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An investigation of the impact of energy performance certificate (EPC) ratings on residential property prices in Oxfordshire: a hedonic study

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ABSTRACT
This paper investigates whether energy performance ratings measured by Energy Efficiency Certificates (EPCs) affect the sales prices of residential properties in Oxfordshire, UK. The study makes use of 186,913 sales transactions that took place between 1995 and 2023. Using a hedonic regression estimation, a nonlinear pattern between energy efficiency levels and the sales prices of dwellings, are observed. The results also show that there is evidence of a significant positive relationship between EPC ratings and detached, semi-detached, terraced houses and flats. In the second part of this study, we examine the effects of age, county and type of dwelling on price premiums. To the best of the authors' knowledge, this study is the only study, using the most comprehensive literature; and the largest, most up to date available data in analysing the Oxfordshire real-estate market, in terms of energy efficiency and price premiums.

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Hedonic regression; energy efficiency certificate; Oxfordshire; property prices; valuation modelling

1. Introduction

Mandatory energy efficiency labelling of residential real estate has been enforced in many countries around the world – as part of the broad goal of fighting climate change. Energy efficiency labelling, which serves as a market-based environmental policy mechanism in the residential sector, provides customers with information about the energy efficiency of dwellings. The key objectives are to minimize quality uncertainty; improve demand; push prices upwards; and increase the availability of energy efficient housing.

This study covers the diverse housing market of Oxfordshire ranging from historic properties in Oxford to new developments in surrounding areas. This diversity provides a rich dataset to analyse how EPC ratings impact different types of properties and market segments. Moreover, as a county with a strong educational and research presence, particularly with the University of Oxford, there is a higher likelihood of an informed and environmentally conscious population. This demographic may place a higher premium on

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energy efficiency, influencing local market trends. On the other hand, Oxfordshire's robust economy, characterized by a blend of high-tech industries, academia and traditional sectors, presents a unique setting to study the intersection of energy efficiency and property values. Understanding these dynamics can help tailor policies and market strategies to local conditions. Therefore, researching the effect of EPCs on house prices in Oxfordshire is a vital and relevant topic that intersects with key economic, environmental and social issues. By providing empirical evidence and actionable insights, this research can significantly contribute to policy development, market strategies and public awareness, ultimately supporting the transition to a more energy-efficient and sustainable housing market. Whilst there are macro-economic drivers influencing demand and consequently market prices, it is uncertain if sustainability features have an impact on market prices in the study area. Even with previous government outlines, which may have indicated up to a 14% increase in the value of properties – as a result of good energy performance – the validity of this still remains inconclusive for all areas. Studies like Fuerst et al. (Fuerst & McAllister, 2011a, 2011b), submit that though there is an existing link between EPC ratings and property prices, this does not necessarily imply a perfect relationship in all regional markets. This study intends to fill this gap.

There are about 317163 housing units constituting the entire residential property population in Oxfordshire. Housing market assessments for the region have indicated high levels of demand. For example, the Cambridge Econometrics report 2020 shows that market conditions are clearly attractive for investment in the sector – due to a concentration of potential tenants. In this regard, Oxfordshire represents a vibrant investment market.

As far as the effect of EPC ratings on demand is concerned, this remains a grey area in Oxfordshire, even though previous studies point at the enhanced viability of high energy efficiency buildings, from an investment perspective. In Fuerst and McAllister (Fuerst & McAllister, 2011a, 2011b) superior returns from energy-efficient assets should provide a financial incentive to allocate investment to assets that are energy efficient. This knowledge gap is sought to be filled by the findings from this research. Further, the use of large data sets particularly, offer novelty to the study as explained in Section 4 of this study.

In this economic study, we investigate the relationship between energy efficiency ratings and housing sales prices in Oxfordshire, UK, using 186913 sale transactions which took place between 1995 and 2023. We first provide some background and context information about the role of energy labelling in the residential real estate market in the UK in general. We then provide some descriptive analyses of the data on the Oxfordshire market in more detail. Lastly, we explain the methodological approaches used in the study, followed by findings discussion and the findings. Although related studies exist, the contribution to the literature in this study is presented in being the most recent and most comprehensive study with the largest number of dwellings involved.

2. Literature review

Over the last decade, both the industrial and residential sectors of the real estate industry have adopted a wide variety of energy-tracking instruments and environmental labels. Although these instruments are a mixture of mandatory and voluntary processes – with some highly energy efficient or zero carbon buildings acquiring multiple labels –

the distinction between mandatory and voluntary environmental labels has become hazy as urban planning authorities make labels – such as the Code for Sustainable Housing BREEAM (the international scheme that provides independent third-party certification of the assessment of the sustainability performance of individual buildings, communities and infrastructure projects); and the Leadership in Energy and Environmental Design (LEED) – a requirement of permission to develop. In 2008, as a result of the European Union's Energy Efficiency of Buildings Directive (EPBD), the estimate of energy usage in new and existing buildings in the UK became compulsory. The Directive required all buildings to have certificates providing details of their energy efficiency at the point of completion, sales or lease (or every 10 years). According to the EIC Partnership (The EIC Partnership, 2024), the UK government's interpretation of embedding EPBD recognizes three streams of certification (for both public and private sectors),

- DECs (Display Energy Certificates) – required by publicly owned or funded buildings on an annual or 10 yearly basis
- TM44/ Air Conditioning Inspections – required for all buildings with installed comfort cooling
- EPCs (Energy Performance Certificates) – required for both domestic and non-domestic new builds, majorly refurbished, sold or let out. The certificates are valid for 10 years from issue and underpin the MEES standard, whereby a building cannot be sold or let with an energy rating below E.

In the UK, Energy Performance Certificates (EPCs) are used to classify buildings on an A–G scale with the most efficient being Band A. The rating report for residential dwellings is intended to inform prospective buyers or occupiers about the essential energy performance of buildings and their related services as constructed. It is a mandatory process and the focus of this paper.

The following section discusses previous related studies on the pricing effects of energy efficiency frameworks on property prices.

2.1. Related studies

In the 1980s, a framework that explored the relationship between energy efficiency mostly funded by energy bills and residential sales prices emerged. The valuable assessment of this work was done by Laquatra et al. (Laquatra et al., 2021). Arguably, the most significant – among a variety of limitations found, is the use of small, highly localized samples consisting of dozens or hundreds of dwellings. As a result, there is a tendency to find a positive relationship between energy efficiency and residential sales prices. Examples of such studies can be found in (Dinan & Miranowski, 1989; Halvorsen & Pollakowski, 1981; Johnson & Kaserman, 1983; Laquatra, 1986; Quigley & Rubinfeld, 1989).

As eco-labelling has become more common, a more recent body of research has emerged, focusing on the pricing effects of intrinsic potential energy efficiency as revealed by a certificate or label rather than performance. However, most of these studies have focused on the US market for commercial offices. The results, generally, indicate a positive relationship between environmental labels and prices (Deng et al., 2011; Eichholtz et al., 2010; Reichardt et al., 2012; Rosen, 1974; Wiley et al., 2010).

