account for the marginal more market based spatial EPC analysis using a variety of
23 geo-statistical techniques (Davis *et al.*, 2017; Taltavull, Anghel and Ciora, 2017; McCord *et al.*,
24 2019; Wilhelmsson, 2019; Bottero *et al.*, 2019; Bisello, Antonucci and Marella, 2020) which have also
25 demonstrated mixed market (pricing) effects. The findings of Davis *et al.* (2017) showed an urban-rural
26 divide and what they termed a 'bungalowification effect' in terms of 'valuing' energy efficiency and
27 performance and efficiency. Taltavull de La Paz *et al.* (2017) examined the green premium effect of
28 retrofitted apartments and evaluated whether a spatial diffusion effect was evident for the
29 Budapest housing market. Their findings suggested a green premium in specific sub-market
30 market areas with further spatial diffusion effects appearing to contribute positively to house
31 prices, nonetheless, highlighted that the unobserved spatial component reduces this effect.
32 Likewise, Bisello, Antonucci and Marella (2020) in the context of Italian housing market, found a price
33 premium in excess of 6% moving from G rated EPC bands to A rated energy efficiency class, and
34 identified the presence of a spill-over effect to nearby properties which they attribute to a co-benefit of
35 market retrofitting. However, McCord *et al.* (2019), when considering numerous spatial frameworks,
36 found that whilst EPCs comprise a *partial* effect on house prices, the spatial variation in EPCs and
37 pricing effects conform to a 'cosmopolitan' effect. Recognising localised spatially varying coefficients
38 and self-similarity over short distances to exist, which they attributed to potential 'pockets of retrofit',
39 their results displayed no concrete presence of an intra-urban agglomeration effect highlighting the
40 spatial differentiation between pricing, EPCs and market structure thus pointing towards both
41 capitalisation and concessionary effects.
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55 In a similar vein, Wilhelmsson (2019) applied a combination of alternative approaches to estimate the
56 causal relationship between house prices and energy performance certificates. Controlling for different
57 types of potential bias, outliers, spatial dependency, and parameter heterogeneity of their estimates and
58 using a traditional hedonic modelling approach they employ a propensity score method to compare
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3 treated houses with a control group using over 100,000 observations. Further, they apply a quantile
4 regression technique to test the hypothesis that the capitalisation effect varies across the price
5 distribution. The findings, indicate the existence of upward bias if failing to control for outlier and
6 selection bias of 3% - with a capitalisation effect of 3% (compared to 6%). Notably, the authors reveal
7 that regardless of the propensity score method approach, the results do not support that the impact of
8 EPCs varying in the price distribution. Their findings therefore suggest that EPCs are not differently
9 capitalized in the high-end housing price segment, however do show that they are more capitalized into
10 house prices in the northern and colder parts of Sweden than in the southern regions.

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16 In keeping with the role of climatic areas, Taltavull de La Paz *et al.* (2019) examined the presence of
17 green premiums based on 9,000 asking prices for the Alicante province in Spain. Applying a data
18 matching exercise, the authors used pool Ordinary Least Squares and Instrumental Variable hedonic
19 models to investigate the existence of green premiums within different climatic zones. Specifically
20 assessing the sensitivity of asking prices to both energy consumption and carbon dioxide emissions, the
21 authors find energy premium effects of circa 3%, and also identify energy efficiency effects between
22 ratings showing associations between G and F ratings of 1.8% and 1.1% between bands F and E.
23 Pertinently, the authors illustrate that there are price variations between climatic zones and advocate
24 that policy tailored towards incentivisation of energy efficiency need to discriminate by climatic areas
25 in order to achieve European Union (EU) objectives.
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34 Further, research has progressed investigating the role of energy efficiency from a more behavioural
35 market perspective. Amecke (2012) examined the adoption and impact of energy performance
36 certificates based on a survey of 1,239 private purchasers in Germany, finding limited evidence of EPCs
37 being a driver of purchaser decisions. Similarly, in terms of buyer awareness, Olausen *et al.* (2019)
38 using data on energy prices in combination with transaction data for Oslo, conclude that not only the
39 energy label, but also the energy performance of dwellings in general, has little to no effect on
40 transaction prices. Likewise, Warren-Myers, Judge, and Paladino (2018) in the Australian context show
41 that sustainable rating systems are not having the desired influence as originally envisaged which
42 the authors deem demonstrates the low awareness and trust in the ratings.
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48 Keeping with behaviour, Charalambides (2019) further extend the insights by focusing upon the effect
49 of EPCs on the renovation of buildings¹. Using online web-based surveys conducted across twelve
50 European Union countries, the findings revealed differences, perhaps not unexpectedly, between
51 countries and age groups as to the role EPCs play in both renovation decisions and whether to rent/buy
52 a certain apartment dwelling. Further, the authors highlight that key drivers and parameters related to
53 energy renovation investment mobilisation do contribute to the promotion of investments for deep
54 energy renovation of buildings and ultimately the effectiveness and benefits of using retrofitting online
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60 ¹ Through the European project ENERFUND.

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3 tools, to target market failures in the building sector. In a similar approach, Fleckinger, Glachant and
4 Kamga (2019) studied EPCs and investment in a buildings energy efficiency and found somewhat
5 contradictory findings as to the role of EPCs as signals for energy performance in housing markets. The
6 authors stress that although EPCs are intended to improve social welfare in the absence of market
7 failures, their impact on energy use and investment is ambiguous which they suggest is dependent on
8 both on the time horizon considered and the distribution of energy needs in the population.
9 Paradoxically, the authors show that whilst EPCs are expected to reduce energy use by increasing
10 retrofitting incentives, that they may indeed increase energy use and reduce retrofitting in certain
11 circumstances. They conclude that there results imply that, in a second-best world where energy
12 externalities are under-priced, EPCs can damage social welfare.
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21 This variation in the uptake and use of EPCs as market signals of energy performance also extends
22 to the assessment community. Semple and Jenkins (2020) examined the methods and input data used
23 to assess the energy performance of residential buildings, concentrating on the assessment methods
24 used to generate EPCs for existing residential properties in six European countries. Their findings reveal
25 significant variation in the methods used to identify and assess energy consumption, limited evidence
26 of 'best-practice' sharing between EU countries and ultimately differences in how they analyse their
27 respective building stock and future proofing of dwellings. For the UK, Hardy and Glew (2019) also
28 examine the potential errors of EPC assessment and resulting scores. The authors estimate that a
29 significant error rate exists within UK EPC records between 36% and 62%, which they attribute to
30 disagreements by assessors relating to simple-to-assess building parameters such as floor type, wall
31 type and built form. Their findings infer that this can impact on the energy efficiency rating of EPCs
32 which they suggest will typically change by four points due to errors. Moreover, the authors indicate
33 that apartments (flats) and maisonettes display more errors in assessment than other dwelling types
34 which is attributed to increased difficulties in assessing their location in the building and the nature of
35 the surrounding space.
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45 **Likewise**, research has evolved examining the heterogeneity of building stock and typology models and
46 enhancing modelling techniques to investigate the impact of energy efficiency measures (Galante and
47 Torri, 2012; McKenna *et al.*, 2013; Aksoezen *et al.*, 2015). As outlined by Österbring *et al.* (2016),
48 traditionally, the description of the building-stock lack the appropriate level of detail to differentiate the
49 potential for EEM within age groups. The research of Österbring *et al.* (2016) therefore integrated
50 building characteristics from EPCs in Gothenburg for measuring energy use and revealed that at the
51 individual building level further refinements in terms of methodological enhancements are necessary.
52 Accordingly, the classification and errors in measurement somewhat relate to pricing studies which
53 have not tested the nature and examined the heterogeneity of the typical housing stock for energy
54 efficiency 'signals' and may therefore result in measurement error.
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3 Building on this idea, McCord *et al.* (2020) examined the nature of the transition between EPC bands
4 and price effects and the likelihood of property characteristics being associated with higher EPC scores.
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6 Using a number of approaches including logit and a polytomous universal framework, their findings
7 illustrated that different property types comprise very distinct and complex relationships in terms of
8 price and EPC band relationship. The authors indicate that, for their sample, both terrace properties and
9 apartments reveal an increased likelihood to obtain higher EPC scores. Alternatively, detached property
10 revealed a decreased probability of having superior energy performance and also a decreased likelihood
11 of showing poorer energy performance. Their estimates suggested that sales price comprises no real
12 relationship with energy performance, concluding that there is no increased probability of an increase
13 in sales price with higher EPC and that there is a mixed effect based on the EPC band and property
14 characteristics. Whilst in line with the earlier findings indicating that the complexity of 'property'
15 characteristics that impact on EPC score do not fully account for energy efficiency - in terms of a
16 capitalisation effect, their analysis of the proportional odds effect of the age coefficients found that older
17 properties tend to reveal higher negative impacts as they move up the EPC banding. Concomitantly,
18 Marmolejo-Duarte and Chen (2019) also examined housing segments in relation to the uneven price
19 impact of EPCs in a metropolitan region of Barcelona in order to consider whether the impact is
20 homogenous across residential segments. Applying hedonic regression and further dissecting the
21 sample on the basis of a multivariate segmentation, the authors found that there is a modest impact of
22 EPC ratings on listing prices, although indicating that this is not homogeneous across housing segments.
23 Pertinently, they reveal that for the most modern apartments, with state-of-the-art features and active
24 environmental comfort, energy ratings seem to play a limited role in the formation of prices.
25 Conversely, they show that for the cheapest apartments, usually located in low-income areas, there is a
26 sizeable "brown discount" effect evident which they infer potentially depreciates the equity of those
27 who have the least resources to carry out an energy retrofit.

