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ENERGY PERFORMANCE RATINGS AND HOUSE PRICES IN WALES: AN EMPIRICAL STUDY

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Abstract

This paper investigates the price effect of EPC ratings on the residential dwelling prices in Wales. It examines the capitalisation of energy efficiency ratings into house prices using two approaches. The first adopts a cross-sectional framework to investigate the effect of EPC band (and EPC rating) on a large sample of dwelling transactions. The second approach is based on a repeat-sales methodology to examine the impact of EPC band and rating on house price appreciation. The results show that, controlling for other price influencing dwelling characteristics, EPC band does affect house prices. This observed influence of EPC on price may not be a result of energy performance alone; the effect may be due to non-energy related benefits associated with certain types, specifications and ages of dwellings or there may be unobserved quality differences unrelated to energy performance such as better quality fittings and materials. An analysis of the private rental segment reveals that, in contrast to the general market, low-EPC rated properties were not traded at a significant discount, suggesting different implicit prices of potential energy savings for landlords and owner-occupiers.

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1 Introduction

In the last decade a range of energy and environmental certification schemes have been introduced in the commercial and the residential property sectors of the real estate industry. In Wales, similar to many property markets, there is a blend of compulsory (e.g. Energy Performance Certificates, Display Energy Certificates) and voluntary (e.g. BREAAM) energy certification and eco-labels. In 2008 the measurement of energy use in new and existing buildings in the UK became obligatory as a result of the EU Energy Performance of Buildings Directive. The Directive required all buildings at the point of construction completion, sale or rent (or every 10 years) to have certificates giving information about their energy performance through a rating of CO_2 emissions. An EPC (and the accompanying recommendation report) is an asset rating which is intended to inform potential buyers or occupiers about the intrinsic energy performance of a building and its associated services. Buildings are rated on a scale of bands from A to G with band A being the most efficient. The rating is based on:

- Age
- Size (dimensions, floor levels)
- Construction (materials, solar gain / heat loss through openings)
- Space and water heating (efficiency, control)
- Lighting
- Insulation and ventilation
- Fuel and power used to provide heating, lighting and ventilation

Ratings are relative to standard energy use for the type of premises being assessed. In other words, assumptions are made, dependent on the dwelling size, regarding household size and composition, heating patterns, temperatures and hot water demand, and ownership and efficiency of domestic electrical appliances. No account is taken of the location of the dwelling. Dwellings are assessed using the UK Government's 2005 Standard Assessment Procedure (SAP) for Energy Rating of Dwellings. It produces annual estimates of:

- Energy consumption per unit of floor area
- SAP rating: 1-100 with higher number for lower running costs (based on energy costs, floor area adjusted so independent of size for a given built form)
- CO_2 emission per unit of floor area ($kgCO_2$/sqm/yr)
- Environmental impact rating: 1-100 with higher number for lower emissions (based on CO_2 emissions, floor area adjusted so independent of size for a given built form)

A reduced data SAP (RdSAP) is used to assess existing dwellings and this is of prime importance given the age of the vast majority of the housing stock. Given that SAP was introduced in 2005 it is fair to assume that EPCs of dwellings constructed (or subject to a change of use) since that year were assessed using full SAP. RdSAP consists of a series of defaults and inferences based on dwelling type, degree of detachment, age, and dimensions (see Table 1). Type and age of dwelling are used to infer window area. Wall type and age are used to infer U-values for walls, roofs and floors. Age is, therefore, a key variable.

Table 1 here

Environmental labels and energy certification schemes such as EPCs provide consumers with information on the environmental or energy performance of a product. With this information consumers are expected to change their behaviour and demand products that are less environmentally damaging and more energy efficient. This should lead to changes in supply and, ultimately, to changes in environmental impacts. Market prices are important in that they send signals from consumers to producers about what, where and when to produce. Price premiums in particular provide an economic incentive for producers to innovate and incur any additional production costs associated with improved energy performance. An important distinction in the residential transaction market is that between owner-occupiers and buy-to-let landlords. The latter category of buyers may value energy efficiency differently as the tenant typically pays energy bills. Thus, a buy-to-let landlord may only be willing to pay a premium for an energy efficient dwelling if the extra cost can be recouped from tenants via higher rents and improved cash flow regardless of energy costs. This study also investigates a sub-sample of properties which had an EPC issued for the purpose of a private rental marketing to compare the energy efficiency price premiums of this segment to the general housing market.

This paper investigates the price effect of EPC ratings on the residential dwelling prices in Wales and is structured as follows. Section 2 reviews studies of the price impact of environmental performance instruments on residential dwelling prices. Section 3 describes the data set and modelling approach used in this study. Essentially it examines the capitalisation of energy efficiency ratings into house prices using two approaches. The first adopts a cross-sectional framework to investigate the effect of EPC band (and EPC rating) on a large sample of dwelling transactions. The second approach is based on a repeat-sales methodology to examine the impact of EPC band and rating on house price appreciation. Section 4 presents the results and section 5 offers some concluding comments.

2 Literature review

Some economic goods and services comprise a bundle of attributes that consumers are willing to pay for. Dwellings are a classic example of this kind of good as they consist of various attributes (location, size, tenure, condition, etc.) that affect price. It can be challenging to measure the contribution of an individual attribute, such as energy performance, to the overall price paid for a bundle of attributes. All of the studies described below use hedonic regression to obtain estimates of the contribution each attribute makes to the overall price.

Deng *et al.* (2012) investigated the residential sales prices of 74,278 dwelling units in 1439 buildings in Singapore between 2000 and 2010. They applied a number of model specifications including OLS and GLS procedures and refined the sample using Propensity Score Matching (PSM). There were significantly different results depending on model specification. For the PSM regression, they estimated an average price premium for Green Mark of about 4-6%. The detailed breakdown was Platinum 14%, Gold Plus 2.3%, Gold 5.5% and Certified 0.1%. In an alternative specification, they estimated average price premium for Green Mark of about 14-21% (Platinum 21%, Gold Plus 15%, Gold 15% and Certified 10%).

In the US Bloom *et al.* (2011) reported that the ENERGY STAR homes in Colorado sold for $8.66 more per square foot than the non-ENERGY STAR homes. However, several modelling biases (e.g. effective controls for area fixed effects) and a small sample of properties (only 300 properties) weaken the argument substantially. Using a sample of 14,055 transactions (of which 6,781 were tagged as green) from the NTREIS housing transaction database for two urban centres in Texas (Frisco and McKinney), Aroul and Hansz (2012) used a standard hedonic procedure to estimate price premium of 2% for green transactions. When disaggregated into mandatory and voluntary green transactions, the respective premiums were 5% and 1%. It is unclear (albeit to the authors) how green and non-green buildings were differentiated given that there seems to have been a mandatory program. The study did not control for location and quality; green transactions may be associated with better quality neighbourhoods and meeting the green standards may be associated with higher specification homes. Kahn and Kok (2014) conducted a hedonic pricing analysis of all single-family home sales in California over the time period 2007 to 2012. Using a sample of matched properties based on the likelihood of having a green label and the local area weather condition, they found almost a 2% premium for green labels. While the perennial difficulty of measuring unobserved non-financial benefits of green label still remains, this study shows a robust positive association based on several alternative specifications. However, the results are based on comparing a relatively small ’treated’ sample with a substantially larger ‘non-treated’ sample.

Using a customised sustainability metric based on 36 variables to provide a sustainability score for each apartment, Feige *et al.* (2013) drew upon rental prices of a sample of 2453 residential apartments in Switzerland. Their results were inconsistent with some sustainability-related features having significantly positive effects, others having no statistically significant effect on price and some having a negative effect. It is notable that they found an unexpected negative relationship between energy efficiency and price. This was attributed to Swiss residential lease structures where landlords tend to recover the estimated cost of energy from tenants in advance. Hence, less energy efficient buildings may have appeared to have a higher rent since the energy cost is 'bundled' with rent.

Kholodilin and Michelsen (2014) also study the residential rental market and find for the Berlin housing market that energy efficiency savings are generally capitalised into prices and rents and that buyers are able to anticipate energy and house price movements sufficiently well. Another relevant finding for the present study is the significantly lower implicit prices of energy efficiency of rental dwellings compared to owner-occupied dwellings. The authors explain these differences as a sign of the market power of tenants or as a result of the split incentive problem. Similarly, Cajias and Piazolo (2013) find higher total returns and higher rents for energy-efficient dwellings in their study of the German housing market in the 2008-2010 period. They estimate that a one percent energy saving raises rents by 0.08 percent and the market value of a property by 0.45 percent.

In a recent study with an interesting focus on presale (dwellings bought from developers) and resale (dwellings sold by owners) prices, Deng and Wu (2014) compared a sample of 13,224 dwellings in 62 Green Mark developments with 55,983 dwellings in 1,375 non-GM developments in Singapore between 2000 and 2010. They applied a range of approaches including hedonic methods (supplemented by PSM) and difference-in-difference (DID) methods to investigate the price effects of the Green Mark certification. Similar to Deng *et al.* (2012), overall they estimate an average price premium of about 4-5%. In terms of the different levels of award, the estimated premium for the Platinum rating was 11%, the comparable figures for the Gold and Certified ratings were 5% and 1.6% respectively. There were significant differences between presale and resale price premiums with premiums for re-sales found to be substantially higher. Using a smaller sample of repeat transactions, DID approach estimates price appreciation premium for Green Mark dwellings of 2% to 3%. They infer from the results that developers are capturing a small part of the green premium. However, without details of costs of achieving GM certification, similar to most previous price studies they were unable to assess whether the price premium compensated developers for additional costs.

