Does energy efficiency matter to home-buyers?

An investigation of EPC ratings and transaction prices in England

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1. Introduction

As part of a broad objective of combating climate change, compulsory energy labelling of residential and commercial real estate has been introduced in many countries across the world. In the residential sector, acting as a market-based environmental policy instrument, energy labelling informs consumers about energy performance of dwellings. The primary objective is to reduce uncertainty about quality, generate positive demand shifts and, in turn, an upward shift in the price and an increase in the supply of energy efficient dwellings. Given that they provide the basis for the operation of well-functioning markets, prices are a key mechanism for 'harnessing market forces' to achieve the objectives of such market-based policies. Empirical research on the existence and extent of the price effects of energy labelling is important in evaluating the effectiveness of this type of policy instrument. This paper reports on an investigation of the relationship between energy performance ratings and sale prices of dwellings in England. Focussing on repeat sales, details of transactions involving 333,095 dwellings that took place in the period from 1995 to 2012 have been analysed. Before reviewing the data in greater detail, describing the statistical approaches to their analysis and discussing the results, we first provide some background and context to the role of energy labelling in the English residential real estate market, review the literature on eco-labelling and dwelling prices and specify a theoretical framework that outlines the expected relationship between energy rating and price.

2. Energy Labelling and Real Estate Markets

Over the last decade, a wide range of energy monitoring instruments and environmental labels has been introduced to both the commercial and the residential sectors of the real estate market. Although these instruments are a mixture of mandatory and voluntary schemes, with some highly energy efficient or zero carbon buildings collecting several labels, the boundary between mandatory and voluntary environmental labels has become blurred as urban planning authorities make labels such as Code for Sustainable Homes, BREEAM and LEED a condition of permission to develop. In 2008, the measurement of energy use in new and existing buildings in the UK became obligatory as a result of the European Union Energy Performance of Buildings Directive (EPBD). The Directive required all buildings at the point of construction completion, sale or rent (or every ten years) to have certificates giving information about their energy performance. For residential dwellings in the UK, an Energy Performance Certificate (EPC), and the accompanying 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 as built. EPCs are similar to the mandatory energy labels used in many consumer products such as tumble dryers and washing machines; buildings are rated on a scale A-G with band A being the most efficient.

In the 1980s, a body of work emerged that investigated the relationship between energy efficiency (typically proxied by energy bills) and residential sale prices. Laquatra *et al* (2002) provide a useful evaluation of this work. Among a range of limitations identified, probably the most important is that the studies typically involve small, highly localised samples consisting of dozens or hundreds of dwellings. However, they tend to find a positive relationship between energy efficiency (or proxies for energy efficiency) and residential sale prices (see Halvorsen and Pollakowski, 1981; Johnson and Kaserman, 1983; Quigley, 1984; Laquatra, 1986; Dinan and Miranowski, 1989; Quigley and Rubinfeld, 1989).

As eco-labelling has become more prevalent, a more recent body of research has emerged that focuses on the price effects of intrinsic potential energy efficiency as revealed by a certificate or label rather than realised performance outcomes. To date, the majority of these studies have concentrated on the US commercial office market. Broadly, the findings reveal a positive relationship between environmental labels and price (see Wiley *et al*, 2010; Eichholtz *et al*, 2010 and 2011, Fuerst and McAllister, 2011a and 2011b; Reichardt *et al* 2011; and Deng *et al*, 2012). One of the first investigations of the price effect of mandatory energy labelling in a residential real estate market was carried out by the Australian Bureau of Statistics (2008). Using a sample of residential sales in the Australian Capital Territory for 2005 (2,385 transactions) and 2006 (2,719 transactions) and standard hedonic procedures, the Bureau estimates the effect of Energy Efficiency Rating (EER) on house prices. For 2005, they estimate a premium of approximately 1% for every 0.5 increase in EER rating (EER ranges from 0-5). For 2006, they estimate a premium of approximately 2% for every 0.5 increase in EER. For a pooled sample, relative to zero rating house, they estimate premiums of 1.6% (EER 1), 3% (EER 2), 5.9% (EER 3), 6.3% (EER 4) and 6.1% (EER 5). The explanatory power of the models is high and a large number of control variables for dwelling quality are included. It is worth noting that they find evidence of a nonlinear effect - the marginal addition to the price effect declines as rating increases.