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43 The existing body of research presents persuasive evidence that the relationship between house prices
44 and energy performance is complex and not valued equally by the market, or households, implying that
45 choice decisions and trade-offs result in pricing differentials with varying levels of energy efficiency.
46 Notably, the literature highlights that energy efficiency comprises differential pricing effects with
47 premium or capitalisation effects evident in some studies and more negligible or inconclusive findings
48 in others. This finds credence with Wilkinson and Sayce (2019) who suggest that the impact of energy
49 efficiency on value is small compared to other 'value' drivers and therefore requires more nuanced
50 discussions in terms of the relationship between energy efficiency and market behaviours. Certainly,
51 the extant literature base indicates that energy performance research and debate should not generalize
52 findings for one market across markets that have different climates or attitudes regarding green
53 amenities, suggesting that it remains very much a behavioural issue which can imply that there is limited
54 uptake across housing markets in an aggregation sense (Aroul and Rodriguez, 2017). This is further
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3 identified in the building-stock-model-based analysis literature of energy performance which illustrates
4 that building (property) characteristics and the heterogeneity of such remains challenging for energy
5 assessment and measurement.
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9 Research such as Cerin *et al.* (2014) has indicated that findings are determined by housing segmentation
10 as the energy performance relationship differs according to the type of housing and particular housing
11 segments **highlighting the requirement to analyse the performance** across the entirety of the sales sample
12 for enhanced policy targeting and support. For pricing studies, a key issue for measuring the effect of
13 energy performance relates to the significance of the EPC coefficients. However, for EPC analysis,
14 there has been limited insights **which investigate and exceed** the conditional mean estimates. Some
15 studies have attempted to control for spatial dependency, nonetheless, the upper or lower quantiles of
16 the response variable depend on the covariates very differently from the mean. Therefore, quantile
17 regression can provide a more complete description of functional changes than focusing solely on the
18 mean for EPC pricing behaviour.
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27 This paper is therefore positioned in this debate and seeks to add to the literature base by identifying
28 the extent to which energy labelling is associated with energy performance, firstly, across the entirety
29 of the pricing distribution and secondly, as Wilkinson and Sayce (2019) noted energy upgrades may
30 increase value, but suggest that this is not to the point where costs outweigh the value gain, we test
31 whether cost effective potential improvements increase this relationship between property value and
32 EPCs. This is important as is standard energy improvements might be in the mindset of the buyers when
33 purchasing the property and acts as a signal for behaviour in energy efficiency which is not captured by
34 the current EPC rating.
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40 **Data and Methodology**

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42 This study uses 1,478 achieved sales transaction drawn from the Ulster University House Price
43 Index for the period Q2 2018 to Q1 2019 for the Belfast housing market, Northern Ireland. The
44 UUHPI is an established property market index dating back to 1984 which is based on a robust
45 sample of achieved price transactions obtained from estate agents on a quarterly basis and is
46 verified and validated using robust data checks and testing procedures. The sales transactions
47 were subject to data validation and outlier removal approaches. The data includes a number of
48 physical attributes of properties within the sales data (Table 1). Where applicable, the variables
49 were transformed from their categorical state into binary variables. **In addition, to control for**
50 **location, initial modelling investigations were undertaken in order to decipher which**
51 **specification provides best model performance. We initially looked at various levels to control for**
52 **location such as administrative boundaries, sub-market delineations and postcode level. Further, we**
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3 tested absolute location co-ordinates for second-order trend surfaces using various combinations of X,
4 Y and X², Y² and X*Y Y's based on a polynomial expansion method to further establish which was
5 superlative. The expansions did not increase model R² explanation. Accordingly, the X, Y co-
6 ordinates are employed to control for location within the models.
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10 Table 1 outlines the variables utilised within the study and the associated transformations. In
11 this research, for measuring the impact of EPCs we apply both the EPC score and the EPC
12 bands (ratings). The score is used in addition to the bands due to property price being a
13 continuous variable and that the EPC rating is provided as a continuous score. This provides a
14 more deterministic relationship, which is more natural for comparison, as this permits model estimates
15 of the EPC score to be assessed as a unitary effect. In addition, within the EPC database, both the current
16 and potential EPC scores and bands are available which provides the current assessed score (rating) and
17 also the potential standard cost-effective improvement score (rating), if a potential owner/purchaser
18 were to undertake common and cost-effective energy improvements to the property (Table 1).
19 Therefore, we use both the existing (current) assessed² EPC score/band and also the potential EPC
20 score/band because it provides a signal of cost-effective improvement of energy performance for
21 potential buyers and may be a better estimate of the EPC labelling systems price effect.
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29 <<<Insert Table 1 – Property variables and descriptions>>>
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32 Similar to most studies examining EPCs, the data comprises some limitations related to missing
33 determinants of energy efficient features which has the potential to introduce omitted variable bias. In
34 this study, one omitted variable represents the condition of the property. However, to some degree, the
35 inclusion of the major attribute information such as property type, age and heating type help control for
36 this dynamic, which Davis *et al.* (2017) state is required for mass appraisal exercises to determine value
37 significant features. Further, quality indicators and attributes can also be potentially highly correlated
38 to EPC and can result in upward bias can also introduce issues pertaining to multicollinearity. Moreover,
39 quality and condition characteristics should be implicitly priced into the assessed value and EPC ratings
40 (scores) through their original valuations and energy performance inspections which buyers (should)
41 take account of when purchasing.
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49 *Descriptive analysis*
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52 A summary of the descriptive statistics for the data is presented in Table 2. The sample mean property
53 price is £140,264 which reveals a high dispersion and positive skewness. The average floor size is
54 123m². with the average EPC score of 54.14 which falls marginally below the EPC category D, and in
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² As per UK law, all properties listed for sale must have a registered EPC assessment.

line with the wider UK average residential EPC band rated D³. Interestingly, the potential EPC score average is 66.97 with a reduced standard deviation (10.03).

<<<Table 2 - Descriptive Statistics>>>

Further disaggregation of the sample data exhibits the average EPC scores and bands across property type (Table 3). The average EPC score for apartments (56.03) is the highest in the sample, nonetheless, the remaining property types all show an average EPC score within a 1.5% range (53.26-54.54). This is also evident for range and standard deviation across property type exhibiting the different types to all have very similar distribution characteristics.

<<<Insert Table 3 EPC bands and scores for property type>>>

When considering the age of the properties (Table 4), there is a low variation across each respective age band in terms of EPC performance (52.72 – 55.15). Pre-1919 properties represent 8.8% of the sample and reveal the lowest average EPC score of 52.74 albeit marginally below the other age categories. Surprisingly, the Inter-War period housing accounts for 17.66% of the sample and have the highest EPC score within the sample, perhaps reflective of refurbishment and retrofitting, followed by the post-1980 period properties which represent 29.91% and have an average EPC score of 54.95.

<<<Insert Table 4: EPC bands and scores for property age categories>>>

Methods

Hedonic modelling is the common approach applied within property analysis to ascertain the marginal effects of property attributes. Typically, the functional relationship between the price P of a heterogeneous good i and its quality characteristics represented by a vector \mathbf{x}_i

$$P_i = f(\mathbf{x}_i; \boldsymbol{\beta}) + u_i \quad (1)$$

Where P_i represents a property with a price P , \mathbf{x}_i the structural attributes, $\boldsymbol{\beta}$ relates to the vector of coefficients which are estimated for the characteristics, with u_i representing the error term.