Turning to energy performance ratings in Europe, Brounen and Kok (2011) investigated the relationship between EPC rating and sale price for 31,993 residential sale prices in the Netherlands in 2008-9. They found price premiums of 10%, 5.5% and 2% for homes in bands A, B and C respectively compared to homes in band D. For dwellings in bands E, F and G they identified discounts of 0.5%, 2.5% and 5% respectively. Their data set contained a broad range of control variables including dwelling size, insulation quality, central heating and level of maintenance. However, their control for location was broad – at the province level – which may explain the low explanatory power of the four variants of the hedonic price model that were tested. A possible issue with the study is that it was based on sales of dwellings that had opted to have an EPC, a minority of total residential sales. Hyland *et al* (2013) analysed the impact of energy efficiency ratings in Ireland on residential asking prices and rental rates based on a rich data set of BER ratings (the Irish equivalent of the EPC) as well as property and price information. The authors found that A-rated properties achieve a sales premium of 9% and a rental premium of around 2% relative to D-rated properties. However, the analysis in Hyland *et al* (2013) does not appear to control for age of buildings and is thus in danger of misattributing age effects to energy efficiency effects. Finally, in a study closely related to this paper, drawing upon a large sample of 333,095 English housing transactions with mandatory energy certificates (in which there were eight A-rated houses) Fuerst *et al* (2015) found:

- The vast majority of houses were clustered in the middle EPC bands (C, D and E). Nearly half of all dwellings were in band D.
- Flats tended to be the most energy efficient dwellings with approximately half placed in band C (40%) or B (9.8%).
- There was a clear relationship between energy efficiency and age. Only 6% of dwellings built before 1900 had an EPC rating of C or better. The comparable figure for dwellings constructed since 2007 was 92%.
- Significant positive price premiums were found for dwellings rated A/B (5%) or C (1.8%) compared to dwellings rate EPC D. Although they are small, for dwellings rated E (-0.7%) and F (-0.9%) statistically significant discounts were estimated.
- Turning to price growth, the findings were less clear-cut. Dwellings in EPC band C experienced significantly higher price *growth* than those in band D. However, this was not the case for the dwellings in bands A and B, which experienced significant price depreciation compared to D-rated dwellings. Dwellings in band E (-0.18%) and F (-0.26%) were also estimated to have had statistically significant lower rates of price growth compared to D-rated dwellings.

A concern with the results of this study is that there was no control for potential omitted variable bias due to the absence of information on improvements and other quality variables such as age and condition of bathrooms and kitchens.

Table 2 summarises the sampling approach and key findings from these studies and provides a brief commentary on each.

Table 2 here

Some general points about these studies can be made. First, hedonic model estimates can be sensitive to choice of model specification and availability of information on variables that determine prices. This is particularly so if it is suspected that the price impact of an attribute (energy performance for example) is likely to be small in comparison to other attributes such as location and age. Data availability is, therefore, a major challenge to researchers in this area. The feasibility and quality of empirical research into the price effects of energy efficiency certification is dependent upon the availability of dwelling-level data on three main areas:

a) Market prices e.g. rents and sales
b) Environmental performance of real estate assets
c) Attributes of buildings – condition, improvements, age, size, location, quality, etc.

Data constraints may mean that certain attributes are omitted from the hedonic model, and this can lead to bias. For instance if age of dwelling is omitted and age and energy performance are considered to be correlated, the negative price effects associated with aging would be reflected in the energy efficiency measure. Alternatively, being energy efficient may only be one part of a bundle of 'extras' that a housing developer has used to create a superior product. For instance, homes with better energy performance may tend to be of a higher quality of construction. By omitting this variable (superior construction) a construction quality price effect may be misattributed as an energy efficiency price effect.

Second, house buyers can obtain a bundle of costs and benefits when they buy energy efficient homes that are not energy related. Certain attributes that enhance energy or environmental performance can also enhance other aspects of performance. For instance, houses need to have double-glazing and/or a modern water heating system in order to obtain a good EPC rating. However, double-glazing has additional benefits such as improved security and noise reduction that provide benefits in addition to reduced energy costs. Dwellings with a modern water heating system will have a more reliable system and/or a longer period to replacement in addition to reduced energy costs.

Third, usually, when reporting the price effect of an attribute, hedonic pricing studies present the result as a percentage price difference. In the case of EPC bands for instance, dwellings in band A may be reported as achieving prices that are 10% higher than those in band D. This is a relative measure and is usually expressed like this due to way that the econometric models were constructed. However, if the benefit of energy efficiency is received largely in absolute terms, then this relative measure may distort the price effect. For example, assume energy efficiency measures in a dwelling lead to savings worth £5 per square metre per annum and that this annual saving is capitalised into a sum of £100 per square metre as a capital saving. If it were further assumed that this capital saving is the main driver of any observed price premium and that the saving is much the same regardless of location, if it is expressed as a percentage of price paid (i.e. a relative percentage price premium) then this would vary substantially between high value and low value locations. So, if homebuyers were prepared to pay an additional £100 for energy savings, in a location with typical sale prices of £1,000 per square metre, this would be 10% price premium. In a location with an average price of £5,000 per square metre, the same absolute price increase (£100) would represent a much smaller relative price premium of 2%. There is some empirical evidence to support this: a study for the Department of Energy and climate Change in England (discussed below) found notable regional variations in the size of relative price premiums. Compared to a dwelling in EPC band D, the estimated premium in the North East was around 14%, in the East Midlands it was 7% and in London no significant price effect was estimated. These variations in relative price effects may be explained, at least in part, by the differences in average sale price; £1,500 per square metre in the North East, £1,800 per square metre in the East Midlands and £4,000 per square metre in London. As a consequence of higher average dwelling prices in England compared to Wales, it is expected that any observed relative price effect of energy performance would be larger for Wales than for England.

3 Data and modelling approach

The data comprised a sample of 191,544 transactions that took place between 2 January 2003 and 26 February 2014. 47,158 (25%) of these included a second transaction within this 11-year time period and this sub-sample was used in a 'repeat sales' hedonic price model. The fields included in the sample, together with descriptive statistics, are listed in the appendix. Two attributes that are essential controls for any residential hedonic price modelling are size (represented by number of bedrooms in this data set) and age. The former was not recorded for 17% of the transactions and the latter 37%. Depending on the extent to which the same observations were missing both data items, this reduces the size of the sample for hedonic price modelling significantly. Whether there is any systematic bias in non-recording of number of bedrooms and age is not known.

Around a third of the transactions involved dwellings located in the Cardiff postcode area, and a quarter in the Swansea area. In all, around two thirds were in south Wales. For those transactions where the number of bedrooms was recorded (83% of the sample) 94% involved dwellings that had between two and four bedrooms. The vast majority of the sample observations involved freehold transactions. It would appear that, generally speaking, if a dwelling was built before the beginning of the twentieth century then it was recorded as having been built in 1900. This seems to be the logical explanation for nearly 16,000 dwellings being allocated to that year, a number comparable to the total built over the following 30 years. On that basis, and having taken the missing values into account, 19% of the sample transactions involved dwellings built before the twentieth century. Each decade from 1950 onwards comprises between 6% and 9% of the total number of transactions for which age has been recorded except 2000-09, which includes 15% of the sample. The effect of price inflation on the second price statistics can be seen. Each dwelling was geo-coded at the postcode level using the National Statistics Postcode Directory. Inclusion of this data set allowed further, potentially value significant, attributes to be appended. These included output area classification, an urban-rural indicator and a variable that recorded whether or not the dwelling was situated in a national park.

We employed a hedonic model to estimate the effect of EPC ratings on house prices. Hedonic modelling is a long-standing and well-established empirical framework to investigate the contribution of individual elements of a multi-faceted economic good. It is especially useful for understanding the pricing of a heterogenous good such as a house, which serves many purposes. The economics of hedonic modelling centre on prospective consumers' willingness to pay for various attributes, the subsequent bidding process and resultant market prices. In the context of this research Fuerst *et al.* (2015) have described the modelling approach in detail and in this paper we follow the approach closely.

Housing as a differentiated commodity can be characterized by a vector h of various physical and locational attributes such as age (a), size (f), location (L), quality (Q) and EPC rating (E). A consumer draws utility variously from these components. Therefore, quantified measures of these attributes can provide a reasonable estimation of the consumer's utility function. However, these individual attributes are not independent of each other and are not exogenously determined, which are what a regression model needs to assume to draw unbiased inferences. For example, we can easily imagine that EPC rating may be determined by a multitude of other confounding factors such as building material quality, design features, lighting, insulation, water heating and glazing. Moreover, current valuation of the benefits (S) to consumers may change and would depend on upon uncertain assumptions about future energy price inflation, behavioural patterns and appropriate discount rates. So, a property's price function can be empirically computed by the following equation:

$$P(h) = f(a, f, L, Q, E, S) \quad (1)$$

Equation 1 can be put through standard regression techniques to estimate individual component effects. However, there are several caveats that need careful consideration before making inferences that are free of severe estimation biases.