For the Netherlands office market, Kok and Jennen (2012) looked at the relationship between EPC rating and rental price for 1,057 transactions in the period 2005-2010. Using standard hedonic techniques, they identified a rental premium of approximately 4.7% for buildings rated C or better compared to buildings rated D and worse. However, it is possible that offices rated C or above may be better quality than buildings with inferior performance. Put simply, the level of energy efficiency may be correlated with unobserved quality variables such as design or interior finish. In the UK, Fuerst and McAllister (2011c) examined effect of EPC rating on capitalisation rate, (appraised) market value and market rent for 708 commercial properties as at September 2010. They found no significant effect of EPC rating on appraised market rent or market value and weak evidence of an effect on capitalisation rates.

In one of the most closely related studies to this research, Brounen and Kok (2011) examined the relationship between EPC rating and sale price for 31,993 residential sales in 2008-9 in the Netherlands. Compared to D-rated homes, they estimate premiums of 10%, 5.5% and 2% for A, B and C ratings respectively. For dwellings rated E, F and G, they identified discounts of 0.5%, 2.5% and 5% respectively. Their sample contained a broad range of control variables including dwelling size, insulation quality, central heating and level of maintenance. It is worth noting that although EPCs are mandatory in the Netherlands, a policy regarding exemptions effectively made them optional. Consequently the adoption rate is low. For instance, in August 2009 this rate dropped to seven percent and never exceeded 25 percent throughout the study period. The authors account for the quasi-voluntary nature of the EPCs with a Heckman correction for selection bias, albeit the explanatory power of their model of label adoption is low.

Another closely related study was conducted by Hyland *et al* (2013) who applied a standard hedonic technique to investigate the impact of energy efficiency ratings on capital and rental asking prices for dwellings in Ireland. Because only 5% of homes for sale (and only 2.3% of homes for rent) have an efficiency rating, the Heckman procedure was employed to control for selection bias. The results showed that, for a sample of 15,060 dwellings on the market between 2008 and 2012, there was a 9.3% price premium for A-rated compared to D-rated dwellings, 5.5% for a B-rating, and a 10.6% discount for F and G ratings. For rented dwellings the premium for an A-rating was 1.8%, 3.9% for a B rating, a discount of 1.9% for E ratings and 3.2% for F and G ratings. These results are broadly in line with the findings from England that are presented in this paper. A limitation of this investigation is the lack of a control for age, which is likely to be significantly negatively correlated with the energy efficiency rating. By contrast, the study presented here includes and pools information on age and vintage from two independent sources as detailed in the 'Data and Descriptive Statistics' section of this paper below.

A key distinction between our analysis and both the Kok and Brounen (2011) and Hyland *et al* (2013) papers is that EPCs are mandatory for virtually all new-build and dwelling transfers in the UK with very few exceptions. This means that selection bias due to missing EPCs, a problem that affects comparable studies published to date, is not a relevant concern here. A second important distinction is our use of official price information as recorded by the authorities (Land Registry data) compared to list prices (Hyland *et al* 2013) or transaction price data gathered by realtor organisations (Kok and Brounen, 2011).