In light of the sale price data showing positive skewness the semi-log hedonic specification is applied where:

³See: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/729052/EPB_Cert_Statistics_Release_-_Qtr_2_2018_final.pdf

$$\ln(P_i) = \alpha + \sum_{j=1}^J \beta_j z_{ji} + u_i \quad (2)$$

where the natural log of the price of the i th house is a function of the J characteristics assumed to influence price, and α , β the coefficients estimated, and u the normally distributed error term.

Quantile regression

Criticisms of traditional least squares regression are that it only provides an approximate of the conditional mean of the distribution and therefore provides an incomplete description of a conditional distribution (Mosteller and Tukey, 1977). Alternatively, quantile regression as introduced by Koenker and Bassett (1978), extends classical least squares regression to an ensemble of models for conditional quantile functions and enables the estimation of conditional quantile functions where each function characterises the behaviour of a specific point in the conditional distribution, and thus fully represents the conditional distribution (Koenker and Bassett, 1978). Thus, examining quantile regression functions across the entire range of τ provides a more complete depiction of the relationship between x and y .

For least squares functions, squared residual errors are minimised with respect to the conditional mean, whereas quantile functions are estimated by minimising an asymmetrically weighted sum of the residual errors (Koenker and Bassett, 1978; Cade et al., 1999; Koenker and Hallock, 2001), and are therefore insensitive to heteroscedastic errors and dependent variable outliers (Buchinsky, 1991) or when the error term is non-normal (Buchinsky, 1998). Additionally Hung, Shang and Wang (2010) discuss that in addition to characterising the full description of the conditional distribution, the quantile regression models employ a linear programming representation which simplifies examination.

For a random variable Y , the τ th quantile is defined by a value y such that the probability of finding a smaller y is less than or equal to τ , and the probability of finding a larger y is less than or equal to $1 - \tau$. Similarly, the τ th quantile regression function, $\mathbf{B}(\tau)$, corresponds to a linear or quadratic function fit through the data such that approximately τ proportion of the observations are less than $\mathbf{B}(\tau)$ and $1 - \tau$ proportion of the observations are greater than $\mathbf{B}(\tau)$. Estimates $b(\tau)$ of $\mathbf{B}(\tau)$ are obtained by minimising the absolute values of the residuals where positive residuals are given weights equal to τ and negative residuals are given weights equal to $1 - \tau$ (for full mathematical descriptions of the algorithms see Koenker and Bassett, 1978). The basic quantile regression can be written as:

$$y_i = x_i' \beta_\theta + u_{\theta i} \quad \text{with} \quad \text{Quant}_\theta(y_i | x_i) = x_i \beta_\theta \quad (3)$$

where x'_i denotes a vector of regressors, β_θ represents the vector of parameters to be estimated, and $u_{\theta i}$ is a vector of residuals. $Quant_\theta(y_i|x_i)$ represents the θ^{th} conditional quantile of y_i given x'_i . The θ^{th} regression quantile solves the following problem:

$$\begin{aligned} \min_{\beta} &= \sum_i \theta |y_i - x_i \beta| + \sum_i (1 - \theta) |y_i - x_i \beta| \\ &= \min_{\beta} \sum_i \rho_\theta u_{\theta i}, \theta \in (0,1) \end{aligned} \quad (4)$$

where ρ_θ is known as the “check function” and defined as:

$$\rho_\theta(\varepsilon) = \begin{cases} \theta \varepsilon & \text{if } \varepsilon \geq 0 \\ (\theta - 1)\varepsilon & \text{if } \varepsilon < 0 \end{cases}$$

Eq. (4) is then solved by the linear programming technique. The median regression, which is a special case of the quantile regression, is obtained by setting $u(\tau) = 0.5$. Other quantile of the conditional distribution can be obtained via variation of $u(\tau)$. To convey a sense for the relationship of selected explanatory variables across the entire conditional house price distribution, the results are reported across quantile deciles ranging from the 10th ($\tau=0.1$) to the 90th ($\tau=0.9$).

Overall, the research applies four regression based models. The first is model is the base OLS model which includes EPC as a score coefficient, with Model 2 including EPCs as binary bands (ratings) ranging from B to G. The EPC score hold-out models (Models 1 and 3) for comparison is a semi-detached, Post-1980 property with oil heating, a garage and sold in Q1, 2019. Equally, the hold-out model for the EPC banded models (Model 2 and 4) is a semi-detached, Post-1980 property with oil heating, a garage, sold in Q1, 2019 and has an energy efficiency assessment of D-rated. For models 5-8, both the hold-out models which apply the EPC score (Model 5 and Model 7) remain the same specification. However, given that this variable measures the potential cost-effective EPC assessment the hold-out models (Model 6 and Model 8) using energy ratings becomes C-rated as the potential improvements remove the G-rated category (binary) and change the most frequently occurring observation (used as the omitted variable) to a EPC C-rated property.

Findings

The empirical analysis is conducted on a series of OLS and Quantile regression models. The initial models are the base OLS which contain the EPC coefficients as a score (Model 1) and the OLS including EPC as bands (Model 2), with Model 3 and Model 4 displaying the EPC score and bands coefficients for the quantile regression approach employing nine quantiles across the house price

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3 **distribution.** The initial OLS models including EPC scores and bands (**Model 1 and Model 2**) show
4 that for every unitary increase in property size (m²) this equates, *ceteris paribus*, to a 0.66% pricing
5 effect (Table 5). The property types all display significant with apartments and terrace properties
6 revealing negative coefficient values of 10.51% and 39.51% respectively. The age coefficients
7 display early-modern (1960-1979) properties to not show statistical significance relative to the
8 Post-1980 hold-out. Inter-war period properties exhibit a 3.16% ($\beta = 0.03164, p < .05$) and 3.29%
9 effect ($\beta = 0.0329, p < .05$), with Pre-1919 properties also indicating a 3.43% and 3.54% effect. The gas
10 heat coefficient also demonstrates that a positive effect in both models equating to 12.49% and 12.35%.
11 In terms of energy performance, when considering the EPC score model (**Model 1**), the EPC coefficient
12 reveals that a unitary increase in EPC score, *ceteris paribus*, culminates in a 0.13% increase in property
13 value significant at the 5% level (Table 5). **Alternatively, the banded EPC model (Model 2)** shows that
14 EPC bands comprise varying degrees of positive and negative effects on house prices. The findings
15 reveal EPC B rated properties to display a 7.2% premium effect, albeit only significant at the 10% level.
16 This effect diminishes to 3.15% ($p < .05$) for properties classified with an EPC rating of C, with no effect
17 evident for E rated properties ($p > .05$) - relative to the hold-out EPC D rated property. Further, both F
18 and G EPC rated housing show a 1.66% and 13.2% discount effect significant at the 10% and 5% levels
19 respectively.
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32 <<<Insert **Table 5** – OLS and Quantile EPC score and band model coefficient estimates>>>
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35 In terms of comparison, examination of the size (m²) parameter within the quantile estimates shows that
36 all are statistically significant at the 1% level. **The quantile analysis between the OLS score model**
37 **(Model 1) and quantile score model (Model 3) however shows that there are differences evident** in the
38 marginal effects across the price distribution suggesting that size is valued differently across the
39 quantiles and that conditional quantiles are not identical (Table 5). The size coefficient increases across
40 the quantile range ($\tau=0.1-0.9$) and demonstrates lower priced properties to comprise a lower pricing
41 effect. Indeed, the results also show this effect is also evident when considering the nature of the
42 property type and age characteristics (Figure 1). For apartments, the quantile estimates within **Model 3**
43 **and Model 4** clearly display increasing magnitude across the pricing distribution. For example, the
44 conditional mean estimate within both the OLS band and score models (**Model 1 and Model 2**) suggest
45 that the apartment coefficient comprises a negative impact of 10.4% and 10.52% respectively.
46 Nonetheless, when examining the quantile estimates **in Models 3 and 4**, the findings show at the 1st
47 quantile the magnitude of the effect increases to negative 23.46% ($p < .001$) in Model 3, which decreases
48 to 11.16% at the 2nd quantile (Table 5). Interestingly, only the 7th and 8th quantiles within Model 3 are
49 statistically significant revealing a negative 7.15% and 5.71% effect with all others statistically
50 insignificant. These findings are also similar for both the terrace properties and detached properties
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3 within both quantile models which exhibit differences in the marginal effects across the price
4 distribution (Figure 1). Notably, terrace properties display a relatively linear effect and increased
5 negative associations whilst moving down the quantiles, whereas detached properties display a u-shape
6 pricing effect revealing higher pricing effects at the lower and upper quantiles.
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8 For the age coefficients, the quantile models (Model 3 and Model 4) show some distinct relationships.
9 Early-modern properties display a negative coefficient at the 1st quantile which then exhibits no pricing
10 effect between the 2nd and 5th quantile and then turns negative across the remaining quantiles (Figure
11 1). Inter-war housing shows an increasing effect across the quantiles until the 7th quantile with the
12 magnitude of the effect decreasing for both the 8th and 9th quantiles. Pertinently, only the 4th-7th quantiles
13 are significant, showing a pricing effect ranging between 7.36% to 8.59% at the 5% and 1% level of
14 significance (Model 4). In a similar vein, Pre-1919 housing exhibits a low effect at the 1st quantile which
15 increases to 5.84% at the 4th quantile which is sizeably higher than the conditional mean estimate of
16 3.4%. Notably, the mid-to-higher price quantiles do not show statistically significant effects.
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25 <<<Insert Figure 1: Size, type and age quantile coefficients effects>>>