First, the presence of correlation between Q and E is highly likely and, as a result, the coefficient estimate may either overstate or understate the true effect. Additionally, given the subjective and multi-faceted nature of the quality variable Q, there may be unobservable attributes that are correlated with the observed ones. Coupled with location dynamics, this presents a significant source of unobserved heterogeneity and omitted variable bias that can severally impair our ability to draw unbiased inferences.

Second, typically energy efficient features tend to generate several direct and indirect and monetary and non-monetary benefits S. These benefits are difficult to quantify and, more importantly, variously contribute to the bias element in an estimation. Additionally, it becomes imperative to make some strong assumptions about future energy price inflation and appropriate discount rates, which also worsen the explanatory power of the estimation.

Third, various types of consumer perceive energy efficiency features differently. More eco-friendly consumers may, for example, behave quite differently from other consumers. Such patterns in consumer behaviour remain un-accounted for in quantitative models.

Finally, generally speaking, a regression framework assumes linearity in the relationship between dependent and independent variable(s). However, it is easily conceivable that some variables may not reveal their effect properly in a linear specification. For example, the price of a dwelling might respond to age in two ways; physical depreciation may reduce price paid but eventually price may respond positively to age – a ‘vintage’ effect. Moreover, older buildings tend to be less energy efficient and may involve significant refurbishment costs in order to comply with contemporary building regulations. Therefore, there may be a high correlation between age and EPC ratings.

With above caveats in mind, we specify a hedonic price model as follows:

$$P_{it} = \propto_i + \sum_{i=1}^{I} \beta_i X_i + e_i \quad (2)$$

Where P_{it} is the transaction price of a property (specified as the natural logarithm of price in £ per square metre), X_i is a vector of several explanatory locational and physical variables including our variable of interest, EPC rating; β_i is a vector of coefficients to be estimated; and e_i is a random error and stochastic disturbance term that is expected to take the form of a normal distribution with a mean of zero and variance of σ^2_e. We allow for temporal variation in the following form:

$$P_{it} = \sum_{j=1}^{J} \beta_j X_{jit} + \sum_{t=1}^{T} c_t D_t + e_{it} \quad (3)$$

where c_t is the additional vector of estimated coefficients for each time period and D_t is a set of variables that takes the value of 1 if a house is sold in the period and 0 if it is not sold.

For the purpose of this study, we specify hedonic models to explain two dependent variables; price per square metre and price per square metre change (appreciation/depreciation). To capture the effects of EPC rating on these variables, we use a set of binary variables to indicate the EPC band of each dwelling at the relevant transaction date. Band D is the 'hold-out' category so the coefficients for the higher bands are expected to be positive. In addition to mitigating the effects of extreme values, the semi-log specification of the hedonic model allows us to interpret the coefficients as average percentage premiums.

In the next step, we restrict the sample to dwellings for which records in our database indicate that an EPC was issued for the purpose of marketing the dwelling on the private rental market. While this identification of buy-to-let properties may not be perfect due to the possibility of switching between owner occupation and renting out for some properties, we assume that the bulk of the properties thus identified are longer-term buy-to-let properties. To restrict the sample further, we only include those transactions in our sub-sample analysis which had an EPC issued before the sale of the dwelling, not earlier. This restriction is introduced to ensure that potential buy-to-let investors were aware of the EPC performance when buying the property and were not forced to gather this information from other sources, inspections, etc.

Finally, to measure the influence of EPC rating on price appreciation, we also undertake a hedonic analysis with the repeat sales transactions only. In doing so, we are able to exercise greater control over biases from the unit fixed effect as two sales of the same dwelling are compared, although, the assumption of no improvement or changes in property quality or other features is a concern. The repeat sales framework may take the following form:

$$P_i^2 - P_i^1 = \left(\sum_{j=1}^{J} \beta_j X_{ji}^2 + \sum_{t=1}^{T} c_t D_i^2\right) - \left(\sum_{j=1}^{J} \beta_j X_{ji}^1 + \sum_{t=1}^{T} c_t D_i^1\right) + e_i^{21} \qquad (4)$$

where the first and second sale periods are denoted by the superscripts 1 and 2 respectively. Equation (4) can be simplified to:

$$P_i^2 - P_i^1 = \sum_{t=1}^{T} c_t (D_i^2 - D_i^1) + e_i^{21} \qquad (5)$$

In our specification, we use a Wales house price index to capture 'expected' appreciation following the national trend as well as the property-specific price components in the following form:

$$\frac{P_t^2}{P_t^1} = \frac{I_t^2}{I_t^1} + \sum_{j=1}^{J} X_{jt} + u_j \quad (6)$$

Thus price changes between two transactions are driven by the Wales-wide house price change, the time elapsed between the two sales and a set of observed and unobserved property characteristics that cause a house price to deviate from the national trend. The first factor is captured by the index ratio while the observed property-specific factors are represented by the vector of characteristics X. Finally, unobserved characteristics are captured in the error term u. Using this framework we are able to observe and estimate the magnitude price differentials that result from dwellings being placed in different EPC bands.

4 Results

Although the data set included 191,554 observations of dwelling transactions (and 47,158 repeat sales transactions), many did not include a complete set of information. 23% did not have floor area recorded, 17% did not have the number of bedrooms recorded and 37% did not have any age information. This meant that the regression models operated on much reduced sample sizes. For example the dependent variable sale price per square metre (saleprice1psm) was computed for 147,116 observations. The descriptive statistics for the continuous variables in the sample are shown in the appendix. The dependent variable saleprice1psm (and saleprice2psm for repeat sales) was positively skewed so a log transformation was performed to normalize the distribution.

The independent variable of interest to this study is the EPC band. Over 85% of the dwellings in the sample are in Band C, D or E. The key control variables are floor area, age, property type, number of bedrooms and location (rural/urban, postcode area, district). Of the total sample of 191,554 dwellings 37% are terraced, 32% semi-detached, 29% detached and only 2% were flats. The dwelling stock is quite old; 71% was constructed before 1960 with 40% built before 1900. Just under 10% was constructed in the last decade of the sample time period between 2000 and 2009. 69% of the sample was located in an urban setting. Figure 1 illustrates the relationship between property type, EPC band and mean sale price. The price differential between detached, semi-detached and terraced houses and flats is as expected; detached dwellings selling for the highest prices and flats the lowest. It is also possible to discern a relationship between price and EPC band, particularly in the case of flats but also, to a less obvious extent, in the case of semi-detached and terraced dwellings. Notwithstanding the point made above in relation to the very small number of observations in bands A, B, F and G, there does not appear to be a discernible relationship between EPC band and price paid for detached dwellings.

Figure 1 here

Figure 2 shows the geographical distribution of EPC ratings for the sample of dwellings. The map was created by interpolating a surface (using an inverse distance weighting algorithm) from the location and EPC ratings of the sample of dwellings. The lighter shading represents areas with relatively high EPC ratings and the darker areas are where dwellings have generally lower EPC ratings. The urban areas, particularly in south Wales, contain greater concentrations of dwellings with higher EPC ratings and dwellings with generally lower ratings dominate the more rural locations in the northwest.

Figure 2 here

After removing observations with missing variables and selecting transactions that had taken place from the beginning of 2008 onwards (84,776 observations), the full cross-section regression sample comprised 62,464 observations and for the repeat sales regression the full sample included 25,189 observations. When analysing the price effect by property type these sample sizes reduce accordingly and are reported at the bottom of the results tables.

4.1 The determinants of price per square metre

Following the modelling approach and data sampling outlined in section three, we first fit regression models to both the full set of observations and the sub-samples of the different types of dwelling. The results are presented in Table 3. The (log of) house price per square metre is explained as a function of four dwelling attributes (age, dwelling type, number of bedrooms and tenure), a neighbourhood attribute (urban-rural index score) and EPC rating/point. The fact that housing transactions took place in different time periods and different areas is controlled for by including quarterly time fixed effects and postcode area fixed effects in the model. The overall explanatory power of the model is good with an adj. R^2 of around 51% for the full sample. The coefficients of the explanatory variables largely have the expected signs. Perhaps surprisingly, for 'number of bedrooms' the coefficient is negative and highly significant. The effect of age on dwelling price per square metre is non-linear and variable between dwelling types. Compared to dwellings constructed pre-1900, dwellings constructed since 1983 have sold for small but statistically significant price premiums. When we look at the results across dwelling types, it is apparent that there are notable differences between semi-detached, terraced properties and detached properties. In contrast to semi-detached and terraced dwellings, detached dwellings constructed between 1900 and 2003 tend to sell for significantly less per square metre than dwellings constructed before 1900. The results for dwelling type are in line with expectations. With terraced dwellings as the 'hold-out' category, flats, semi-detached and detached properties achieve significantly higher prices per square metre, with the latter category selling for an approximately 28% more per square metre than terraced dwellings. The coefficients for the urban-rural indexes also have the expected signs. Compared to leasehold, the coefficient for freehold is insignificant.