The Australian Bureau of Statistics carried out one of the first enquiries on the pecuniary impact of mandatory energy labelling on the residential real estate industry (Kok & Jennen, 2012). Using samples from residential sales in the Australian Capital Territory – consisting of 2385 transactions that took place in 2005, and 2719 transactions in 2006, they used hedonic pricing procedures to estimate the effect of Energy Efficiency Rating (EER) on house prices. The study estimated a price premium of about 1% for each 0.5 rise in EER for 2005 (with EER ranges being from 0 to 5) and a premium of approximately 2% for every 0.5 rise in EER for 2006. For the pooled sample relative to zero-rating properties, the Australian Bureau of Statistics estimated premiums of 1.6% (EER 1), 3% (EER 2), 5.9% (EER 3), 6.3% (EER 4) and 6.1% (EER 5). The results suggested that the marginal contribution to the price effect decreases as the rating rises with evidence of a nonlinear effect. Using a large number of dwelling quality control variables, the models' explanatory power were found to be high and reliable.

In the Netherlands office market, Kok and Jennen (Brounen & Kok, 2011) looked at the relationship between EPC ratings and rental prices on 1057 transactions covering the period between 2005 and 2010. Using standard hedonic techniques, they identified a rental premium of approximately 4.7% for buildings rated C or better compared to buildings rated D or worse. The authors, however, argue that offices rated C or above are possibly better quality than buildings with lesser performance due to the level of energy efficiency correlated with unobserved quality variables such as design and interior finish.

In another study, also in the Netherlands, Brounen and Kok analysed the relationship between EPC ratings and sales prices for 31,993 residential sales in 2008–2009 (Hyland et al., 2013). They estimated premiums were 10%, 5.5% and 2% respectively for A, B and C ratings relative to D-rated dwellings. They identified discounts of 0.5%, 2.5% and 5% respectively for dwellings rated E, F and G. A wide range of control variables were included in their study, including dwelling size, insulation efficiency, central heating and maintenance level. Despite that EPCs are mandatory in the Netherlands, they were effectively made optional through policy, on exemptions which means that the adoption rate is therefore low.

Hyland et al. (Heckman, 1974) applied a traditional hedonic methodology to investigate the effect of energy efficiency ratings on capital and rental asking prices for dwellings in Ireland. Due to the fact that only 5% of homes for sale (and only 2.3% of homes for rent) involved in this study had efficiency ratings, the authors applied the technique called the 'Heckman method', to control for selection bias (Fuerst et al., 2015). The findings in this closely related study estimated found a 10.6% discount for F and G ratings. In the study, the authors used a sample of 15,060 dwellings in the market between 2008 and 2012. For dwellings with tenure labelled as rent, the estimated premium for an A rating was 1.8%, 3.9% for a B rating, a 1.9% discount for E ratings and 3.2% for F and G ratings. It is worthwhile mentioning that the absence of age monitoring in this study, which is likely to be substantially negatively associated with energy efficiency ratings, is considered a shortcoming of this investigation.

In the United Kingdom, Fuerst and McAllister (Fuerst & McAllister, 2011a, 2011b) analysed the influence of EPC rating on capitalization rate, (appraised) market values and market rents using 708 commercial properties during September 2010 (de Haan & Krsinich, 2018; Fuerst & McAllister, 2011a, 2011b). No major impact of the EPC rating on the appraised market rent or market value was found, with poor evidence of impacts on the rates of capitalization, found.

Another study on the UK market more recently, also by Fuerst et al. (Kok & Jennen, 2012) investigated whether energy performance ratings, as measured by mandatory Energy Performance Certificates (EPCs), were reflected in the sales prices of residential properties. The study was the first large-scale empirical study on this topic in England, and involved 333,095 dwellings sold at least twice in the period between 1995 and 2012. By applying hedonic regression analysis, and an augmented repeat sales regression, the authors found a positive relationship between the energy efficiency rating of a dwelling and the transaction price per square metre.

The main difference between Brounen and Kok (Hyland et al., 2013), Hyland et al. (Heckman, 1974) and the Fuerst et al. (Kok & Jennen, 2012), is that EPCs are compulsory for nearly all new-build and dwelling transfers in the UK, meaning that selection bias due to missing EPCs would not be significant. Moreover, both Brounen and Kok (Hyland et al., 2013) and Hyland et al. (Heckman, 1974) used listing prices or sales price data obtained by realtor organizations whilst Fuerst et al. (Kok & Jennen, 2012) used official price information as reported by the authorities (Land Registry data).

Nearly all studies apply a variant of Rosen's hedonic model (Melser, 2005) to estimate the price impact of an environmental mark. We expand on the above work in this paper and use a broad sample of first sales transactions to examine whether and to what degree an energy rating may affect the price of dwellings and the rate of change in the prices of dwellings in Oxfordshire. Before explaining the dataset and procedure, in the next section, we present the mathematical formulation of the hedonic regression which will be used to analyse the impact of EPC ratings on property prices. Table 1 summarizes relevant literature review findings on EPC valuation.

3. Mathematical representation

Direct hedonic regression is the common approach to constructing a quality-controlled price index. With the direct hedonic approach, also known as time-dummy hedonic method, a pooled regression is estimated with the logarithm of price explained by a set of quality characteristics and time-dummy variables indicating the time periods (Bajari & Benkard, 2005; de Haan & Krsinich, 2018). By exponentiating the time dummy coefficients, quality-adjusted price index numbers are simply obtained. In most applications, time dummy models are calculated by Ordinary Least Squares (OLS) regression, where each observation receives the same weight (Blomquist et al., 1988).

The Hedonic model was first introduced by Rosen in 1974 (Melser, 2005). Later the theoretical foundations and empirical framework of the model were developed through many other works (see Bartik, 1987; Edlefsen, 1981; Epple, 1987; Gross et al., 1990; Martínez, 1992; Roback, 1982). The main principle of the Hedonic price index assumes that housing is a differentiated economic good characterized by a vector H of several physical and locational attributes. The features in this study consist of: dwelling age (a), size (f), number of rooms (r), type (q), district (l) and EPC rating (E). We can then represent a house with respect to the vector H such that:

$$H = H(a, f, r, q, l, E) \tag{1}$$

The main purpose of this study is to investigate how much a consumer is willing to pay for a house given a specific EPC rating? Later, we will use the same principles to examine

Table 1. Summary of relevant literature review main results on EPC valuation.