26 Examination of the EPC quantile coefficients in Model 4 clearly demonstrates that the effects of the
27 energy performance banding is not constant or significant across the entirety of the pricing structure
28 (Figure 2). Indeed, examination of EPCs with a B rating (Model 4), exhibits only property prices at the
29 6th-8th quantile range display statistically significant effects with magnitudes ranging from 9.88% to
30 11.41% (Table 5), with the 9th quantile showing a moderately weaker effect (6.37%, $p > .05$). Conversely,
31 property values at the lower quantile range show reduced effects and at the lowest quantiles negative
32 effects, albeit statistically insignificant ($p > .05$), arguably symbolising the complex heterogeneity of
33 property characteristics and the capitalisation relationship. This finding infers that only properties
34 comprising the highest values with an EPC rating B show a premium effect and suggests that EPC B-
35 rated properties are valued differently across the quantiles and that conditional quantiles are not
36 identical.
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38 With regards to EPC band rating C, whilst the OLS conditional mean estimate in Model 2 indicates the
39 presence of a positive 3.15% pricing effect, the quantile analysis within Model 4 shows only the 3rd and
40 4th quantiles to be statistically significant at the 5% and 10% level, demonstrating a 3.42% and 4.68%
41 effect (Model 4). The findings indicate an increasing effect evident between the 1st and 4th quantiles
42 with a relatively consistent effect across the remaining price bands. Indeed, within both the higher and
43 lower quantiles of the pricing distribution, the EPC C rating does not show a significant relationship
44 suggesting that only lower-to-mid range of the market show a capitalising effect. Similarly, for EPC E-
45 rated properties, the OLS model (Model 2) revealed no statistical pricing effect. In contrast, the quantile
46 findings in Model 4 show that pricing effects range from -2.17% at the 1st quantile and turn positive in
47 the mid-price range (between 3rd-5th quantile) before becoming negative at the higher pricing
48 distribution. Pertinently, the findings suggest, albeit at the 10% level, that at the 9th quantile there is
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3 statistically significant negative effect of 4.34% suggesting that the highest priced properties show a
4 negative EPC effect. In terms of the lower EPC bands F and G, the conditional mean estimates
5 **evidenced in Model 2** displayed a -1.6% and -13.2% effect, however, the quantile estimates **in Model 4**
6 show that for EPC F-rated properties, only the 9th quantile ($\beta = 0.0271, p < .10$) exhibit statistical
7 significance at the 10% level.
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11 Notably, for EPC G-rated properties the lower quantiles show positive effects, albeit statistically
12 insignificant, with the medium and higher priced properties displaying negative effects from the 5th
13 quantile, of which the 8th and 9th quantiles are statistically significant. Indeed, as opposed to the OLS
14 estimate ($\beta = -0.132, p < .05$) observed in Model 2, the results within the quantile models (Model 4) infer
15 that higher priced properties in the F category command significantly higher discount effects of -15.57%
16 and -21.21% at the 5% level.
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20 With regards to the EPC score model (**Model 1**) which applies the EPC assessed score, the OLS
21 conditional mean coefficient illustrated a positive 0.13% effect for every unitary increase in EPC score.
22 When considering the quantile estimates **in Model 3**, the results show more of a parabolic effect, namely
23 that the lower priced properties at the 1st and 2nd quantiles reveal higher positive effects, although
24 statistically insignificant, than properties located between the 3rd and 6th levels of the pricing
25 distribution. However, only the pricing levels at the 7th-9th quantiles exhibit statistically significant
26 pricing effects ranging from 0.11% at the 7th quantile to 0.20% at the 9th quantile (Figure 2) indicating
27 an increasing capitalisation effect is only evident for the higher priced properties.
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34 <<<Insert Figure 2: EPC quantiles bands and score>>>

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37 In order to account for standard cost energy improvements (retrofit potential), the EPC potential score
38 is further applied to test the relationship of a properties energy efficiency and pricing. The findings
39 **evidenced in Table 6** indicate that the potential EPC score (**Model 5**) has an increased effect on pricing
40 of 0.22% for every unitary increase in EPC score ($\beta = 0.0022, p < .05$). Moreover, in terms of the
41 quantiles, the potential EPC score demonstrates an increased and indeed more consistent pricing effect
42 across the price distribution (**Model 7: Table 6**) compared to the current EPC score quantile model
43 observed in Model 3 (Table 5). Analogous with the EPC score findings, the potential energy efficiency
44 **score model (Model 7)** only displays statistically significant pricing effects at the higher quantile range
45 of the pricing distribution - however only the 7th quantile ($\beta = 0.0023, p < .05$) and 8th quantile ($\beta =$
46 $0.0026, p < .05$) are significant with the 9th quantile showing a slightly reduced statistically insignificant
47 effect (Table 6). This suggests when accounting for cost effective standard energy efficiency
48 improvements, the highest values in the market may be capitalised already given that the cost
49 improvement essentially would be subject to a 'ceiling effect' and diminishing returns.
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59 <<<Insert Table 6: EPC potential EPC score and band score model coefficients>>>
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For the potential energy performance band model (Model 6), the findings⁴ signal increased effects for B-rated properties ($\beta = 0.1227, p < .05$) and also reduced negative effects for the lower rating bands of E ($\beta = -0.009, p > .05$) and F rated properties ($\beta = -0.098, p > .05$). Further scrutiny of the potential band effects across the quantiles (Model 8) serves to reinforce the earlier findings. There is no significant effects evident across all band ratings (B-F) below the 5th quantile, however, whilst not significant, it is noticeable that the magnitude of the B-rated properties display positive increases across the price distribution with the poorest energy efficient housing - as denoted by Band G – showing more pronounced discount effects (Figure 3). The potential EPC band B, as observed in Model 8, exhibits no pricing effect and the 1st quantile, however increases at a reducing rate until the 5th quantile where it evens out and remains consistent across the remaining quantiles. At the 5th quantile, the B-rated EPCs display a 15.22% pricing effect, significant at the 1% level. This pricing effect is also evident between the 6th ($\beta = 0.1306, p < .01$) and 8th quantiles ($\beta = 0.1202, p < .01$), indicating that market participants may be differentiating between more ‘ephemeral’ energy efficiency issues (those that can be effectively dealt with by cost effective measures) and more ‘persistent’ energy efficiency concerns (those which cannot be cost effectively addressed). Pertinently, the potential EPC F-banded properties in Model 8 exhibit a significant effect at the 8th ($\beta = 0.0376, p < .10$) and 9th ($\beta = 0.1239, p < .05$) quantiles suggesting that the highest priced housing discounts lower EPC values – further supporting the concept that if poor energy efficiency can be remediated straightforwardly it will not affect the price to the same extent, whilst persistent problems will be penalised.

<<<Insert Figure 3: EPC potential bands and score Quantiles>>>

Discussion

Energy performance and its understanding and relationship with property value is not straightforward. Early research in this area has tended to show positive relationships and capitalisation effects, however, with data improvements and evolving techniques to assess the extent of the capitalisation effect, studies are indicating that this confounding effect is very much idiosyncratic to the nation, region, market, household and individual level behaviour. This differentiation has been shown in extant research which has demonstrated that tenure differences in their perception of EPCs, the assessment methods used to identify, generate and assess EPCs, and indeed differences in the level of capitalisation effects which reveals significant variation all remain challenging for analysing energy consumption within housing. Wilkinson and Sayce (2019) concluded in their research that ‘visible’ characteristics, may be more important than any certification. Moreover, they elucidated that barriers to upgrading residential property to improve energy efficiency still exist and these collectively reduce the pace at which

⁴ Note that the hold-out becomes EPC band C.