Turning to the variable of interest, EPC rating, and using band D as the 'hold-out' category, the pattern of price effects is consistent with a positive relationship between energy performance rating and sale price. For the whole sample model there are significant positive premiums for dwellings in bands A and B (11.3%) or C (2.1%) compared to dwellings in band D. For dwellings in EPC bands lower than D there are statistically significant discounts; -2.1% for band E dwellings, -4.7% for band F dwellings and -7.2% for dwellings in band G. The price impact varies depending on the type of property: a terraced dwelling rated B has sold for approximately 17.1% more per square metre than a terraced dwelling EPC rated D. The comparable figure for a semi-detached dwelling is 8.2%. Relative to the other dwelling types detached dwellings are likely to display the greatest degree of heterogeneity, particularly in rural areas. Recognising this, detached dwellings were categorised as urban or rural. Table 2 shows that the price impact is more marked and for urban dwellings in bands E and F than for rural dwellings in the same bands. This might be a result of purchasers willing to pay higher prices for rural dwellings (perhaps because of their character and setting) regardless of their energy performance. In the last column in Table 3 the results of the estimation when energy efficiency score, rather than band, is used as the independent variable are displayed. The expected positive relationship between energy efficiency and dwelling sale price is also found.

These estimated price premiums are much higher than for the comparable study conducted in England (Fuerst *et al*, 2015). One reason for this effect is the lower average house price in Wales. The findings for Wales are very similar to the results for the North East region of England where significant positive premiums were estimated for dwellings in bands A and B (14.4%) or C (2.7%) compared to dwellings in band D and statistically significant discounts for dwellings in band E (-2.5%) and F (-6.0%).

Table 3 here

4.2 The private rental market

The private rental segment of the housing market is of particular interest in that energy costs are not borne by the buyer but by a third party, the tenant. Based on the extant literature, buy-to-let landlords may value energy efficiency only to the extent that they enable them to charge higher rents, achieve shorter vacancy period or increase the attractiveness of their investment otherwise. Due to the well-documented split incentive problem, it has been observed in past studies that rental properties generally achieve a lower energy efficiency standard than owner-occupied properties (Rehdanz 2007). This may extend to the general quality of the rental stock being poorer. For example, Iwata and Yamaga (2008) purport that the optimal condition of a rented dwelling is lower if an investor expects heavy utilisation of the dwelling by the tenant. Even if this paper is not directly concerned with this issue, the potential difference in the quality of the stock may introduce a serious bias in our estimation results, particularly if some of the quality characteristics are unobserved and are correlated with the EPC ratings. However, the summary statistics suggests that this is not a major concern for the present study of Wales. The average sale price in our private rental subsample is very similar to the overall average price (£142,000 and £145,000 respectively). In terms of energy efficiency ratings, we find a similar distribution of EPC bands and scores. The average EPC score in the private rental segment is 57.3 compared to 58.3 in the overall sample, only marginally lower. To further mitigate the potential for any omitted variables bias due to unobserved quality differences, we conduct the estimation of the subsample separately rather than including interaction terms in the main model. Hence, the reference point for EPC band capitalisation is an average D-rated rental property, rather than a standard D-rated property of either tenure status.

Table 4 reveals that energy efficient dwellings in bands A, B and C achieve price premiums that are comparable to the general market. This is to be expected in a market setting where buy-to-let landlords compete with owner-occupiers for these properties. However, we do not find significant discounts for rental dwellings with below average energy efficiency ratings. This may be taken as further evidence of the split incentive problem. Buy-to-let buyers may not apply the same discounts to low-EPC dwellings that owner-occupiers would because energy costs are passed on to tenants. Given that rental premiums paid by tenants are uncertain, buy-to-let buyers may outbid owner-occupiers in this segment of the market. As a consequence, we do not observe a significant discount for lower-rated properties. This finding is in line with the previous literature, in particular Hyland *et al.* (2013) who find that the rental premium captures only 14-55% of the net present value of energy savings. Rehdanz (2007) and Kholodilin and Michelsen (2014) arrive at similar conclusions in their studies of German housing markets. The implicit lower return on energy efficiency for landlords compared to owner occupiers thus leads to a levelling of prices between D, E, F and G bands, all else equal. A diverging result compared to the German studies is our finding of a significant premium for A, B, C rated properties which may be explained by the fact that the owner-occupied and rental tiers of the market are less segmented in the UK market and the Welsh market in particular. The fraction of 'dedicated' rental stock on the overall market is lower and most properties could be used for either owner occupation or as a rental investment, which is not necessarily the case in Germany.

Table 4 here

4.3 The determinants of price appreciation per square metre

We also apply a similar regression specification with dwelling price *appreciation* per square metre as the dependent variable. We do not have definite prior expectations for either positive or negative effects. It is possible that price premiums associated with superior energy performance have been factored into initial prices and that there is no 'growth premium'. On the other hand, it is possible that the increasing awareness of energy and environmental issues in the last decade has meant that price effects have produced positive effects on price appreciation. In other words, the effects of superior energy performance on initial prices may be positive and, due to subsequent greater demand for energy efficient dwellings, the effects on price appreciation may also be positive.

Table 5 provides estimates of the determinants of the dwelling price appreciation. For all types of dwelling, number of bedrooms has a significant positive effect on growth rate. Compared to dwellings built post-2007, the prices of dwellings constructed between after 1983 and 2006 have appreciated at a significantly lower rate. In contrast, dwellings constructed prior to 1983 have experienced slightly, but statistically significant, higher appreciation rates compared to the 'hold-out' category (dwellings constructed post-2007). Given the sample period and the over-supply of apartments in many markets, it is perhaps not surprising that, compared to other dwellings, flats have experienced significantly lower rates of price appreciation. Overall, on a per square metre basis, flats tend to sell for less than other dwelling types and have experienced lower growth rates. Similarly, freehold dwellings have experienced a higher rate of price appreciation. However, in terms of statistical significance, this is marginal.

Turning to the variable of interest, the results for the price appreciation *per square metre* model are not as consistent as the price model. For the full sample, C-rated dwellings have experienced significantly higher price appreciation than D-rated dwellings. However, this is not the case for the dwellings in the A/B bands which have experienced no statistically significant higher price appreciation than D-rated dwellings. Dwellings rated E and F are also estimated to have grown statistically significant lower rates compared to D-rated properties. When we look at the estimates for the dwelling type sub-samples, we see that the effects on price appreciation are largest for terraced dwellings with no significant effect on flats. There is a significant and positive price impact for detached dwellings in urban areas in band C, and for dwellings in bands E and F the negative price impact is also significant.

Table 5 here

4.4 Robustness checks

As noted above, a common issue with hedonic estimations is potential omitted variable bias. In the context of this research one particular concern is that houses with better EPC ratings may have been subject to unobserved improvements that enhance the quality of dwellings in addition to enhancing energy performance. In order to try to counteract such potential bias, we run the models with a number of restricted samples. The main purpose of the restrictions is to exclude dwellings that are more likely to have been improved or that may be unusual in some way e.g. dwellings that have been re-sold within a short period of time or dwellings exhibiting high levels of unexplained variance in the estimations. In order to try to eliminate the effects of potential unobserved changes to houses to bias the estimates, we restrict the sample to houses built relatively recently (since 2000).

The results are presented in Table 6 and it is reassuring to see that they remain broadly stable. For the cross-sectional price models, the results of the restricted sample models estimate similar patterns of premiums and discounts compared to EPC band D as the full sample model. Whilst restricting the sample to dwellings with low unexplained variance reduces the sample to only 9,866 sale transactions, the estimates of price premiums and discounts remain indistinguishable from the full sample results. When the sample is restricted to the 9,851 dwellings that have been built and sold since 2000, the results do change. Compared to a band D dwelling, the estimated price premium for band A/B dwellings drops to 4.5%. The price premium for band C dwellings decreases to less than 1%. Bearing in mind that only a small proportion of modern houses will have energy ratings below D, we find no significant discount for poor energy efficiency performance. Similarly, excluding dwellings that have been sold twice or 'flipped' in under two years has no notable effect on the estimated coefficients. Applying similar restrictions to the data applied to price appreciation results in a similar pattern with little variation in the estimated coefficients for the various restricted samples. The exception is EPC band G where the similar-sized effect has taken on a degree of statistical significance.

Table 6 here

5 Conclusions

The introduction of mandatory energy performance ratings for the commercial and residential real estate sectors across the European Union and in many other countries reflects a growing focus on reducing carbon emissions from the real estate stock. The main objective of energy efficiency certification is to influence the behaviour of house buyers. EPCs are intended to provide trustworthy information to house buyers about energy efficiency. Given rapidly rising energy prices over the last decade, it is expected that energy savings associated with energy efficient attributes such as insulation, double/triple glazing, efficient water heating, low energy lighting, etc. will lead to house price premiums which will, in turn, lead to increased adoption of energy efficient features. However, it is important to acknowledge that untangling and isolating the effect of a single variable on the price of a house presents many methodological challenges. A range of approaches to estimating the influence on house prices of features such as school catchment area, proximity to transport nodes and parks has been used in hundreds of research studies on housing markets. In this study the variable that we are trying to estimate is the effect of the EPC rating on house price.