Author(s)	Country	Method	Dependent variable	Main findings
Brounen and Kok (2011)	Netherlands	Logit regression	Transaction price/m^2	Relative to D-labels, A-labelled homes sell at a 10.2% price premium and G-labelled homes at a 5% discount
Cajias and Piazolo (2013)	Germany	Hedonic regression	Transaction price/m^2 Rents/m^2	−1% energy consumption results in a premium of 0.45% in sales price and 0.08% in rental price.
Hyland et al. (2013)	Ireland	Hedonic regression	Listed price Rents	Relative to D-labels, A-labelled homes sell at a 9% price premium and rent at a premium just under 2%
Feige et al. (2013)	Switzerland	Hedonic regression	Rents/m^2	Sustainable features positively relate to rents
Högberg (2013)	Sweden	Hedonic regression	Transaction price	+1% energy performance results in a premium of 0,04% in sales price
Cerin et al. (2014)	Sweden	Hedonic regression	Transaction price/m^2	Energy performance levels command higher property values relative to reference values of similar properties.
Fuerst et al. (2015)	England	Hedonic regression + Repeat sales	Transaction price/m^2	Relative to D-labels, A- and B-labelled homes sell at a 5% price premium. C-labelled at a 1.8% premium. E- and F-labelled at a 1% discount. G-labelled homes sell at a 7% discount.
Chegut et al. (2016)	Netherlands	Hedonic regression	Transaction price/m^2	Relative to C-labels, A-labelled homes sell at a 6, 3% premium. B-labelled at a 2% premium.
Wahlström (2016)	Sweden	Hedonic regression	Market value	No premium prices for energy efficient houses found
Fuerst et al. (2016)	Finland	Hedonic regression	Transaction price	Relative to D-labels, A-, B- and C- sell at a 3.3% price premium
Olaussen et al. (2017)	Norway	Hedonic regression + Repeat sales	Transaction price/m^2	Energy label itself has no or a slightly negligible effect
Kholodilin et al. (2017)	Germany	Hedonic regression	Asking price/m^2 Rents/m^2	Energy efficiency is capitalized in house prices
Dressler & Cornago (2017)	Belgium	Hedonic regression	Rents/m^2	Highly energy efficient dwellings result in an average rent premium of 4.8%
Aydin et al. (2017)	Netherlands	Hedonic regression + Repeat sales	Transaction price	EU energy labels do not lead to change in buyer's valuation
Cajias et al. (2019)	Germany	Hedonic regression	Rents	Energy efficient rentals receive small premiums
Khazal & Sønstebø (2020)	Norway	Hedonic regression	Rents	Relative to non-labelled homes, rent premiums of respectively 6.9%, 6.6% and 5.5% for A-, B- and C-labels.

whether other factors may also affect the consumer's willingness to pay for a house given some value from that factor.

Therefore, it is convenient, in the context of this study to introduce the concept of bid-rent, a geographical economic theory initially developed to study how the price and demand for real estate change as the distance from the central business district (CBD) increases (Costello, 2000; Galster, 1977; Wheaton, 1974; Whitehand, 1972). The theory assumes that whilst in commercial sectors are willing to pay maximum premiums for properties located in central business districts, industry sector participants on the other hand do not necessarily prefer to be located at the CBD due to the impact on production costs and the large area requirements for developing their businesses.

Suppose for any customer, M is level of income, U represents the utility, S represents a range of annual savings or benefits, B is the bid-rent for the house, and then the individual's budget constraint can be written as.

$$M = B + c + t - S(1 - \partial)^n, \tag{2}$$

Where c is the undifferentiated numeraire commodity, t is any additional cost obtaining energy efficient features and appliances to comply with regulatory standards, the bid–rent, B, is the consumer's willingness to pay for a house h and ∂ is the discount rate and n is number of years over which savings will accrue.

Combining Equation (1) and (2), we can then represent the bid–rent B in our case as follows:

$$B = B\{a(.), f(.), r(.), q(.), l(.), E(.)\} \tag{3}$$

The empirical estimation of the theoretical model represented in Equation (3) is governed by the following:

$$lnp_i^t = \delta^t + \sum_{k=1}^{K} \beta_k Z_{ik} + \varepsilon_i^t, \tag{4}$$

where p_i^t denotes the price of the item I; Z_{ik} is the fixed quantity of the feature k (age, size, number of rooms, EPC rating, etc.) for item I, and β_k the corresponding parameter; δ^t is the intercept; by assumption, the error ε_i^t are independently distributed with an expected value of zero.

The parameters β_k in (1) are constant over time, which allows us to estimate the model on the pooled data of the item samples $S^0, S^1, \cdots, S^T$ (e.g. EPC rating $N^0, N^1, \cdots, N^T$) in periods $t = 1, \cdots T$.

The estimating equation for the pooled data is:

$$lnp_i^t = \delta^0 + \sum_{t=1}^{T} \delta^t D_i^t + \sum_{k=1}^{K} \beta_k Z_{ik} + \varepsilon_i^t, \tag{5}$$

where the time-dummy variable D_i^t has the value 1 if the observation pertains to period t and the value 0 otherwise; the time-dummy parameters δ^t shift the hedonic surface upwards or downwards as compared to the base period value δ^0.

Suppose Equation (5) is estimated by WLS regression using weights w_i^0 and $w_i^t(t = 1, \cdots T)$, yielding parameter estimates $\delta\hat{0}$, $\delta\hat{t}$ and $\beta_{\hat{k}}(k = 1, \cdots K)$. We assume the weights are normalized such that they sum to unity in each period, i.e. $\sum_{i \in S^0}^{K} w_i^0 = 1$ and $\sum_{i \in S^t}^{K} w_i^t = 1$. Since changes in the item characteristics are controlled for, $\exp(\delta\hat{t})$ is an estimator of quality-adjusted aggregate price change going from the base period 0 to period t. An explicit expression for the time dummy index can be derived as follows. The predicted prices for the base period and the comparison periods $t(t = 1, \cdots T)$

$$p_{\hat{i}}^0 = \exp(\delta\hat{0}) \exp\left[\sum_{k=1}^{K} \beta_{\hat{k}} Z_{ik}, \right]; \tag{6}$$

$$p_{\hat{i}}^t = \exp(\delta\hat{0}) \exp(\delta\hat{t}) \exp\left[\sum_{k=1}^{K} \beta_{\hat{k}} Z_{ik}, \right]. \tag{7}$$

Taking the weighted geometric average of the predicted prices for all items belonging to the samples $S^0, S^1, \cdots, S^T$, using the weights w_i^0 and w_i^t, yields

$$\prod_{i\in S^0}(p_{\hat{i}}^0)^{w_i^0} = \exp(\delta\hat{0})\exp\left[\sum_{k=1}^{K}\beta_{\hat{k}}\sum_{i\in S^0}^{K} w_i^0 Z_{ik}\right]; \tag{8}$$

$$\prod_{i\in S^t}(p_{\hat{i}}^t)^{w_i^t} = \exp(\delta\hat{0})\exp(\delta\hat{t})\exp\left[\sum_{k=1}^{K}\beta_{\hat{k}}\sum_{i\in S^t}^{K} w_i^t Z_{ik}\right]; \tag{9}$$

Dividing Equation (9) by (8) and some rearranging gives

$$\exp(\delta\hat{t}) = \frac{\prod_{i\in S^t}(p_{\hat{i}}^t)^{w_i^t}}{\prod_{i\in S^0}(p_{\hat{i}}^0)^{w_i^0}}\exp\left[\sum_{k=1}^{K}\beta_{\hat{k}}\left(\sum_{i\in S^0}^{K} w_i^0 Z_{ik} - \sum_{i\in S^t}^{K} w_i^t Z_{ik}\right)\right]; \tag{10}$$