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3 improvements are carried out and add complexity in terms of understanding how far the market will
4 translate energy efficiency into increased value. The results emerging from this research show that the
5 impact of EPCs do vary across the price distribution and appear to be differently capitalised into the
6 higher priced segment of the housing market. These findings contrast to those of Wilhelmsson (2019)
7 which revealed no differentiation in capitalisation effects within the price distribution and further
8 highlights that these differences are arguably a consequence of different housing stock, climate and
9 market perceptions, behaviour and sentiment towards energy performance.
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16 Accounting for standard cost energy improvements only serves to reinforce this capitalisation effect. It
17 may well be the case that market participants view the EPC current and potential mutually, with the
18 following rationale being applied: If the current score is good, purchasers pay a little more than
19 otherwise. If the current score is poor but potential score is good, they pay up and move on. If the current
20 score is poor and potential score is poor, then a discount is evidenced. Whilst this does imply that
21 participants are capitalising the benefits of potential improvements into their purchase price (and
22 therefore 'paying twice' for the benefit), this must be viewed in terms of the actual product being
23 transacted and the nature of the brokerage.
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30 Equally, residential vendors may hold out for a premium for a good quality *in situ* attribute, which the
31 purchaser may be prepared to pay for, despite an intention to replace or upgrade in line with their choice
32 or tastes. Indeed, they may be prepared to pay up to a 'mark' due to the 'potential' to install an
33 appropriate attribute, which may involve some reconfiguration at cost – a decision that would make no
34 financial sense to a property developer. The same rationale applies to a range of *relatively* benign costs
35 associated with interior decoration and furnishings, including light fittings, wall and floor coverings
36 and even items such as doors and windows. Accordingly, a pricing structure will emerge within a local
37 market which generally reflects the 'fundamentals' of the stock, whereby both vendors and purchasers
38 may have to reflect capitalisation losses. Rolling these all together, it does not seem unlikely that the
39 market may place as much, if not more emphasis on *potential* EPC performance as on current, accepting
40 and paying for the *facility* or *capacity* of acceptable performance and financially punishing only
41 persistent poor quality in this regard. This appetite has the potential to vary across a pricing structure,
42 with varying implied capacity for discretionary expenditure. Of course, this phenomena also reflects
43 the fact that EPC current and potential ratings (scores) and the associated property sale data used here
44 do not necessarily, or at all, capture or reflect the more general 'condition' of a property, implying that
45 many if not all of the 'cost effective measures' implied by the potential EPC score may in fact be 'rolled
46 in' to a modernisation, refurbishment or retrofit programme that would be transpiring in any case,
47 therefore offsetting any implied additional cost to address energy efficiency concerns.
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3 Taking stock of these considerations, it seems that there are both positives as well as negatives to be
4 drawn from the role of EPC's in fostering the energy efficiency agenda. In the negative sense, it appears
5 that EPCs continue to represent a relatively minor consideration in price setting behaviour. There is also
6 support for the view that some of the potential gains to be made on 'green' refurbishment are already
7 be being capitalised into unimproved prices. Therefore, it seems that this does little to advance attempts
8 to factor this 'value uplift' into cost modelling to improve the economic case for energy efficiency
9 interventions. However, it is also discernible that the relatively bleak findings of analysis using current
10 EPC assessed scores is improved using the potential scores and can be seen to be varying across the
11 pricing structure – suggesting that the information is being used more than it initially appears. These
12 constructive insights also suggest that activity to augment simple assessments of performance with
13 'pathways to improvement' may find purchase with market participants, as helping to address the
14 'lemon market' which would otherwise tend to persist in this regard. Overall, it would appear that telling
15 'rational' people more about what they are buying is more likely than not useful in helping them make
16 appropriate choices in addressing both their own financial position with regards to energy costs and
17 energy policy compliance costs, as well as for the wider climate change mitigation agenda.
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28 **Conclusion**

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30 Over the past decade there has been an increasing policy focus targeting energy performance within
31 buildings and specifically residential property. The introduction of mandatory certification within EU
32 Directives was intended to incentivise and foster consumer behaviour and awareness by providing
33 reliable information on the energy performance of dwellings to buyers in order for them to make rational
34 choices. A wealth of studies have examined the role of energy efficiency from a myriad of perspectives
35 and, to some extent, largely show consensus that this desired impact is not being realised and remains
36 arguably partial from a behavioural, assessment and pricing viewpoint.
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42 This study has taken a nuanced approach by examining the nature of the EPC and price relationship
43 using the quantile process to measure the EPC premium effect across the entirety of the price
44 distribution and also accounted for the potential improved energy performance. The findings show that
45 the capitalisation effect is far from complete as evidenced by applying the current EPC rating and the
46 potential ratings and illustrating only premiums to exist in the higher energy rated properties at the
47 higher levels of the price distribution. Equally, and in line with Marmolejo-Duarte and Chen (2019),
48 Davis *et al.* (2015) and Wilkinson and Sayce (2019), the results show that the premium may not always
49 be straightforward - where the market is pricing energy efficiency and where behaviour or sentiment is
50 accounting for a brown discount. Pertinently, the findings infer that EPCs (in the UK format) appear to
51 comprise a 'latent' attribute, which when applying the potential scores and ratings shows that the highest
52 price segments of the B rated energy efficient properties are commanding the premium, but equally that
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3 the lowest ratings are showing higher 'brown discount' effects with the lower and mid-range of the
4 pricing segment of the market seemingly 'idle'.
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7 Interestingly, the results show that accounting for the average cost effective improvement in energy
8 efficiency only serves to increase the level of the premium, again however, only for the B rated
9 properties at the mid-to-higher pricing levels. Further, the findings show the level of the discount effect
10 also diminishes for the lower EPC rated properties at the higher pricing levels – signalling that there
11 still remains concessionary effects, but that market participants are reflecting on the performance of the
12 property after 'reasonable, cost effective actions' (which estimates the inherent capacity of the structure
13 to be efficient), as well as the more ephemeral 'current' position, which may rapidly be amended by
14 reasonable post purchase activities. The findings imply that energy performance is a complex feature
15 that is not easily 'averaged' for valuation effect purposes. This complex relationship is cemented when
16 examining the average cost improvement potential EPC ratings. The premium effect increases for the
17 higher priced B rated properties and discount effects diminish for the lowest rated properties, inferring
18 that to an extent, it is the 'potential EPC' that is being 'priced in'. This is perhaps understandable, given
19 the range of costs involved in purchasing a home and tailoring it to the requirements of the new owner.
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28 From a policy perspective, our findings suggest that providing the market with more information, such
29 as the CRREM pathways for residential property, may help to foster a more discerning marketplace.
30 Whilst current owners of poor performing property may continue, for now, to be 'rewarded' for the
31 *potential* of their property, it seems likely that this will evolve through time to better reflect the costs
32 and benefits of taking action to address energy efficiency issues, particularly where these are relatively
33 free from personal choice and 'taste' considerations. Energy Performance Certification and the regime
34 surrounding its production and use does need to evolve, and are likely to do so. As worrying as their
35 lack of earlier effect is, this must always be contextualised by the reality of the residential market, often
36 driven more by sentiment than evidence. Fostering of positive sentiment does require evidence
37 however, and effective solutions need to accompany the identification of problems if the
38 decarbonisation of the housing sector is to meet the Paris accord targets.
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Journal of European Real Estate Research

Tables and Figures

Tables

<<<Table 1 – Property variables and descriptions>>>

Variable	Description	Type
Sale Price	Transacted price	C
In(Price)	Log of Price	C
Size	Floor area in m ²	C
Property Type	Type of property (1 if terrace; 0 otherwise)	B
Property Age	Age of property (1 if Pre1919; 0 otherwise)	B
Heating type	Type of heating (1 if gas; 0 otherwise)	B
Garage	If a property has a garage (1 if Garage; 0 otherwise)	B
Current EPC rating	Assessed energy efficiency rating in bands (A-G) (1 if B; 0 otherwise)	B
Current EPC score	Assessed energy efficiency score (0-100)	C
Potential EPC rating	Standard cost-improvement energy efficiency rating in bands (A-G) (1 if B; 0 otherwise)	B
Potential EPC score	Standard cost-improvement energy efficiency score (0-100)	C
Location	X and Y coordinates of a property (Absolute location co-ordinates)	C