In summary, whilst there are fairly plausible *a priori* grounds to expect a willingness to pay for energy efficiency by housing consumers, in contrast to the large volume of research on the effects of

school quality, accessibility and other amenities on houses prices, the empirical research on the effect of energy or environmental labelling remains limited. Most of the work is focussed on commercial real estate markets. Nearly all studies apply a version of Rosen's (1974) hedonic model to estimate the price effect of an environmental label. In this paper we build on the work described above and use a large sample of repeat sales transactions to investigate whether and to what extent an energy rating might influence dwelling price and the rate of change in dwelling price. Before describing the data set and method, in the next section we attempt to formalise a theoretical framework that may be used to analyse the effect of EPC ratings on property prices.

3. Theoretical Framework

We employ a hedonic model to estimate the effect of EPC ratings on house prices. The theoretical foundations and empirical framework of the model have been developed through many works, see Rosen (1974), Edlefsen (1981), Roback (1982), Bartik (1987), Epple (1987), Blomquist, Berger and Hoehn (1988), Bajari and Benkard (2005) and many others (see review of literature by Malpezzi, 2003). Essentially, the capitalization process works through constrained utility maximisation by consumers.

In the first instance, we assume that housing is a differentiated economic good characterized by a vector H of several physical and locational attributes. For illustration, the list of these attributes consists of: dwelling age (a), size (f), number of rooms (r), locational desirability (L) and EPC rating (E). We also assume that there is a variable indicating quality of the housing unit, Q. Assume one undifferentiated numeraire commodity, c. The utility function, having the usual continuity and convexity properties, is then specified as follows. Note that the continuity and convexity properties are not applicable for non-continuous variables.

$$U = U(H, c) \tag{1}$$

$$H = H(a, f, r, L, Q, E) \tag{2}$$

Moreover, it is also conceivable that location, quality and EPC rating may also be determined by a multitude of factors, as shown in equations (3), (4) and (5):

$$L = L(d, x) \tag{3}$$

where d is distance to the town centre; x is a vector of urban features and amenities such as level of infrastructure, school quality, crime rate and availability of public services among others.

$$Q = Q(z, k, g) \tag{4}$$

Where z is building material quality; k is a vector of design features; g is a vector of energy performance features such as lighting, insulation, water heating and glazing.

$$E = E(e, Q, L) \tag{5}$$

Where e represents energy consumption and L and Q are as defined above in equations (3) and (4) respectively.

Our question of interest is: how much is a consumer willing to pay for a house with a specific attributes, namely an EPC rating? Consumers' utility depends on income level and will be reflected by the revealed preferences of different types of consumers. For a level of income M_0, utility is given as U_0. The price of c is normalized to unity and bid-rent for the house is B. It is also conceivable that a range of financial benefits and savings per annum (S) may accrue to the consumer due to superior energy performance. Such monetary savings generated by energy efficient features will be a function of the present value of the energy cost savings. However, this is dependent upon uncertain assumptions about future energy price inflation, behavioural patterns and appropriate discount rates. Let us assume, therefore, that such expected savings are associated with a probability distribution. We also include the additional cost (t) of obtaining energy efficient features and appliances to comply with regulatory standards. So the individual's budget constraint can be written as:

$$B + c + t - S(1-\partial)^n = M \tag{6}$$

The *bid-rent, B,* is the consumer's willingness to pay for h. ∂ is the discount rate and n is number of years over which savings will accrue. Therefore, equation (1) may be represented by:

$$U = U\{h(.), (M + E(S) - B - t)\} = U\{a, f, r, L(.), Q(.), E(.), (M + S(1-\partial)^n - B - t)\} \tag{7}$$

Inverting equation (7) leads to a *bid-rent* function as follows,

$$B = B\{a, f, r, L(.), Q(.), E(.), (M + S(1-\partial)^n - t)\} \tag{8}$$

Using any attribute of $h(.)$, the shape of the bid-rent function in equation (5) is then represented by the partial derivatives e.g. with respect to EPC ratings.

$$B_E = U_E / U_c \tag{9}$$

The assumption of a strictly diminishing marginal rate of substitution means that B will increase with e, but at a decreasing rate. We can interpret the slope B_E as the price that a consumer is willing to pay for an incremental increase in the EPC rating of a house or, in other words, as the hedonic price of EPC ratings. Given this interpretation, equation (6) is analogous to the usual utility maximization condition equating the price ratio and the marginal rate of substitution. Equation (8) can be estimated using regression techniques and our focus is on price effect or coefficient of each parameter i.e. equation (9). Before employing these regression techniques, there are several possible sources of bias that may impede the ability to estimate equation (8) consistently and these are described below.