Due to the inclusion of time dummies into Equation (5), the weighted regression residuals sum to zero in each time period, yielding in:

$$\prod_{i\in S^0}(p_{\hat{i}}^0)^{w_i^0} = \prod_{i\in S^o}(p_i^t)^{w_i^0} \text{ and } \prod_{i\in S^t}(p_{\hat{i}}^t)^{w_i^t} = \prod_{i\in S^t}(p_i^t)^{w_i^t}$$

Substitution into (10) gives

$$P_{\hat{TD}}^{0t} = \exp(\delta\hat{t}) = \frac{\prod_{i\in S^t}(p_{\hat{i}}^t w_i^t)}{\prod_{i\in S^0}(p_{\hat{i}}^0 w_i^0)}\exp\left[\sum_{k=1}^{K}\beta_{\hat{k}}\left(\sum_{i\in S^0}^{K} w_i^0 Z_{ik} - \sum_{i\in S^t}^{K} w_i^t Z_{ik}\right)\right]; \tag{11}$$

The bracketed exponential factor in (11) adjusts the ratio of weighted geometric average prices for changes in the weighted average characteristics. This factor is equal to 1 if the average characteristics are constant over time. The time dummy index then simplifies to the ratio of weighted geometric average prices.

4. Methodology

4.1. Primary research data

To establish the relationship between EPC ratings and house prices, following the literature review, this study employs a large sample of Oxfordshire properties sold (i.e. the entire market) between 1995 and 2023 that cover all districts of the Oxfordshire region. Considering the entire market sales would mitigate the potential biases arising from investigating small samples by ignoring some unobserved property features. According to Yin (Yin, 2009), larger data sets increase precision and bigger sample sizes reduce potential bias. Therefore, this up-to-date dataset is expected to offer accurate analysis of the market, identify recent trends and patterns concerning the residential market in Oxfordshire and also capture any possible impact of COVID, BREXIT and any potential energy crisis caused by the Russia-Ukraine conflict.

In this analysis, the hedonic estimate, used data from three main areas: market rates, energy efficiency and location. The required data for these areas were collected from different sources and they have been merged into a central database. The UK Land Registry was used to provide data on the market price including the transactions prices, dwelling age and year of sale. Furthermore, other data sets were collected from the Ministry of Housing, Communities & Local Government on current EPC ratings, number of rooms, and dwelling type, total floor area and location. Figure 1 summarizes the research methodology.

In this study, a sample of sales dwellings that were sold between 1995 and 2023 in the Oxfordshire region were used. Furthermore, it was considered that at least one transaction occurred after August 2008, when all residential transactions in the UK were 'subjected' to mandatory energy efficiency labelling. As shown in Figure 1, the analysis focuses on dwelling attributes: dwelling type (i.e. detached, semi-detached, terraced and flat), dwelling age, year of sale, number of rooms, total floor area, EPC rating and the district. The collected data from both datasets were correctly matched, the sample was further defined by removing duplications and eliminating outlier dwellings such as a very large number of rooms in a very small area or prices that do not reflect the actual cost of a dwelling. The resultant sample used in this study included 186913 transactions. It can be seen from Figure 2 that the sample distribution across the districts of Oxfordshire is nearly close, with the largest sales in Cherwell (29.9%) and the least sales in West Oxfordshire (15%). In terms of dwelling type, terraced houses were most prevalent (66,749), followed by semi-detached (62,806), flats (38,911) and detached houses (35,016). Unidentified dwelling types (743) were excluded.

In addition to the methodology summary in Figure 1, further descriptive statistics about the sample is presented in Table 2.

The distribution of dwelling types shows that around 34% of the dwelling units in the sample are terraced dwellings, followed by semi-detached (31%.) Flats come in third place at 19% and then detached dwellings (16%). The distribution of dwellings across EPC bands as also presented in Table 2 shows that most dwellings (85%) fall in bands B and C. Only 2869 dwellings (2%) account for properties in band A, 9% in band D, 1.9% in E and finally 0.45% in bands F and G. This is indicative that the market is responsive to policy signals of optimizing the energy efficiency of buildings. From a broader perspective, Heath (Heath, 2021) points out that the vast majority of homes receiving one of the top energy efficiency grades were in band B, with 82% of new homes in England achieving a B and 83% of new homes in Wales.

4.2. Descriptive analysis

Table 2 suggests that terraced houses appear to be the most energy-efficient form of dwelling with the highest numbers falling in bands A (with 4.17%) and B (with 54.13%). In comparison, flats falling in bands A or B, are showing the least numbers suggesting that they are the least energy-efficient form of all dwelling types, followed by semi-detached and detached with 1.57% in band A, 53.69% in B, and with 0.54% in band A, 45.89% in B, respectively.

The distribution of age across the EPC band on the other hand is presented in Figure 2. The Figure shows that dwellings built in 2012 onward, appear to have the highest percentage of dwellings rated A, whereas dwellings, constructed in 2007 onward, fall mostly in band B. Further, those constructed in the 1990s onward tend to fall in bands D and E, and

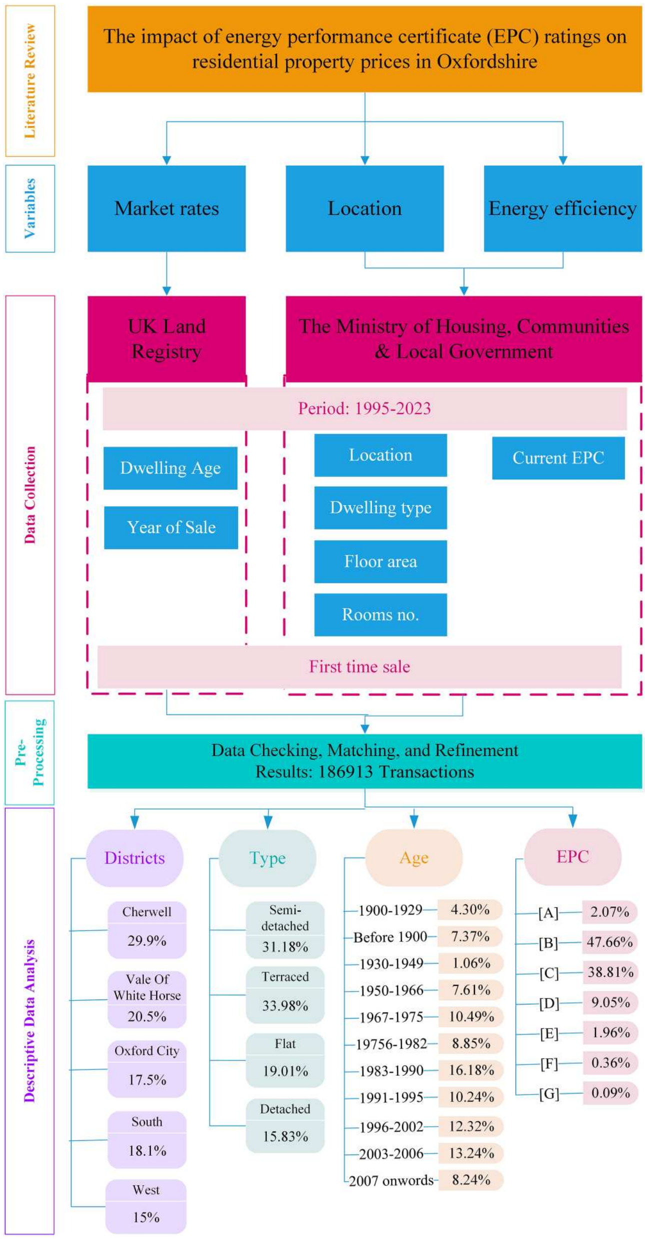

Figure 1. Research methodology summary.