C = continuous; B = binary; O = ordinal

<<<Table 2 Descriptive Statistics>>>

Variables	Minimum	Maximum	Mean	Std. Dev
Sale Price	34,500	900,000	140,264	102,239
In(Price)	10.106	13.710	11.818	0.605
Floor Area (m ²)	31	447	122.77	59.36
EPC Bands Current	G	B	D	C-E
EPC Bands Potential	F	B	C	B-D
Current EPC	16	85	54.14	15.046
Potential EPC	24	86	66.97	10.026
N	1,476			

<<<Table 3 EPC bands and scores for property type and age>>>

Statistics	Apt			Detach			Semi			Terrace		
	C. EPC	P. EPC	Band	C. EPC	P. EPC	Band	C. EPC	P. EPC	Band	C. EPC	P. EPC	Band
Min	19	36	B	19	33	B	18	30	B	16	24	B
Max	84	86	G	83	86	G	83	86	G	85	86	G
Mean	56.03	67.01	D	54.54	67.25	D	53.26	66.41	D	54.27	67.38	D
Std. Dev.	15.18	10.59	C-E	15.02	10.12	C-E	15.04	9.88	C-E	15.00	9.91	C-E
N	134			408			527			407		

C. EPC denotes current EPC score. P.EPC denotes potential EPC score.

<<<Table 4: EPC bands and scores for property age categories>>>

Statistics	Pre1919		Inter-war		Post-war		Early-modern		Post-1980	
	C. EPC	P. EPC	C. EPC	P. EPC	C. EPC	P. EPC	C. EPC	P. EPC	C. EPC	P. EPC
Min	18	28	19	24	16	27	18	31	19	36
Max	83	86	83	86	83	86	85	86	83	86
Mean	52.74	66.42	55.15	66.92	53.85	66.09	53.64	67.15	54.54	67.07
Std. dev	15.41	11.27	15.06	10.01	15.42	10.99	15.11	9.85	15.02	10.31
N	130		261		265		380		442	

C. EPC denotes current EPC score. P.EPC denotes potential EPC score.

<<<Table 5: OLS and Quantile EPC score and band model coefficient estimates>>>

Variable	<i>Model 1</i>					<i>Model 3</i>				
	<i>OLS score</i>	$\tau=0.1$	$\tau=0.2$	$\tau=0.3$	$\tau=0.4$	$\tau=0.5$	$\tau=0.6$	$\tau=0.7$	$\tau=0.8$	$\tau=0.9$
Size	0.006573***	0.0056***	0.0062***	0.0065***	0.0066***	0.0071***	0.0072***	0.0074***	0.0076***	0.0075***
Apt	-0.103978***	-0.2346***	-0.1116**	0.0198	0.0028	-0.0038	-0.0380	-0.0715**	-0.0571*	-0.0732
Detach	0.094162***	0.1478***	0.1061***	0.0791***	0.0731**	0.0588**	0.0669**	0.0740**	0.0800***	0.1145***
Terr	-0.393361***	-0.5292***	-0.4843***	-0.4721***	-0.4445***	-0.4027***	-0.3459***	-0.3078***	-0.2980***	-0.2495***
Early mod	-0.028601	-0.0180	-0.0031	-0.0049	-0.0031	-0.0067	-0.0113	-0.0168	-0.0242	-0.0182
Inter war	0.032944**	0.0178	0.0314	0.0591	0.0712*	0.0839*	0.0836**	0.0860**	0.0467	0.0423
Post war	0.000747**	-0.0371	0.0137	0.0392	0.0561*	0.0681**	0.0521	0.0550	0.0412	-0.0100
Pre1919	0.035410**	0.0098	0.0246**	0.0472**	0.0584**	0.0528	0.0440	0.0486	0.0688	0.0630
Elec heat	-0.025740	0.1139	0.1265	0.0994	0.2030**	0.2764**	0.3472**	0.3706**	0.3164*	-0.3949**
Gas heat	0.123518***	0.1968***	0.2966***	0.3197***	0.3414***	0.4014***	0.4791***	0.4246***	0.4410***	-0.3470*
No Gar	-0.017443	-0.0476	-0.0204	-0.0092	-0.0161	-0.0075	-0.0017	0.0005	0.0020	-0.0345
EPC score	0.001268**	0.0014	0.0013	0.0006	0.0004	0.0004	0.0007	0.0011*	0.0016**	0.0020**
C	11.47080***	11.9876***	10.9341***	11.2025***	11.3097***	11.2406***	11.7982***	11.3904***	11.3287***	12.0370***
Adj. R ²	0.6761	0.4045	0.4258	0.4341	0.4321	0.4389	0.4466	0.4547	0.4659	0.4852
Pseudo R ²		0.4045	0.4258	0.4341	0.4321	0.4389	0.4466	0.4547	0.4659	0.4852
Variable	<i>Model 2</i>					<i>Model 4</i>				
	<i>OLS band</i>	$\tau=0.1$	$\tau=0.2$	$\tau=0.3$	$\tau=0.4$	$\tau=0.5$	$\tau=0.6$	$\tau=0.7$	$\tau=0.8$	$\tau=0.9$
Size	0.006579***	0.0057***	0.0062**	0.0065***	0.0066***	0.0070***	0.0071***	0.0073***	0.0075***	0.0075***
Apt	-0.105171***	-0.2531***	-0.1264	0.0156	0.0159	-0.0079	-0.0409	-0.0720	-0.0543	-0.1030**
Detach	0.094096***	0.1355***	0.1052***	0.0781***	0.0684***	0.0556**	0.0688***	0.0740***	0.0776**	0.0967***
Terr	-0.395122***	-0.5370***	-0.4882***	-0.4689***	-0.4508***	-0.4084***	-0.3464***	-0.3083***	-0.2957***	-0.2608***
Early mod	-0.029253	-0.0184	-0.0002	-0.0111	-0.0018	-0.0057	-0.0137	-0.0167	-0.0200	-0.0357
Inter war	0.031644**	0.0142	0.0318	0.0516	0.0736**	0.0864**	0.0816**	0.0859***	0.0465	0.0356
Post war	-0.000572**	-0.0444	0.0012	0.0307	0.0569*	0.0700**	0.0500	0.0549	0.0427	-0.0114
Pre1919	0.034300**	0.0028	0.0143**	0.0381**	0.0603**	0.0504	0.0412	0.0496	0.0578	0.0449
Elec heat	-0.025990	-0.0004	-0.0804	-0.1332	-0.0331	-0.0080	-0.0197	0.0631	-0.0094	0.0528
Gas heat	0.124961***	0.1282***	0.0967***	0.0887***	0.1137***	0.1188***	0.1089***	0.1171***	0.1173***	0.1254***
No Gar	-0.016829	-0.0476	-0.0230	-0.0092	-0.0160	-0.0075	-0.0017	0.0005	0.0020	-0.0345
EPC B	0.072029*	-0.0230	-0.0834	0.0473	0.0310	0.0896	0.0988**	0.0644*	0.1141*	0.0637
EPC C	0.031524**	-0.0087	0.0263	0.0342**	0.0468*	0.0303	0.0209	0.0261	0.0333	0.0520
EPC E	1.04E-05	-0.0217	-0.0023	0.0154	0.0060	0.0230	0.0036	-0.0053	-0.0240	-0.0434*
EPC F	-0.016578*	-0.0596	-0.0049	0.0029	0.0232	0.0173	-0.0027	-0.0020	-0.0121	0.0271*
EPC G	-0.132030**	0.1645	0.0672	0.0320	0.0133	-0.0034	-0.0846	-0.0932	-0.1557***	-0.2121***
C	11.43551***	11.750***	11.165***	11.438***	11.621***	11.566***	12.158***	11.698***	11.684***	11.809***
Adj. R ²	0.6805									
Pseudo R ²		0.4108	0.4330	0.4412	0.4398	0.4466	0.4543	0.4617	0.4738	0.4943

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3 Huber Sandwich SE and Covariance. Tau =0.1 to 0.9. Sparsity method: Kernal (Epanechnikov) using residuals. Bandwidth method: Hall-Sheather, bw = 0.085293. Parsimonious model
4 presented: Time and spatial coefficients are available upon request. In the Potential Band models, EPC rating C becomes the hold-out.