First, the EPC rating, as in equation (5), may be associated with the presence (or absence) of a range of energy efficient features in a dwelling. Key features tend to be associated with the type and nature of lighting, insulation, water heating and glazing. This implies presence of correlation between Q and E in equation (8). Given the subjective and multi-faceted nature of the quality variable Q, there may be unobservable attributes that are correlated with the observed ones. In other words there may be unobserved heterogeneity leading to a significant omitted variable bias. Similarly, location, as reflected in equation (3), may be a significant source of unobserved heterogeneity.

Second, given that energy efficient features generate a blend of direct and indirect and monetary and non-monetary benefits, in terms of *a priori* expectations, it is difficult to quantify S. As a baseline we might expect that a direct price impact of superior energy performance will result from the monetary savings generated by energy efficient features, and this will be a function of the present value of the energy cost savings. However, even this baseline effect is dependent upon uncertain assumptions about future energy price inflation and appropriate discount rates. Therefore, the budget constraint in equation (6) may be mis-specified.

Third, making a reasonable assumption that the energy efficient features will tend to be newer, it is expected on average that other life cycle costs associated with maintenance and replacement will be lower. Even more difficult to quantify is the value of the hedge that energy efficient features provide against increases in energy costs and changes to energy regulation. In addition to these direct financial benefits, dwellings with energy efficient features are likely to obtain other non-energy related benefits such as, acoustic and security improvements from energy efficient glazing and improved thermal comfort. These are essentially quality effects in that the presence of energy efficient features improves the overall quality of the dwelling. Such a bundle of positive attributes has the potential to increase marketability of dwellings, leading to shorter time on market as well as a price impact. This effect may be more discernible where there are concentrations of eco-consumers who, in turn, obtain utility

from the presence of energy efficient features. The presence of such potentially correlated influences is likely to prevent a precise and exclusive quantification of the price impact of an eco-label.

Finally, some variables may call for a non-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.

Next, we turn to the empirical estimation framework appropriate for addressing a number of issues raised above.

4. Estimation Strategy

The empirical estimations of the theoretical model in equation (8) can be undertaken in the following form: we derive the following:

$$P_{it} = \beta_0 + \sum_{i=1}^{I} \beta_i X_i + e_{it} \tag{10}$$

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. The hedonic weights assigned to each variable are equivalent to their overall contribution to price (Rosen, 1974). However, hedonic models of property sales almost always involve a time dimension as sales transactions are collected over a period of months, quarters or years. To capture this inter-temporal variation, we enrich equation (10) with a set of binary variables that represent the average effect of each time period separately in the following form (see Bailey et al, 1963; Gatzlaff and Haurin, 1997):

$$P_{it} = \sum_{j=1}^{J} \beta_j X_{ji} + \sum_{t=1}^{T} c_t D_t + e_{it} \tag{11}$$

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[1].