even older dwellings are distributed between bands F and G. The Figure, therefore, suggests that the relationship between EPC ratings and age variables indicate that older dwellings tend to have lower EPC ratings than modern ones Figure 3.

Aside age, it can be seen from Figure 4 that most dwellings fall in Bands B and C. For example, in the '1930–1949' category, the highest proportion of properties (about 44%), fall in B and C. However, the generally held assumption that older buildings might not be as energy efficient should be of note here. According to the Office for National Statistics

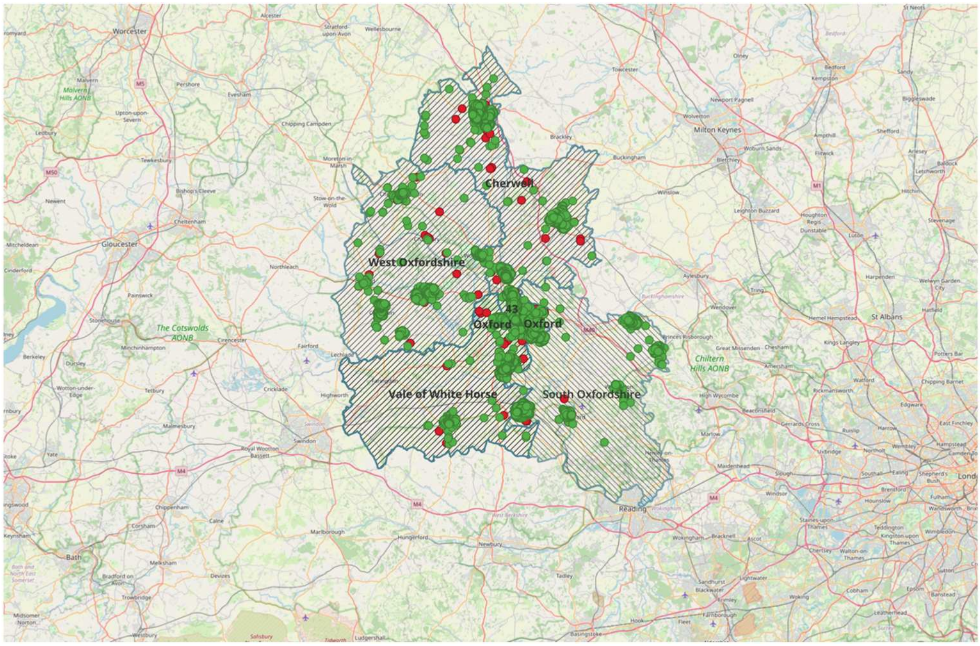

Figure 2. Distribution of dwellings involved in the study across the four districts in Oxfordshire.

(Famuyiwa & Babawale, 2014), the age of a property is the biggest single factor in energy efficiency of homes. However, in this market, this 'notion' may be diminished, due to specific retrofit strategies. This may not be too far from the partnerships formed by the Oxfordshire County Council in transforming domestic retrofit provisions in Oxfordshire. Again, as mentioned above, this is indicative that the market is responsive to policy

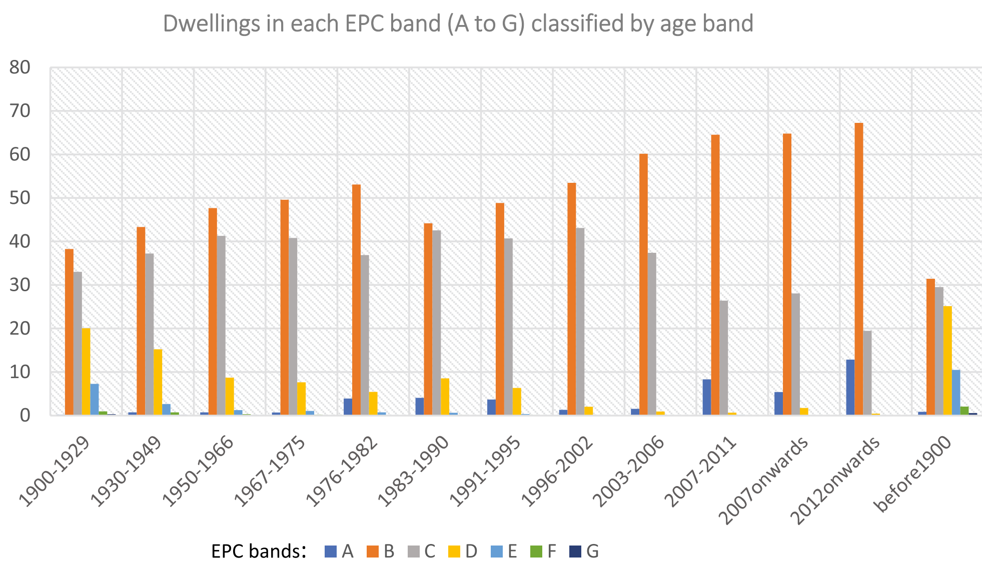

Figure 3. Dwellings in each EPC band (A–G) classified by age band.

Table 2. Cross tabulation between property type and EPC rating.