5 *denotes significance at the 10%; **5%; ***1% level.
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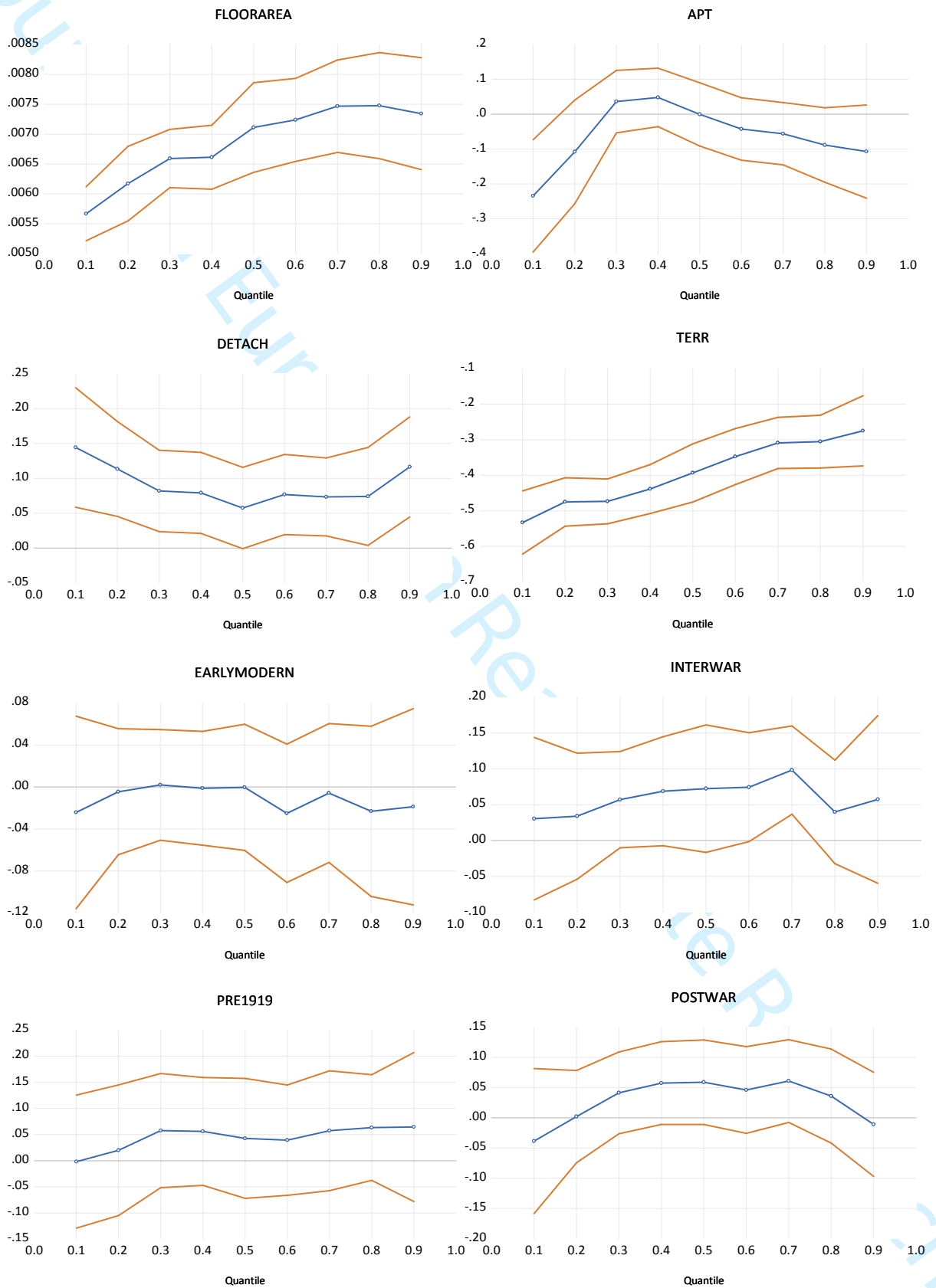
<<<Table 6: Potential EPC band and score OLS and Quantile model coefficient estimates>>>

	<i>Model 5</i>		<i>Model 7</i>							
	<i>OLS Pot. Score</i>	$\tau=0.1$	$\tau=0.2$	$\tau=0.3$	$\tau=0.4$	$\tau=0.5$	$\tau=0.6$	$\tau=0.7$	$\tau=0.8$	$\tau=0.9$
Size	11.394***	0.0057***	0.0062***	0.0066***	0.0066***	0.0070***	0.0072***	0.0074***	0.0075***	0.0075***
Apt	0.0065***	-0.2361***	-0.0986	0.0349	0.0279	-0.0103	-0.0363	-0.0568	-0.0891**	-0.0737
Detach	-0.1034***	0.1526***	0.1136***	0.0828***	0.0661**	0.0696**	0.0789***	0.0749***	0.0713**	0.1124***
Terr	0.0934***	-0.5425***	-0.4700***	-0.4710***	-0.4375**	-0.4077***	-0.3456***	-0.3146***	-0.3077***	-0.2399***
Early mod	-0.3964***	-0.0374	-0.0169	-0.0085	-0.0045	-0.0095	-0.0188	-0.0035	-0.0094	-0.0092
Inter war	-0.0301	0.0313	0.0348	0.0573*	0.0557	0.0715	0.0829**	0.0923***	0.0533	0.0642
Post war	0.0334	-0.0297	0.0101	0.0351	0.0607*	0.0618*	0.0572	0.0620	0.0382	0.0173
Pre1919	0.0001	0.0313	0.0133	0.0473	0.0519	0.0657	0.0424	0.0668	0.0742	0.0506
Elec heat	0.0344	0.0416	-0.0736	-0.1202	-0.0115	0.0093	0.0077	0.0568	-0.0015	0.0216
Gas heat	-0.0261	0.1338***	0.0974***	0.0886***	0.1113***	0.1285***	0.1130***	0.1223***	0.1276***	0.1282***
No Gar	0.1254***	-0.0496	-0.0274	-0.0091	-0.0088	-0.0089	0.0006	-0.0039	0.0106	-0.0138
Pot. EPC	-0.015	0.00171	0.00175	0.00148	0.00154	0.00088	0.00145	0.00226***	0.00257**	0.00203
C	0.0022**	11.927***	11.19270***	11.255***	11.408***	11.603***	11.944***	11.670***	11.887***	11.281***
Adj. R ²	0.6770									
Pseudo R ²		0.4046	0.4249	0.4333	0.4315	0.4380	0.4459	0.4543	0.4659	0.4824
	<i>Model 6</i>		<i>Model 8</i>							
	<i>OLS Pot. Bands</i>	$\tau=0.1$	$\tau=0.2$	$\tau=0.3$	$\tau=0.4$	$\tau=0.5$	$\tau=0.6$	$\tau=0.7$	$\tau=0.8$	$\tau=0.9$
Size	0.0065***	0.0056***	0.0062**	0.0065***	0.0066***	0.0071***	0.0072***	0.0074***	0.0076***	0.0075***
Apt	-0.1067***	-0.2346***	-0.1116**	0.0198	0.0028	-0.0038	-0.0380	-0.0715**	-0.0571*	-0.0732
Detach	0.0960***	0.1478***	0.1061**	0.0791**	0.0731**	0.0588**	0.0669**	0.0740**	0.0800***	0.1145***
Terr	-0.3923***	-0.5292***	-0.4843***	-0.4721***	-0.4445***	-0.4027***	-0.3459***	-0.3078***	-0.2980***	-0.2495***
Early mod	-0.0299	-0.0180	-0.0031	-0.0049	-0.0031	-0.0067	-0.0113	-0.0168	-0.0242	-0.0182
Inter war	0.0313	0.0178	0.0314	0.0591	0.0712*	0.0839*	0.0836**	0.0860**	0.0467	0.0423
Post war	0.0000	-0.0371	0.0137	0.0392	0.0561*	0.0681**	0.0521	0.0550	0.0412	-0.0100
Pre1919	0.0349	0.0098	0.0246**	0.0472**	0.0584	0.0528	0.0440	0.0486	0.0688	0.0630
Elec heat	-0.0224***	0.1139	0.1265	0.0994	0.2030**	0.2764**	0.3472**	0.3706**	0.3164*	-0.3949**
Gas heat	0.1236***	0.1968***	0.2966***	0.3197***	0.3414***	0.4014***	0.4791***	0.4246***	0.4410***	-0.3470*
No Gar	-0.014	-0.0476	-0.0204	-0.0092	-0.0161	-0.0075	-0.0017	0.0005	0.0020	-0.0345
Pot. EPC B	0.1227**	0.0277	0.0294	0.1028	0.1275	0.1522***	0.1306***	0.1684***	0.1202***	0.0945
Pot. EPC D	0.007	0.0227	-0.0007	-0.005	-0.0118	-0.0000	-0.000	0.0094	0.0357	0.0385
Pot. EPC E	-0.009	-0.0675	-0.0361	-0.007	0.0000	0.0161	0.000	-0.0118	0.0061	0.0017
Pot. EPC F	-0.098	-0.0093	-0.0720	-0.053	-0.099	-0.1229	-0.1001	-0.0119	-0.03766*	-0.1239**
C	11.455***	11.9876***	10.9341***	11.2025***	11.3097***	11.2406***	11.7982***	11.3904***	11.3287***	12.0370***
Adj. R ²	0.6770									