The standard hedonic regression model uses price per square metre of the dwelling as the dependent variable and a number of property and local area attributes as independent variables. However, a common problem is lack of control for unobserved heterogeneity. There are two sources of unobserved heterogeneity in equation (8): locational attributes L and dwelling quality Q. If these unobserved effects are correlated with observed attributes then the estimates will be biased. One way to control for locational attributes is to include local area fixed effects (specified as dummy variables) in the model under the assumption that correlated unobservables are time-invariant. In our cross-section model, we explicitly control for such unobserved effects. With regard to dwelling quality, several variables are typically incorporated in residential hedonic price models that describe objectively the attributes of a dwelling. These include property type, age and number of bedrooms for example. It is not usually possible to obtain a 'quality' rating of a dwelling nor a measure of how this quality might have changed over time, perhaps as a result of home improvements. It appears plausible that the EPC rating is not a proxy for the overall condition or the visual appeal of a property as it is possible to obtain a high EPC rating for a property with poor non-energy related maintenance, decoration and visual appeal (and vice versa). In the absence of detailed information on the nature of improvements, we assume that they are evenly distributed throughout the stock of dwellings. However, it may be suspected that unobserved improvements are correlated with the EPC ratings. Any such correlation would only be problematic if it concerned non energy-related features, such as a new kitchen, bathroom or an extension to the existing property. By contrast, upgrades such as better doors, windows and boilers have clear implications for the energy efficiency of a building even if they may at the same time be upgrades in terms of aesthetics, safety, etc. Hence, even if we could identify improved properties, it would be difficult to disentangle the energy-related value enhancements from those of other dimensions. To ensure the robustness of our empirical estimates, we attempt to mitigate the effects of potential omitted variable bias by removing observations that are more likely to have been improved.

To measure the influence of EPC rating on price appreciation, we also undertake a hedonic analysis

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[1] The 'raw' coefficients of the EPC dummy variables require adjustment to determine the percentage premiums (or discounts) as suggested by Halvorsen and Palmquist (1980) and Giles (2011): our simplified adjustment formula follows the van Garderen and Shah (2002) method where the proportional impact p_j of a binary variable on the dependent variable in a semi-logarithmic regression is computed as: $p_j=[exp(c_j)-1]$ with c_j being the estimated coefficient of the dummy variable.

with repeat sales transactions only. Effectively, we are controlling for the unit fixed effects by comparing two sales of the same dwelling. Specifically, the difference in sales prices between two transaction dates are regressed on a set of dwelling attributes that includes the EPC rating in the following form:

$$P_i^2 - P_i^1 = \left(\sum_{j=1}^J \beta_j X_{ji}^2 + \sum_{t=1}^T c_t D_i^2\right) - \left(\sum_{j=1}^J \beta_j X_{ji}^1 + \sum_{t=1}^T c_t D_i^1\right) + e_i^{21} \qquad (12)$$

where the first and second sale periods are denoted by the superscripts 1 and 2 respectively. Assuming that most house characteristics remain the same between two sales of the same house, equation (12) simplifies to:

$$P_i^2 - P_i^1 = \sum_{t=1}^T c_t (D_i^2 - D_i^1) + e_i^{21} \qquad (13)$$

Hence, a 'pure' repeat-sales model only requires information on prices and time of transaction. However, as the mix of properties that are sold in each period changes (for example, large detached houses might be transacted more often than other types during certain periods), it is also necessary to control for hedonic characteristics such as size, age, and type.

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

$$\frac{P_t^2}{P_t^1} = \frac{RI_t^2}{RI_t^1} + \sum_{j=1}^J X_{jt} + u_j \qquad (14)$$

Thus price changes between two transactions are driven by the regional or local housing market that a property is located in, 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 regional trend. The first factor is captured by the regional 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. More specifically, the empirical modelling will comprise:

- Cross-sectional models for price levels disaggregated by property type, region and EPC rating
- Repeat sale models for price appreciation disaggregated by property type and EPC rating.
- Robustness checks for restricted samples.

5. Data and Descriptive Statistics

The economic analysis of house price determination, and the pricing of housing attributes, benefits from a large sample of properties to ensure that the findings are representative of the entire market. This is particularly relevant in cases where the variables of interest are expected to have only a moderate impact on prices. This might be because the relatively weak pricing signal is overwhelmed by idiosyncratic price components in a small sample with large residual errors or due to unobserved attributes of a particular property or set of properties. Such concerns are addressed, at least in part, by obtaining a large sample of dwelling transactions and associated control variables. In the context of this study, the hedonic estimation was dependent upon the availability of data in three main areas; (1) market prices, (2) energy performance and (3) building and location attributes. The collection and assembly of data from these three areas is described below.