EPC Band	Detached		Semi-Detached		Terraced		Flat		Totals	
A	161	0.54%	915	1.57%	2647	4.17%	146	0.41%	3869	2.07%
B	13,579	45.89%	31,289	53.69%	34,378	54.13%	9846	27.70%	89,092	47.66%
C	12,104	40.91%	19,351	33.21%	19,191	30.22%	21,887	61.59%	72,533	38.81%
D	3006	10.16%	5152	8.84%	5724	9.01%	3028	8.52%	16,910	9.05%
E	595	2.01%	1302	2.23%	1290	2.03%	469	1.32%	3656	1.96%
F	113	0.38%	215	0.37%	228	0.36%	123	0.35%	679	0.36%
G	32	0.11%	48	0.08%	54	0.09%	40	0.11%	174	0.09%
Totals	29,590	100	58,272	100	63,512	100	35,539	100	186,913	100

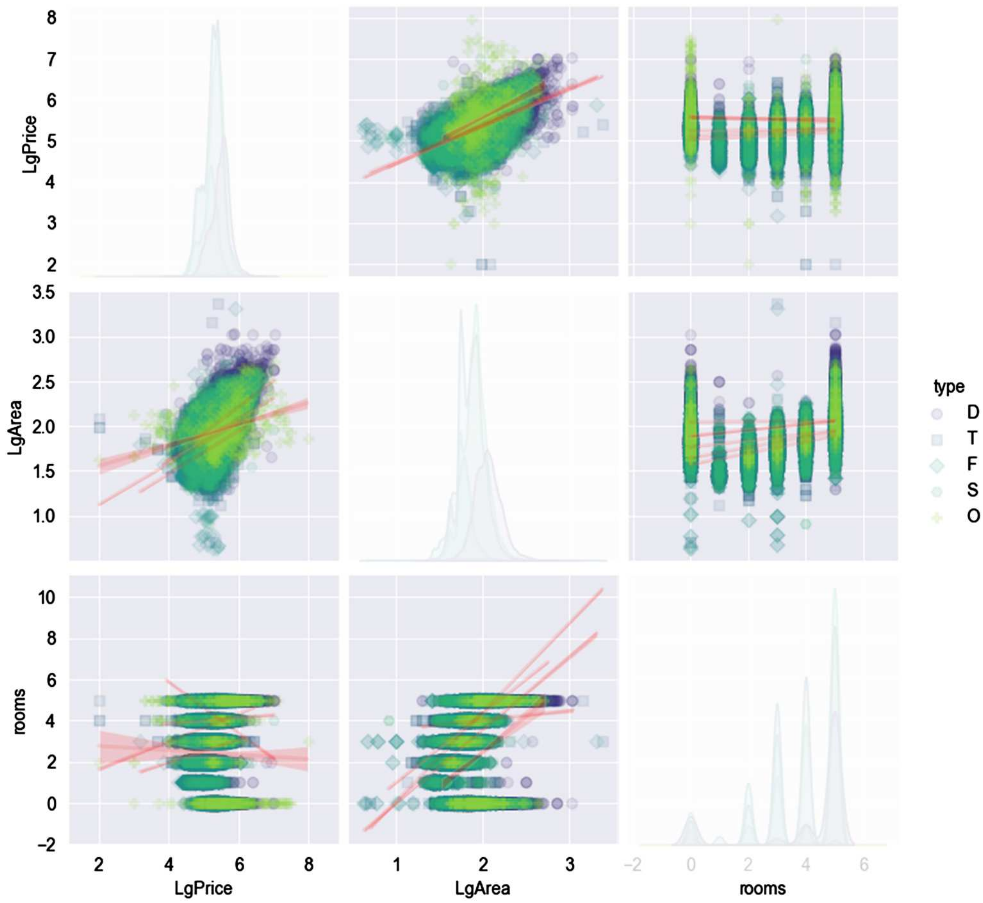

Figure 4. Correlation between price and both number of rooms and floor area.

signals of optimizing energy efficiency of buildings. Most dwellings in this study are owned on a freehold tenure. However, tenure type was not examined in this study. Moreover, dwellings with missing data, such as dwellings with missing age information (10%) were dropped. For variables such as the 'number of bedrooms'; and 'area of dwelling', we used the log value, since both are not the focus of this study and are obvious factors for increasing house premiums. To emphasize the effect of such a factor we introduce Figure 3.

As for the distribution of dwellings: Table 2 also provides information about housing distribution in different districts. Cherwell has the highest number of houses with 49,378, accounting for 32.62% of the total housing count, and 8148 flats, making up 22.93% of the sub-total flats. Oxford follows, with 29,093 houses, representing 19.22% of the total house count, and 9989 flats, contributing to 28.11% of the sub-total flats. South district has 28,183 houses, representing 18.62% of the total house count, and 5126 flats, comprising 14.42% of the sub-total flats. In the West district, there are 24,432 houses, representing 16.14% of the total house count, and 5334 flats, accounting for 15.01% of the sub-total flats. Finally, the Vale of White Horse district has 20,288 houses, making up 13.40% of the total house count, and 6942 flats, contributing to 19.53% of the sub-total flats. Overall, Cherwell and Oxford have the highest percentage of houses, while

Oxford has the highest percentage of flats among the districts. The table also presents information about dwelling age, and EPC analysis across houses and flats.

Lastly, before discussing the results, we show the number of sales between 1995 and 2023 – as presented in Figure 5. At first glance, it is clear that the number of sales continued to behave in the same pattern up until the year 2007 where a sharp decline can be seen during 2008. This drop could be attributed to the global crises in the real-estate market which took place in that same year. The graph shows that in 2009, sales to recover and continue up until the year 2020, where another decline can be seen in number of sales. To recover from the COVID crises, the UK government imposed a number of initiatives to encourage sales, including the waiving of stamp duty. The effect of such acts can be clearly seen as a sharp rise in sales start during 2021. The same pattern again can be seen after 2022 with another sharp drop in sales due to the Ukrainian crisis, which again, aligns with global market trends.

5. Results

Next, we fit regression models to both the full collection of observations and the subsamples of the various types of dwellings and present the results in Table 3. The table summarizes the trends that provide insights into the relative performance of dwelling prices first. In this study, the log–log hedonic regression functional form was used, to express the relationship between our dependent and independent variables. Variations in hedonic regression models exist, on the basis of model specification, variable selection, data quality and analytical techniques. Specifically, this study adopted the use of the log–log model for model specification, due to the large data set employed. In Taylor (Taylor, 2022), the log–log model is often used when dealing with large data sets.

Essentially, the log of the dwelling total price is defined as a function of the log of the number of bedrooms, and the log of the total area in addition to EPC rating, dwelling type, county and dwelling age. Although this approach would reduce the effects of a property's size and number of rooms in the estimation, it would, however, increase the model's predictive ability to reflect on the effect of other attributes of interest in this research (i.e. the EPC rating, dwelling type, county, age) on house prices. The overall

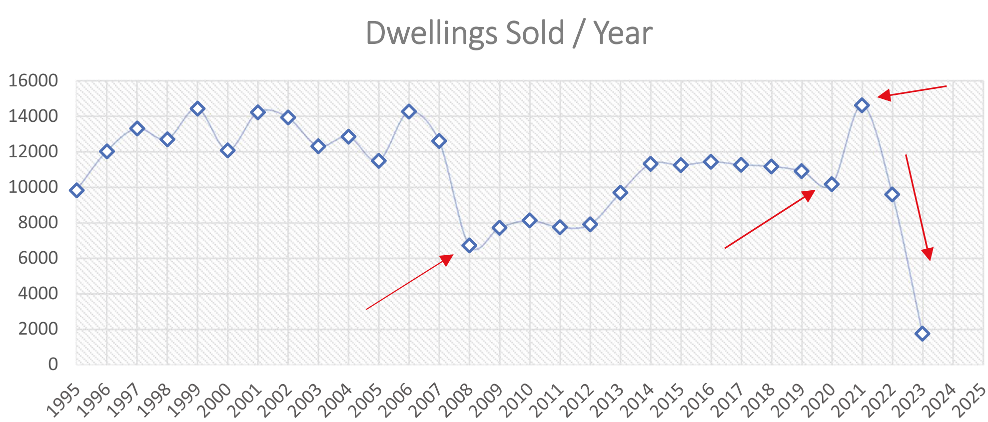

Figure 5. The actual number of houses sold between 1995 and 2023.