There are several reasons for expecting house buyers to pay more for an energy efficient house relative to a very similar house that is less energy efficient. Lower energy bills essentially result in higher household disposable income. The Building Research Establishment found, for a sample of 125 dwellings that represented a broad range of house types, a strong correlation between annual energy costs and EPC rating/band (BRE, 2014). The presence of high quality water heating equipment, lighting, etc. should reduce expenditure on replacement and maintenance. Some house buyers may obtain a psychic income from eco-consumption. There can be additional benefits from energy efficient features that have little to do with energy efficiency. For instance, double-glazing reduces noise pollution and increases security. In short, there are grounds to expect a positive price effect of energy efficiency – all else equal. However, the relative effect is not expected to be uniform. If buyers pay an additional £100 per square metre for a dwelling in EPC band B compared to a dwelling in band D, this would represent a 10% price premium in an area where the typical house price was £1,000 per square metre. However, in inner London where prices of £5,000 per square metre are common, it would represent a 2% price premium. The methodological challenges of measuring the impact remain.

In order to isolate and estimate the effect of the EPC, it is important to be able to take into account all the other factors that are affecting the price of the house - the time of sale, its condition, location, age, size, type, quality of fittings, etc. Such comprehensive data is rarely available and researchers trying to isolate and identify house price determinants tend to be concerned about omitted variable problems. A particular concern in this study is that an unobserved variable such as condition, quality, recent improvements or modernisation, may be related to energy efficiency and consequently their (unobserved) effect on house price may be mis-attributed as being due to energy efficiency. Missing variables that are not linked to energy efficiency (aspect, view and proximity to busy road for example) may affect house prices and reduce the explanatory power of the statistical model but they will not bias the estimations. In this study we have tried to reduce the risk of this type of problem by removing houses from the sample that are more likely to have been improved or have better quality fittings.

Drawing upon a large sample of house sales, we find similar patterns to the comparable study for England. As expected, there is a clear relationship between energy efficiency and age. A small proportion of houses built before 1900 had an EPC rating of C or better. The comparable figure for dwellings constructed since 2007 is around 90%. The vast majority of houses are clustered in the EPC bands C, D and E. Approximately 40% of all dwellings are rated D. Flats tend to be the most energy efficient with approximately half allocated to EPC band C or B.

There is a positive association between dwelling price per square metre and energy performance rating. Almost certainly due to a lower average house price, these estimated price premiums are much higher than for the comparable study in England. It is notable that the findings for Wales are very similar to the results for the North East region of England. Albeit the number of dwellings with EPC A rating are negligible, overall there are statistically significant positive price premiums for dwellings in bands A and B (12.8%) or C (3.5%) compared to houses in band D. For dwellings in band E (-3.6%) and F (-6.5%) there are statistically significant discounts. The relative price effects are highest for terraced dwellings. In order to try to take account of dwellings that may have been improved or be of better quality or condition, we also excluded dwellings whose prices were being poorly explained by the econometric model. When these houses are excluded, the pattern of price effects remains broadly unchanged. However, it may not be regarded as plausible that house buyers pay approximately 10% more because the property has features intrinsic to EPC B energy performance compared to EPC C. This requires further investigation.

The findings for the effect of EPC rating on house price growth are less consistent. Compared to EPC D rated dwellings, those in band C have experienced significantly higher house price growth. Surprisingly this is not found for dwellings in band A or B, which have experienced no statistically significant higher price appreciation than D-rated dwellings. The DECC study in England actually found significantly lower rates of growth for this category. There is evidence of a negative effect of poor energy efficiency on house price growth. Dwellings rated EPC E and EPC F are also estimated to have grown at statistically significant lower rates compared to EPC D-rated dwellings.

Finally, our finding of no discounts for E/F/G-rated dwellings adds to the emerging evidence of the split incentive problem and its impact on transaction prices in the private rental segment of the market. Incoming legislation in the UK which forbids the renting out of dwellings below a minimum energy efficiency rating from 2017 onwards may alter the price patterns for low-energy efficiency properties dramatically which warrants a follow-up study which should also model the relationship between prices, rents and energy bills more explicitly than this paper was able to do with information on sales transaction prices only.

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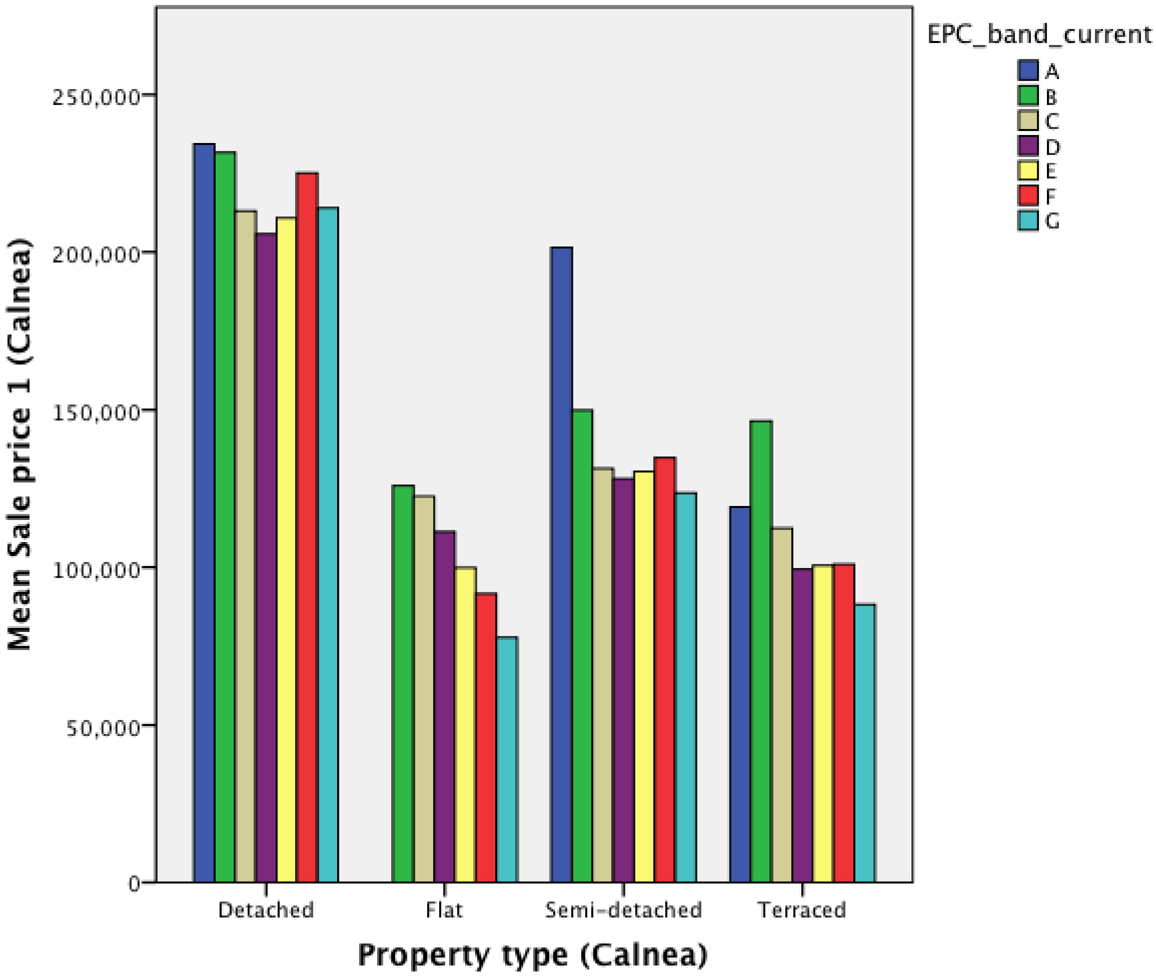