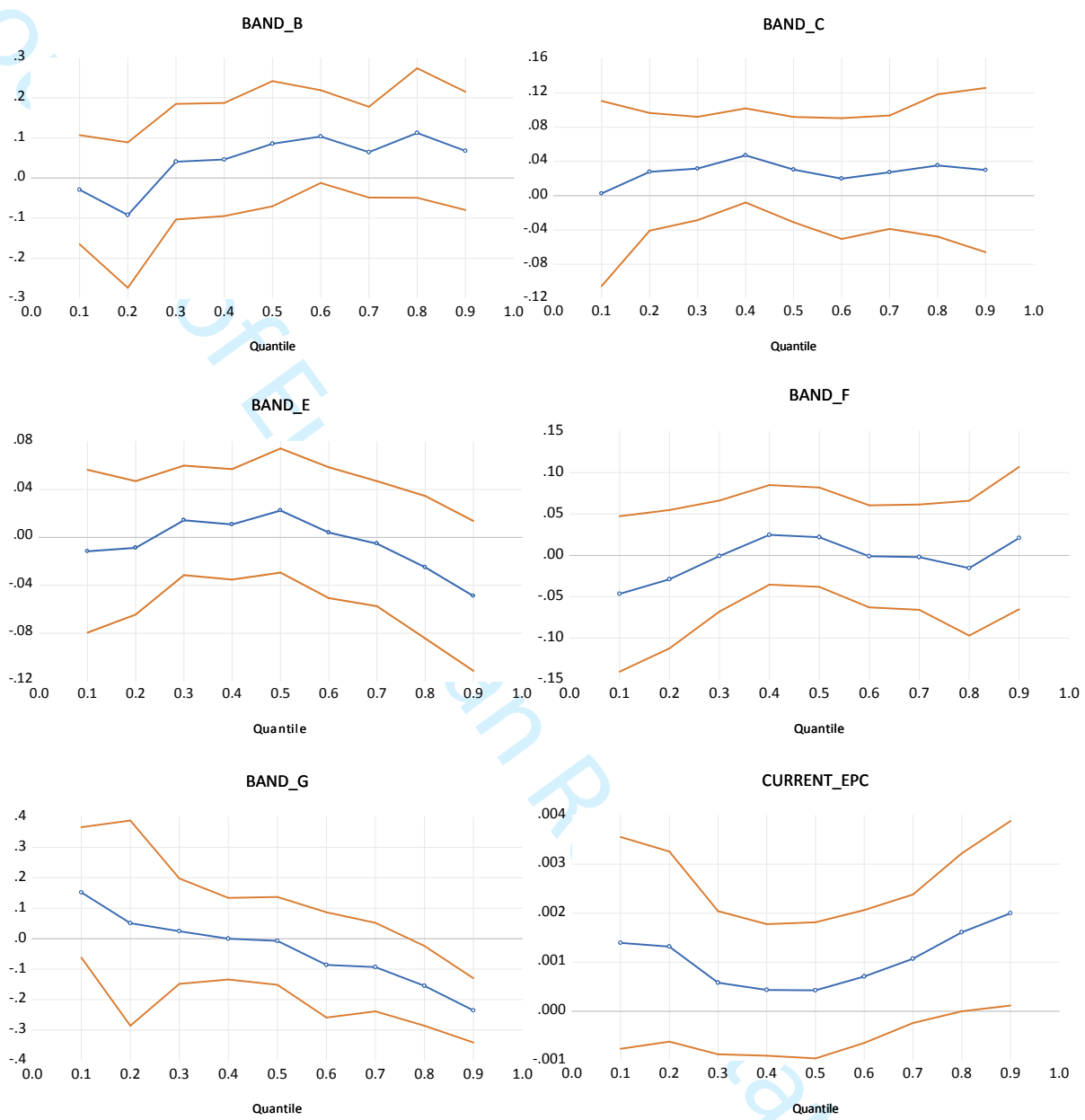
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Figures

<<<Figure 1: Size, type and age quantile coefficients effects>>>

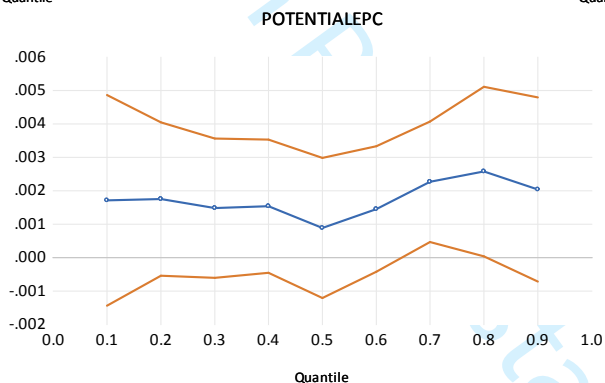
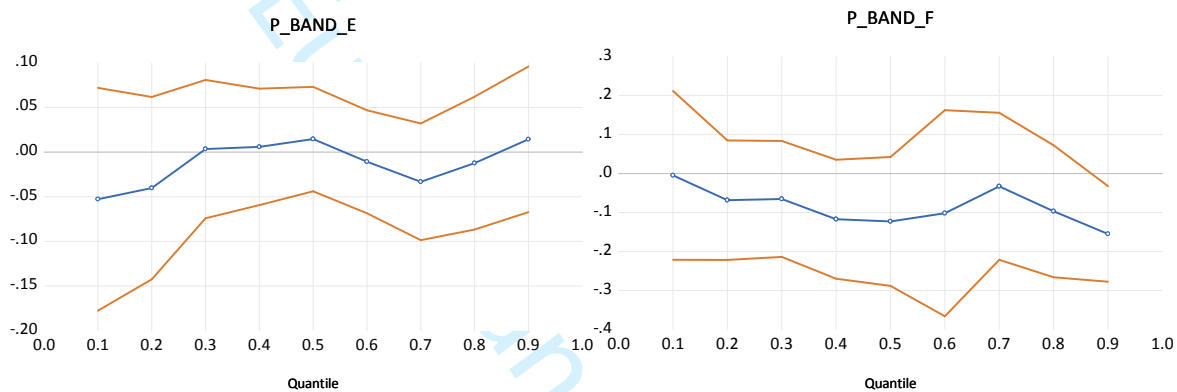
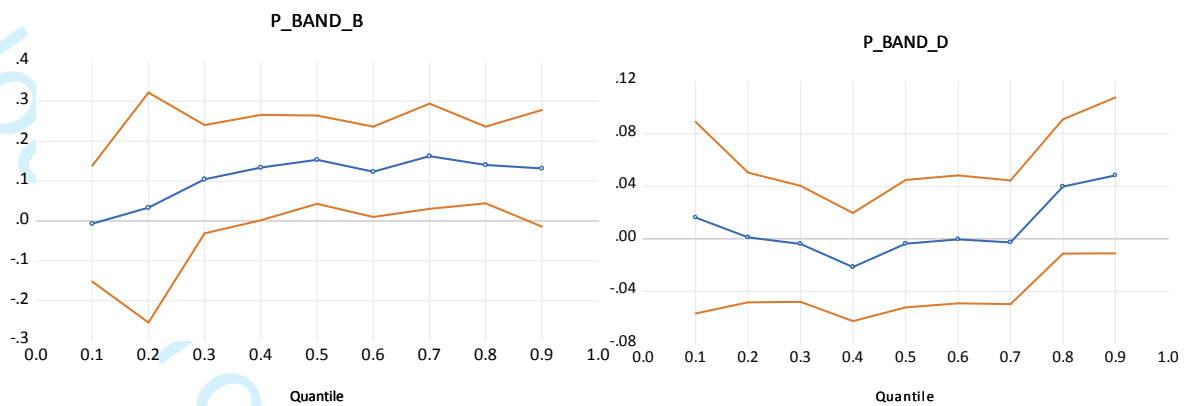


<<<Figure 2: EPC quantiles bands and score>>>



<<<Insert Figure 3: EPC potentiel bands and score Quantiles>>>

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