Table 3. Energy rating and price: hedonic estimations (dependent variable: log of total price).

	ALL		Detached		Semi-detached		Terraced		Flats	
			EPC Band							
EPC A	0.308	***	0.385	***	0.266	**	0.331	***	0.308	***
EPC B	0.317	***	0.425	***	0.208	*	0.341	***	0.317	***
EPC C	0.309	***	0.407	***	0.214	**	0.331	***	0.309	***
EPC D	0.289	***	0.381	***	0.203	*	0.312	***	0.289	***
EPC E	0.170	***	0.305	**	0.053		0.207	**	0.170	***
EPC F	0.111	*	0.072		0.047		0.177	*	0.111	*
EPC G	hold-out		hold-out		hold-out		hold-out		hold-out	
Dwelling Type										
Detached	0.199	***	–		–	–	–	–	–	–
Semi	0.011	***	–		–	–	–	–	–	–
Terraced	hold-out		hold-out		hold-out		hold-out		hold-out	
Flats	−0.111	*	–		–	–	–	–	–	–
Year Built										
1900–1929	−0.043	***	0.012		−0.035	*	−0.065	***	−0.043	***
1930–1949	−0.123	***	−0.008		−0.154	***	−0.159	***	−0.123	***
1950–1966	−0.119	***	0.016		−0.153	***	−0.189	***	−0.119	***
1967–1975	−0.150	***	−0.077	***	−0.174	***	−0.178	***	−0.150	***
1976–1982	−0.139	***	−0.068	***	−0.203	***	−0.120	***	−0.139	***
1983–1990	−0.164	***	−0.123	***	−0.228	***	−0.131	***	−0.164	***
1991–1995	−0.229	***	−0.221	***	−0.296	***	−0.177	***	−0.229	***
1996–2002	−0.132	***	−0.174	***	−0.148	***	−0.084	***	−0.132	***
2003–2006	0.074	***	0.024		0.060	***	0.108	***	0.074	***
2007–2011	0.191	***	0.084		0.212	**	0.236	***	0.191	***
2007 Onwards	0.146	***	0.127	***	0.122	***	0.165	***	0.146	***
2012 Onwards	0.293	***	0.245	**	0.312	***	0.378	***	0.293	***
Before 1900	hold-out		hold-out		hold-out		hold-out		hold-out	
District										
CHERWELL	−0.163	***	−0.152	***	−0.160	***	−0.156	***	−0.159	***
OXFORD	0.190	***	0.272	***	0.114	***	0.252	***	0.169	***
VALE	0.059	***	0.058	***	0.036	***	0.088	***	0.063	***
WEST	−0.018	***	−0.044	***	−0.047	***	0.034	***	−0.013	*
SOUTH	hold-out		hold-out		hold-out		hold-out		hold-out	
(Intercept)	9.161	9.298	9.233	9.670	9.344					
Adjusted R^2	0.634	0.319	0.251	0.273	0.317					
Signif. codes:	0 '***'	0.001 '**'	0.01 '*'	0.05 '.'	0.1 ' '					

explanatory power in this table also shows that for the full study, the adjusted R^2 is around 63% and the coefficients of the independent variables are highly significant and largely have the expected signs.

The coefficients corresponding to all variables affecting the housing prices (i.e. column 1, Table 3) have been presented in Figure 6.

It is noteworthy that the hedonic model's explanatory power is lowest for the sub-samples of all dwellings with R^2 ranging between 30% for mid-terraced up to 44% for detached and bungalow sub-samples, but much higher for the whole sample (around 63%). In general, high R^2 values will normally give the best specification (Babawale & Johnson, 2012) Other reasons for this phenomenon may be attributed to this particular group's greater heterogeneity, which would include large homes along with a wide range of dwellings, constructed over many centuries in vernacular styles.

First, we begin with the most obvious observation in Table 3 which is the variable under investigation – EPC rating. Band G represents the 'hold-out' category. When applying the estimation on the full sample (column 1 of Table 3), the findings show a consistent pattern – a positive relationship between energy performance rating, and sales price. The

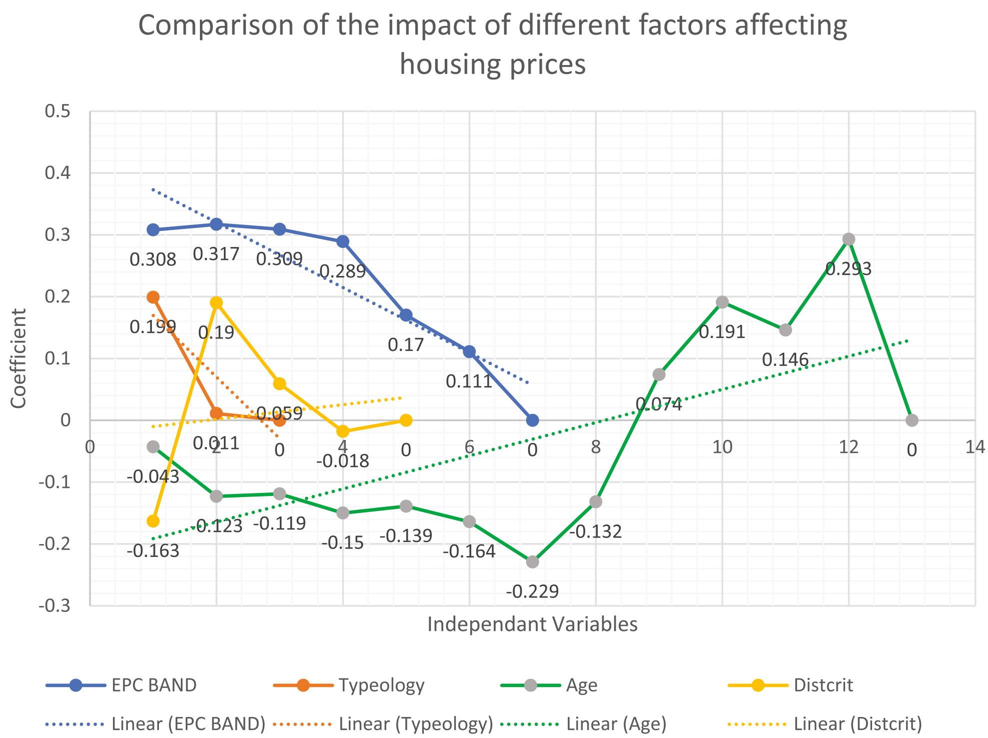

Figure 6. Comparison of the impact of different factors affecting housing prices.

same full-sample analysis, also suggests that with a 32% influence, band B ratings, show the most significant positive impacts on house prices. This is also true for detached, terraced and flats, but not equally significant for semi-detached category. The same exact pattern can also be seen in EPC band D and across all the sub-samples, corresponding to different dwelling types on the same row. Conversely however, band F exhibits an almost non-significant impact on neither the whole sample nor in any of the sub-samples corresponding to different dwelling types on that same row. Finally, in the EPC analysis, Band E shows the greatest variability in dwelling prices, with a statistically significant impact on the overall sample and on flats, whilst showing no strong relation across the other sub-samples (detached, semi-detached, terraced) on that same row. This may be due to the prohibition of renting out such 'low banded' properties (F), as the minimum requirement is a Band E – based on government regulations. At the same time, the existence of other implicit demand indicators would create some amount of consideration for potential owner occupiers in house purchase decisions.