Figure 1: Relationship between property type, EPC band and sale price

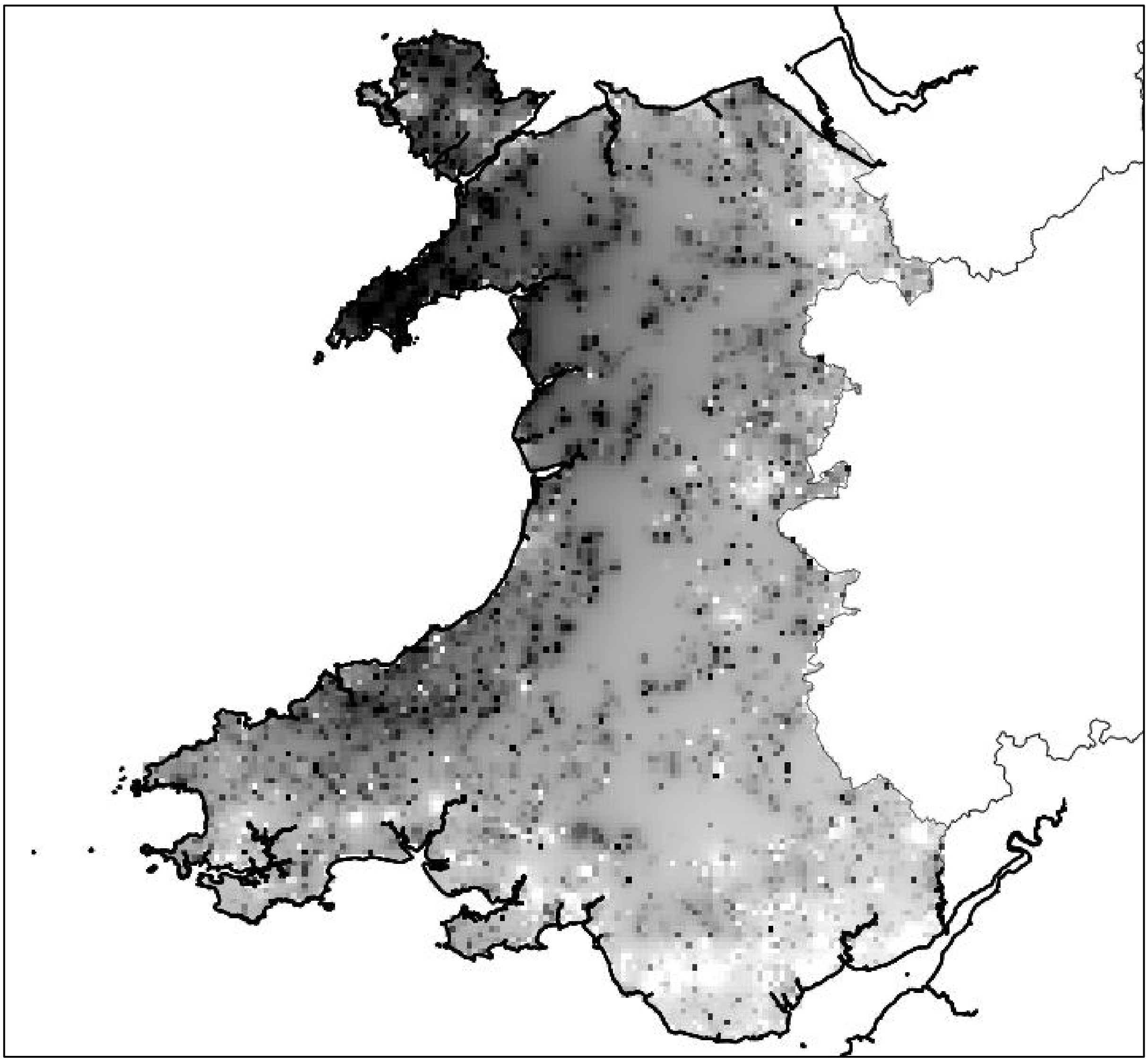

Figure 2: EPC ratings (darker areas low rating, lighter areas high rating)

Table 1: RdSAP dwelling categorisations

Type	Degree of detachment	Age band
House	Detached	Before 1900
Bungalow	Semi-detached	1900-1929
Flat	Mid-terrace	1930-1949
Maisonette	End-terrace	1950-1964
	Enclosed mid-terrace	1965-1975
	Enclosed end-terrace	1976-1982
		1983-1990
		1991-1995
		1996-2002
		2003-2006
		2006-

Table 2: Summary of literature review findings

Authors	Sample	Key Findings	Comments
Australian Bureau of Statistics (2008) Report for Department of Environment, Water, Heritage and the Arts	Draws upon a database of residential sales in the Australian Capital Territory for the period 2005 (2385 transactions) and 2006 (2719 transactions) Since a four star rating was a mandatory requirement, houses less than 10 years old are excluded.	For 2005 sample, estimate an (approximately) 1% premium for every 0.5 increase in rating (EER ranges from 0-5). For 2006 sample, estimate an approximately 2% premium for every 0.5 increase in EER. For pooled sample, relative to zero rating house estimates premiums of 1.6% (EER 1), 3% (EER 2), 5.9% (EER 3), 6.3% ((EER 4) and 6.1% (EER 5) Explanatory power of model is high and there is a large range of quality controls.	This is one of the first studies of the price effects of mandatory eco-labelling in real estate markets. Find interesting result that the marginal addition to the premium declines as rating increases. The independent variables seem to be different between the 2005 and 2006 models. No rationale is provided.
Brounen and Kok (2011)	31,993 residential sale prices in the Netherlands in 2008-9 for dwellings with EPC rating.	Compared to dwellings rated D, they estimate premiums of 10%, 5.5% and 2.5% for A, B and C respectively. For dwellings rated E, F and G, the estimate discounts of 0.5%, 2.5% and 5% respectively. All coefficients are statistically significant. No statistically significant effect estimated for time on market.	The models include a wide range of controls for quality and other features. However, it is notable that the study is based on sales of dwellings that had opted to have an EPC. This represented a minority of total residential sales. They used a Heckman correction to try to eliminate the effect of potential selection bias.
Fuerst and McAllister (2011)	Examines effect of EPC rating on yield, Market Value and Market Rent for 708 commercial property assets in UK. Included BREEAM rated buildings. Date of data is Q3 2010. Given the large geographical scope of the sample and the number of EPC and geographical 'segments', it is likely that there were small sample effects.	Finds no significant effect of EPC rating on Market Rent and Market Value. Very similar results for yield estimation. For one EPC rating (E compared to G for retail) was the coefficient significantly negative at the 10% level. The BREEAM results were similar. The coefficient on the BREEAM dummy was statistically significantly negative at the 10% level.	They conclude that a larger sample is needed to provide a robust estimation of whether weak effects are being missed.
Kok and Jennen (2012)	Examines the effect of EPC rating and Energy Index on 1057 rental transactions in Netherlands for the period 2005-2010.	Finds a rental premium of approximately 4.7% for buildings rated C or lower compared to buildings rated D and above. Compared to D rated buildings, find significant premiums of about 10% for C rated and 5% for B rated. Significant discount for E (0.8%), F (0.5) but G rated offices had a 2.3% premium.	There *may* be a potential omitted variable problem. Buildings rated Class A, B and C *may* be better quality than buildings with inferior performance. The level of energy efficiency *may* be correlated with other unobserved quality variables e.g. design, interior finishes etc. The sample of transactions covers the period 2005-2010. EPCs may have been optional in that period. Buildings may have multiple EPCs.

			This issue is not discussed.
Fuerst, van de Wetering and Wyatt (2012)	Looks at the relationship between a sample of asking and achieved rent and EPC rating for a sample of 817 offices in the UK in the period 2008-2010 Includes potential price determining variables such as lease incentives and lease lengths.	Finds that, compared to D rated buildings, in a pooled (of asking and contract rents) sample with 817 buildings, there is a statistically significant premiums for properties rated A-C **and** E-G. When only asking rents are modelled a similar pattern is found with very similar premiums for A-C and E-G in relation to D. For actual contract rents, no significant effects on rents are identified for EPC rating.	The obvious issue is the finding of a premium for lower rated offices. There are some typical potential omitted variable problems – condition, design, internal specification etc. They also find no relationship between service charge and EPC rating.
Hyland, Lyons and Lyons (2013)	Where information is provided on energy efficiency score, the sample has asking sale prices for approximately 20,000 dwellings in Republic of Ireland. Asking rental rates for approximately 40,000 dwellings over the period Jan 2008-Mar 2012.	Find substantial asking price premiums related to D-rated properties for A (9%), B (5%) and C (1.7%). Find no significant discount for EPC E rated dwellings and a discount of approx. 11% for F/G. For rental rates, find rental rate premiums related to D-rated properties for A (1.8%), B (1.8%). Find no significant price effect on EPC C rated dwellings. Discounts for EPC E-rated (1.9%) and 3.2% for F/G.	The major limitation of this research seems the lack of control for age. Since age and (quality of) location are likely to be significantly positively correlated with EPC rating, it seems unlikely that the energy labels cause the price effects. A more plausible explanation is that depreciation due to age is also included in the apparent discounts for energy efficiency.
European Commission (2013)	A series of studies that attempts to measure the effect of EPC rating on prices in a range of EU countries	Varied – see below	Find substantial variation in implementation of EPC across EU. Also there was a lot of variation in scope of control variables. Lack of control for age is a particular concern since there is likely to be a negative relationship between age and energy performance.
Austria	1077 listed rental prices 2246 listed sale prices mainly in Greater Vienna	Estimate an approx. 8% increase in price per change in EPC grading for selling prices. Estimate approx. 4% increase in price per change in EPC grading for rental prices.	Small proportion of transactions had EPC. No controls for age.
Belgium	In total 26000 listed prices. Approximately one third involved rental listings and the majority were in Flanders.	Find a 3%-5% increase in price is associated with an increase in every 100 CPEB points.	Estimate that an EPC was produced for a large proportion of transactions. No controls for age.
France	Based on 1263 and 1915 sale transactions for Marseilles and Lille respectively.	Estimate an approx. 4% increase in price per change in EPC grading for selling prices.	Unclear what the proportion is. Age control is included.
Ireland	Approx. 26,500 listed rental prices Approx. 11000 listed sale prices	Estimate an approx. 2.8% increase in price per change in EPC grading for selling prices. Estimate approx. 1.4% increase in price per change in EPC grading for rental prices.	Small proportion of transactions had EPC. No age controls.
United Kingdom	Highly localised, small sample for Oxford	No significant effect	Sample size is a concern. No control for age.
Fuerst, McAllister, Nanda and Wyatt (2015)	Repeat sale prices of 325,950 residential properties in England and Wales with EPC rating.	Estimate that, compared to dwellings rated EPC D, dwellings rated EPC F and E sold for approximately 1% less. Dwellings rated G sold for approximately 6% less. Dwellings rated C sold for approximately 2%	Like all hedonic studies, it is possible that there is omitted variable bias. Dwellings rated EPC B will tend to have more up to date water heating systems, double-glazing etc. compared to EPC G

		more and dwellings rated EPC band A/ B sold for 5% more. The findings for price growth were less clear-cut. EPC C -rated dwellings experienced significantly higher price growth compared to EPC rated D dwellings. However, EPC A/B dwellings and EPC E, F and G dwellings experienced lower sales appreciation rates.	rated buildings. However, EPC B dwellings may also tend to have more up to date kitchens, bathrooms etc. Since these variables are not included in the econometric model, their possible price effect is not taken into account.