Another rather, expected impact on house premiums is the dwelling type. It can be observed that detached dwellings are almost 20% more expensive, when compared with terraced units (the hold-out category). Additionally, semi-detached dwellings also show a significant positive effect on price premiums, but with a marginal difference of around 1% only. Lastly, flats, unlike other dwelling types, show a negative impact, when compared to terraced dwellings – with about 11% negative deviation in price. It is worth mentioning that when purchasing flats in the UK, buyers are also required to pay a ground rent, and an annual service charge which may account for why flats are the least desirable dwellings to purchase.

On the other hand, the effect of age on the total price, tends to be significantly negative with dwellings built between 1900 and 2002 compared to those built before 1900 (the hold-on category). This is also true for both the terraced and flat sub-markets. This may however be attributable to the fact that buildings which may be classified as 'historic' tend to have price premium effects that deviate from the negative correlation impact which age is known to have on price (as with buildings constructed at later dates). Moreover, period properties are sought after, so can achieve higher asking prices. Detached dwellings however show some variability pattern where only those built between 1967 and 2002 share the same negative impact, whilst those built before 1967 have no significant impact. The positive impact of age on total price is primarily significant in dwellings built from 2003 onwards, which also applies to all other sub-market, except for detached buildings, built between 2003 and 2011 which, again, show no statistical significance.

Lastly, looking at the effect of location on property prices, results suggest that properties in the city of Oxford are sold for significantly higher premiums than those around the city. This is also true for all types of dwellings in the other submarkets across the table. Table 3 further demonstrates that dwellings in Cherwell consistently experienced statistically significant lower dwelling prices ranging from between 15%, for detached, to around 16% less, for semi-detached dwellings, compared to the South Oxfordshire district – over time. Conversely, the Vale of White Horse district experienced statistically significant higher dwelling prices ranging between 3% for semi-detached and 8% for terraced houses, indicating strong and positive effects. Dwellings in the West of Oxfordshire district, on the other hand, exhibited more variability in dwelling prices, with both decreases (detached, semi, flats) and increases (terraced). These trends provide insights into the relative performance of dwelling prices in these counties, compared to the South of Oxfordshire. This conforms to existing theory on location having one of the greatest effects on price. Greer and Kolbe (2003) in Famuyiwa and Babawale (Famuyiwa & Babawale, 2014) assert that a property's location is a primary determinant of its market share as the usefulness of other characteristics of a property will wane with the passing of time.

6. Conclusion and policy implications

As mentioned in the earlier part of this paper, energy labelling enforcement of buildings could prompt market vibrancy through an upward movement in prices, serving as policy instruments (market-based policies) towards a rich supply of energy-efficient buildings. Empirical studies of this nature, on the existence and extent of the price effects of energy labelling, is important in evaluating the effectiveness of this type of policy instrument.

There has been an increasing effort over the past decade on improving the environmental performance of housing units, due to the growing concern about man-made impacts on climate change. At its core, the EU's compulsory energy efficiency certification has been enforced, to improve customer behaviour by supplying consumers with accurate information on the energy output of dwellings. Moreover, the primary concept underpinning the implementation of market-based policy instruments, such as EPC certifications is due to the fact that it is often difficult for customers to determine those desired characteristics directly such as energy efficiency. Therefore, it would exploit energy-efficient characteristics, which in turn, would stimulate an increased supply of new energy-efficient dwellings and refurbish existing dwellings in order to boost their energy efficiency.

Based on a sample of **186913** dwellings with mandatory energy certificates, the vast majority of dwellings in the middle EPC bands are clustered (C, D and E). A 'B rating' is associated with nearly half of all dwellings. From Figure 2, it is not surprising, that the connection between energy efficiency and age is apparent. Only 29% of dwellings constructed before 1900 have at least a B – rating or higher, compared to 65% of dwellings built since 2007. The findings suggest a strong linear relationship between energy efficiency ratings and the total price, on the overall sample, and across all other sub-samples.

As in the majority of the UK markets, house prices in Oxfordshire are influenced primarily by location, size and dwelling type. Hence, it is not surprising that there is, generally, a positive relationship between price and the energy efficiency of a dwelling. It should be noted that there are major challenges when estimating the equilibrium prices of the component characteristics in house price. For example, it is not practical to include the full range of price-determining variables in the model since not all dwellings share the same exact characteristics (e.g. swimming pool, or a garage). This is a common issue in Hedonic analyses and known as the omitted variable bias that can lead to biased estimates of the effects of included variables and consequently inaccurate predictions of property prices. Hedonic studies are afflicted by the 'omitted variable' bias and endogeneity problems as a result of using only the common price-determining variables in the Hedonic model. We also conclude that in the Oxfordshire residential market, such energy-efficient market-based policy mechanisms mentioned in the earlier part of the paper, have been efficient in selected market segments. The reasons attributable to the variations within the market will create the basis for further studies.

The study analyses Oxfordshire's diverse housing market, from historic Oxford properties to new developments, to understand how EPC ratings impact property values. With a knowledgeable and eco-conscious population, and a strong economy blending high-tech, academia, and traditional sectors, Oxfordshire offers a unique setting for this research. Findings aim to inform policies, market strategies and public awareness, supporting a more energy-efficient and sustainable housing market.

The anticipated implications of this study's findings can be divided into three main areas: First, Policy Recommendations: The findings can inform local and national policymakers on the effectiveness of EPCs in driving market behaviour and supporting energy efficiency goals. This can lead to more effective and targeted energy policies. Secondly, Real Estate Market Insights: Real estate professionals can use the research to better understand buyer preferences and adjust their marketing strategies accordingly. This can enhance the marketability of energy-efficient homes and guide investment decisions. Thirdly, Public Awareness: Increased understanding of the financial benefits of energy efficiency can drive public demand for greener homes, contributing to broader environmental goals and improving overall housing quality.

Finally, whilst it would have been interesting to have gone further to analyse the pricing effects between energy efficiency rankings (e.g. the differences in pricing effects between EPC level C to EPC level B, or B to A), this was not covered in the study, due to the focus of study being broad. This may therefore be considered a limitation of study, and would create a basis for further studies in the area. In the same vein, the reasons attributable to the pricing variations within energy efficiency rankings within the market will create the basis for further studies.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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