Table 3: Energy Rating and Price: Hedonic Estimations

(dependent variable: log of price per square metre)

	Full sample (EPC bands)	Detached	Detached (rural)	Detached (urban)	Semi-detached	Terraced	Flat	Full sample (EPC rating)
EPC band A/B	0.113***	-0.0199	-0.0181	-0.0200	0.0824***	0.171***	0.0355	
	(11.37)	(-1.20)	(-0.52)	(-1.10)	(4.76)	(8.80)	(0.76)	
EPC band C	0.0206***	0.00197	-0.00155	0.00274	0.00395	0.0234***	0.0388	
	(6.10)	(0.33)	(-0.14)	(0.40)	(0.73)	(3.76)	(1.46)	
EPC band D	Hold-out	Hold-out	Hold-out	Hold-out	Hold-out	Hold-out	Hold-out	
EPC band E	-0.0209***	-0.0174**	-0.00580	-0.0214**	-0.0204***	-0.0361***	-0.0824	
	(-6.76)	(-2.72)	(-0.55)	(-2.67)	(-3.97)	(-7.63)	(-1.86)	
EPC band F	-0.0473***	-0.0442***	-0.0305*	-0.0687***	-0.0551***	-0.0945***	-0.105	
	(-8.58)	(-4.45)	(-2.16)	(-4.90)	(-5.60)	(-10.70)	(-1.30)	
EPC band G	-0.0717***	-0.0499**	-0.0591**	-0.0527	-0.0832***	-0.140***	-0.150	
	(-6.90)	(-2.78)	(-2.76)	(-1.44)	(-4.11)	(-8.55)	(-1.83)	
EPC rating								0.0432***
								(11.21)
Number of bedrooms	-0.0601***	-0.0557***	-0.0721***	-0.0431***	-0.0382***	-0.0529***	-0.0489*	-0.0607***
	(-33.93)	(-19.34)	(-15.67)	(-12.20)	(-11.36)	(-16.90)	(-2.27)	(-34.27)
1900	-0.142***	-0.174***	-0.133***	-0.130***	-0.150***	-0.0811***	-0.0903	-0.145***
	(-21.14)	(-9.24)	(-5.58)	(-3.86)	(-9.22)	(-9.87)	(-1.14)	(-21.47)
1901-29	-0.106***	-0.138***	-0.113***	-0.0442	-0.0851***	-0.0565***	-0.0855	-0.108***

	(-15.62)	(-8.00)	(-4.74)	(-1.43)	(-5.56)	(-6.67)	(-1.32)	(-15.90)
1930-49	-0.0792***	-0.0812***	-0.108***	0.0469	-0.0626***	-0.0631***	0.0940	-0.0796***
	(-11.14)	(-5.26)	(-4.32)	(1.63)	(-4.31)	(-5.64)	(1.07)	(-11.17)
1950-59	-0.141***	-0.0457**	-0.0879***	0.0842**	-0.145***	-0.143***	-0.297*	-0.140***
	(-19.41)	(-2.87)	(-3.66)	(2.86)	(-9.88)	(-12.94)	(-2.27)	(-19.36)
1960-69	-0.0594***	-0.0550***	-0.0805***	0.0659*	-0.0172	-0.150***	-0.141*	-0.0586***
	(-8.12)	(-3.87)	(-4.38)	(2.32)	(-1.14)	(-12.96)	(-2.07)	(-7.99)
1970-79	-0.0127	-0.0814***	-0.107***	0.0385	0.0657***	-0.0796***	-0.0891	-0.0105
	(-1.78)	(-6.08)	(-6.59)	(1.37)	(4.37)	(-6.69)	(-1.27)	(-1.48)
1980-89	0.0509***	-0.0603***	-0.0853***	0.0589*	0.112***	0.128***	-0.00250	0.0552***
	(6.86)	(-4.37)	(-5.03)	(2.07)	(7.14)	(10.53)	(-0.04)	(7.45)
1990-99	0.0893***	-0.0373**	-0.0667***	0.0796**	0.148***	0.219***	-0.0111	0.0959***
	(12.65)	(-2.77)	(-3.95)	(2.85)	(9.72)	(20.01)	(-0.19)	(13.71)
2000-09	0.0867***	-0.0177	-0.0551**	0.105***	0.162***	0.191***	0.0530	0.109***
	(11.53)	(-1.27)	(-3.07)	(3.69)	(10.04)	(14.80)	(0.93)	(14.95)
2010-	0.110***	0.0205	-0.0341	0.155***	0.176***	0.219***	0.208**	0.172***
	(10.35)	(1.14)	(-1.22)	(4.96)	(8.58)	(10.24)	(3.00)	(19.42)
Detached	0.277***							0.272***
	(69.75)							(68.98)
Semi-detached	0.127***							0.126***
	(39.08)							(38.68)
Terraced	Hold-out							Hold-out

Flat	0.0406**							0.0449**
	(2.77)							(3.05)
Tenure	0.0174*	0.0235	0.0425	0.0119	0.0133	0.0272*	-0.392**	0.0166*
	(2.33)	(1.59)	(1.40)	(0.75)	(1.14)	(2.13)	(-3.07)	(2.23)
Urban-rural indicator	0.00111	0.0316***			-0.0138*	-0.0244***	0.206*	0.00000389
	(0.28)	(4.78)			(-2.03)	(-3.30)	(2.31)	(0.00)
Constant	7.422***	7.712***	7.770***	7.584***	7.446***	7.376***	7.799***	7.247***
	(512.80)	(236.90)	(123.94)	(183.50)	(285.27)	(339.82)	(85.07)	(352.01)
Quarterly fixed effects	Y	Y	Y	Y	Y	Y	Y	Y
Postcode fixed effects	Y	Y	Y	Y	Y	Y	Y	Y
adj. R-sq	0.505	0.260	0.201	0.343	0.429	0.571	0.518	0.504
N	62,464	18,568	7,686	10,882	21,069	22,109	718	62,461

t statistics in parentheses * $p<0.05$, ** $p<0.01$, *** $p<0.001$

Table 4: Energy Rating of Private Rental Properties and Price: Hedonic Estimations (dependent variable: house price appreciation per square metre)

	Private rentals
EPC band_A/B	0.185**
	(3.11)
EPC band_C	0.040*
	(2.27)
EPC band_E	-0.022
	(-1.55)
EPC band_F	-0.017
	(-0.60)
EPC band_G	-0.072
	(-1.41)
Full set of controls	Y
adj. R^2	0.497
N	3,182

t statistics in parentheses
* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 5: Energy Rating and Price: Hedonic Estimations
(dependent variable: house price appreciation per square metre)

	Full sample (EPC bands)	Detached	Detached (rural)	Detached (urban)	Semi-detached	Terraced	Flat
EPC band A/B	-0.00169	-0.00580	-0.0195	0.0266	-0.0351	0.0798**	-0.0154
	(-0.11)	(-0.15)	(-0.21)	(0.71)	(-1.71)	(2.96)	(-0.33)
EPC band C	0.0322***	0.0326***	0.0493*	0.0319**	0.0114	0.0505***	-0.0159
	(5.44)	(3.37)	(2.45)	(3.06)	(1.21)	(4.12)	(-0.50)
EPC band D	Hold-out	Hold-out	Hold-out	Hold-out	Hold-out	Hold-out	Hold-out
EPC band E	-0.0449***	-0.0489***	-0.0114	-0.0776***	-0.0336**	-0.0518***	0.0248
	(-7.40)	(-3.62)	(-0.47)	(-5.01)	(-3.28)	(-5.60)	(0.43)
EPC band F	-0.0591***	-0.122***	-0.0745**	-0.185***	-0.0720***	-0.0205	0.101
	(-5.35)	(-6.05)	(-2.70)	(-6.53)	(-3.40)	(-1.12)	(0.90)
EPC band G	-0.0153	-0.104*	-0.0539	-0.208**	-0.0174	0.0369	-0.251
	(-0.62)	(-2.35)	(-1.01)	(-2.63)	(-0.35)	(0.89)	(-1.47)
House price index	1.215***	0.977***	1.021***	0.938***	1.277***	1.351***	0.695***
	(70.89)	(35.13)	(19.47)	(29.54)	(42.38)	(44.36)	(6.03)
No. of beds	0.00913**	0.0141**	0.0188*	0.0110	0.00874	0.0110*	-0.0490
	(3.10)	(2.60)	(1.99)	(1.66)	(1.73)	(2.06)	(-1.79)
1900	0.0305**	0.0211	0.00723	0.0375	0.0115	0.0351*	-0.298*
	(2.67)	(0.60)	(0.16)	(0.56)	(0.41)	(2.53)	(-2.08)
1901-29	0.0145	-0.0229	-0.0394	-0.0400	0.0286	0.0122	-0.195
	(1.28)	(-0.76)	(-0.95)	(-0.71)	(1.07)	(0.86)	(-1.33)
1930-49	0.0119	-0.0161	-0.0412	-0.0399	0.0217	-0.00511	-0.338
	(0.96)	(-0.58)	(-0.84)	(-0.79)	(0.83)	(-0.26)	(-1.86)

1950-59	0.0427**	0.0459	0.119	-0.0226	0.0438	0.0436	-0.259
	(2.99)	(1.21)	(1.50)	(-0.40)	(1.61)	(1.73)	(-1.91)
1960-69	-0.00770	-0.0225	-0.00407	-0.0650	-0.0133	0.000116	-0.219
	(-0.60)	(-0.78)	(-0.09)	(-1.26)	(-0.50)	(0.01)	(-1.64)
1970-79	-0.0580***	-0.113***	-0.110***	-0.141**	-0.0430	-0.0385	-0.411**
	(-4.91)	(-4.45)	(-3.33)	(-2.78)	(-1.69)	(-1.84)	(-2.95)
1980-89	-0.0887***	-0.135***	-0.111***	-0.184***	-0.0640*	-0.102***	-0.310*
	(-7.50)	(-5.21)	(-3.41)	(-3.55)	(-2.39)	(-5.86)	(-2.49)
1990-99	-0.118***	-0.167***	-0.153***	-0.214***	-0.101***	-0.0972***	-0.375**
	(-10.33)	(-6.69)	(-4.73)	(-4.28)	(-3.88)	(-5.73)	(-2.93)
2000-09	-0.145***	-0.179***	-0.137***	-0.239***	-0.124***	-0.158***	-0.437***
	(-12.01)	(-6.86)	(-3.97)	(-4.67)	(-4.69)	(-8.69)	(-3.40)
2010-	-0.139***	-0.131*	0.0676	-0.276***	-0.127***	-0.236***	
	(-4.77)	(-2.12)	(0.48)	(-4.38)	(-3.37)	(-8.05)	
Detached	0.0921***						
	(4.79)						
Semi-detached	0.0844***						
	(4.52)						
Terraced	0.0925***						
	(5.00)						
Flat	Hold-out						
Freehold	0.0109	0.0181	0.0420	0.00857	0.0257	-0.00260	-0.520***
	(0.95)	(1.05)	(1.36)	(0.39)	(1.49)	(-0.12)	(-5.45)
Urban-rural indicator	0.0100	0.0285*			-0.00992	0.0218	0.0643
	(1.31)	(2.16)			(-0.79)	(1.42)	(0.67)

Constant	0.0895***	0.185***	0.144**	0.254***	0.155***	0.190***	0.434**
	(4.78)	(5.25)	(2.74)	(4.44)	(4.79)	(6.71)	(3.12)
Postcode fixed effects	Y	Y			Y	Y	Y
adj. R^2	0.256	0.213	0.179	0.244	0.287	0.263	0.422
N	25,189	6,971	2,600	4,371	8,066	9,813	339

t statistics in parentheses * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

Table 6: Robustness Checks - Model results with restricted samples

	House price models		House price appreciation models
Sample Restriction	Built since 2000	Residual within 0.05	Winsorized residual
EPC band A/B	0.0454***	0.112***	-0.00441
	(3.82)	(53.12)	(-1.51)
EPC band C	0.00757	0.0196***	0.0294***
	(1.04)	(22.38)	(26.78)
EPC band D	Hold-out	Hold-out	Hold-out
EPC band E	-0.0914**	-0.0215***	-0.0438***
	(-3.13)	(-27.23)	(-36.07)
EPC band F	-0.110**	-0.0478***	-0.0598***
	(-2.82)	(-36.72)	(-26.02)
EPC band G	-0.0868	-0.0724***	-0.0150**
	(0.58)	(-31.71)	(-2.99)
Adj. R^2	0.230	0.990	0.975
N	9851	9866	5414

t statistics in parentheses * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

APPENDIX – data set

Field Name	Description	Data type	Descriptives
SalePrice1	1st sale price	Numeric (continuous)	n: 191,554 Mean: £144,017 Median: £125,000 Std. Deviation: £85,543 Min: £9,000 Max: £1,900,000
SaleDate1	1st sale date	Date (interval)	Range: 2 Jan 2003 – 26 Feb 2014
SalePrice2	2nd sale price	Numeric (continuous)	n: 47,158 Mean: £151,405 Median: £132,000 Std. Deviation: £81,637 Min: £10,000 Max: £1,775,000
SaleDate2	2nd sale date	Date (interval)	Range: 27 Feb 2003 – 26 Feb 2014
Property Type		Category (ordinal)	D (detached): 55,702 (29%) S (semi-detached): 61,153 (32%) T (terraced): 70,570 (37%) F (flat): 4,129 (2%)
Tenure	Legal interest	Category (nominal)	F (freehold): 179,802 (94%) L (leasehold): 11,751 (6%) U (unknown): 1 (-)
Beds	Number of bedrooms	Numeric (interval)	0: 53 (-) 1: 2,864 (2%) 2: 38,602 (20%) 3: 83,659 (44%) 4: 26,374 (14%) 5: 4,952 (3%) 6: 1,173 (1%) 7: 288 (-) 8+: 194 (-) Missing: 33,395 (17%)
YearBuilt	Year of construction (age categories were computed from this variable)	Date (interval)	<1900: 7,669 (4%) 1900: 15,790 (8%) 1901-1929: 15,088 (8%) 1930-1949: 10,263 (5%) 1950-1959: 8,989 (5%) 1960-1969: 9,178 (5%) 1970-1979: 10,323 (5%) 1980-1989: 6,955 (4%) 1990-1999: 11,260 (6%) 2000-2009: 18,014 (9%) 2010-2013: 8,019 (4%) 2014 - : 21 (-) Missing: 69,985 (37%)
Postcode2	Unit postcode	String	
Parea	Postcode area	Category (nominal)	CF: 64,882 (34%) CH: 8,806 (5%) GL: 1 (-) HR: 279 (-) LD: 2,797 (2%) LL: 34,136 (18%) NP: 29,232 (15%) SA: 45,844 (24%) SY: 5,637 (3%)
InspectDateEPC	Date of EPC inspection (EPC)	Date (interval)	Range: 7 Feb 1988 - 31 Jan 2014
LodgeDateEPC	Date of EPC	Date (interval)	Range: 22 Apr 2007 – 31 Jan 2014

	lodgement (EPC)		
FloorAreaEPC	Total floor area (EPC)	Numeric (continuous)	n = 147,116 Mean: 98 Median: 88 Std. Deviation: 52 Min: 2 Max: 8,412
Energy_Rating_Current	Current energy rating (EPC bands were computed from this variable)	Numeric (interval)	n = 191,553 Mean: 58 Median: 60 Std. Deviation: 15 Min: 0 Max: 111 Missing: 1
RU11IND	Rural-urban classification (2011 Census)	String	A1 Urban major conurbation: OA falls within a built-up area with a population of 10,000 or more and is assigned to the 'major conurbation' settlement category. The wider surrounding area is less sparsely populated; B1 Urban minor conurbation: OA falls within a built-up area with a population of 10,000 or more and is assigned to the 'minor conurbation' settlement category. The wider surrounding area is less sparsely populated; C1 Urban city and town: OA falls within a built-up area with a population of 10,000 or more and is assigned to the 'city and town' settlement category. The wider surrounding area is less sparsely populated; C2 Urban city and town in a sparse setting: OA falls within a built-up area with a population of 10,000 or more and is assigned to the 'city and town' settlement category. The wider surrounding area is sparsely populated; D1 Rural town and fringe: OA is assigned to the 'town and fringe' settlement category. The wider surrounding area is less sparsely populated; D2 Rural town and fringe in a sparse setting: OA is assigned to the 'town and fringe' settlement category. The wider surrounding area is sparsely populated; E1 Rural village: OA is assigned to the 'village' settlement category. The wider surrounding area is less sparsely populated; E2 Rural village in a sparse setting: OA is assigned to the 'village' settlement category. The wider surrounding area is sparsely populated; F1 Rural hamlet and isolated dwellings: OA is assigned to the 'hamlet and isolated dwelling' settlement category. The wider surrounding area is less sparsely populated;

			F2 Rural hamlet and isolated dwellings in a sparse setting: OA is assigned to the 'hamlet and isolated dwelling' settlement category. The wider surrounding area is sparsely populated.
SalePrice1psm	Sale price per square metre for transaction #1	Computed variable	n = 147,116 mean = 1,537 sd = 782 range = 49,942, min = 33 max = 49,975
SalePrice2psm	Sale price per square metre for transaction #2	Computed variable	n = 37,043 mean = 1,654 sd = 700 range = 39,601, min = 33 max = 39,634