Data sets from several sources were merged into a unified database. In the first step, data on market prices were obtained from Calnea Analytics, comprising residential transaction prices as submitted to the UK Land Registry. To enable repeat-sales as well as pooled cross-sectional analysis, the sample contains the prices of dwellings that were sold at least twice in the period 1995-2012. The start of the study period is determined by the availability of comprehensive attribute data. The second transaction in each pair of sales is determined by the availability of energy labelling information to ensure that an EPC rating was available at the time of at least one transaction for each dwelling. This effectively means that at least one of the transactions must have occurred after August 2008 when EPCs became mandatory for all residential transactions in the UK. The sample was further refined by the availability of essential information on property location, type and size. This information is captured in the Calnea database through both estate agency listings and surveyor visits. Applying these criteria, we obtained a sample of 500,000 dwellings and one million transaction prices in England and Wales, randomly drawn from a pool of approximately five million transactions that match the above criteria. No transaction prices and/or EPC information were available for Scotland and Northern Ireland.

In the next step of data assembly, we obtained and matched socio-economic data from the Office for National Statistics as well as a series of indicators collected and published by the UK Census using a Geographic Information System. The geographic reference of these area variables is a combination of postcode districts, Output Areas (urban-rural indicator) and Lower Level Super Output Areas. A full list of these variables is available in Appendix 1. In the third step, EPC data, maintained by Landmark on behalf of the Department of Communities and Local Government, were added to the database. This was carried out using address-matching software. Landmark was unable to match transactions to EPC records for Wales so, following the removal of duplicate records and those that contained input and administrative errors, the resultant sample included 333,095 dwellings.

Descriptive statistics are provided in Tables I and II and there are a number of notable points. Terraced and semi-detached dwellings account for approximately one-third of the sample. Detached dwellings represent around a quarter with flats accounting for just less than 8% of the total. Most dwellings in the sample are held on freehold tenure. There is no information on age for nearly 15% of the observations but where this has been recorded the maturity of the housing stock is clear; 44% of the sample was built more than 50 years ago. Two variables measure dwelling size: number of bedrooms, the vast majority (89%) of dwellings comprising two to four bedrooms with 44% of the sample in the three-bedroom category; and floor area, with a median size of 85 square metres. In terms of energy efficiency, most dwellings (93%) are in band C, D or E. Only seven are in band A, which is why we formed a combined A/B category for the purpose of this analysis. Table III reveals that flats tend to be the most energy efficient dwelling type with 50% in bands B and C. In contrast, 21% of detached properties were in bands B or C.

[INSERT TABLES I, II AND III HERE]

The impact of age on EPC band is shown in Figure I; more modern dwellings, built since 2003, are in band B, those built in the 1990s tend to be found in bands C and D whereas older dwellings are predominantly found in bands E, F and G. Combining EPC band with the size and age variables and the urban/rural indicator variable (which scores each dwelling according to the extent to which it is located in an urbanised area), reveals that older, larger dwellings located in rural areas tend to have lower EPC ratings than smaller, modern dwellings in urban areas. This finding from the descriptive statistics is borne out in the hedonic modelling below.

[INSERT FIGURE I HERE]

6. Findings

Following the analytical strategy and data sampling outlined above, 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 IV. The log of dwelling price per square metre is explained as a function of four dwelling attributes (age, dwelling type, number of bedrooms and tenure), two composite neighbourhood attributes (urban-rural index score and deprivation index score), quarterly time fixed effects, postcode area fixed effects and EPC rating. In terms of explanatory power, the adjusted R^2 is nearly 70% for the full sample and the coefficients of the independent variables largely have the expected signs. The 'number of bedrooms' coefficient is negative and highly significant. By

expressing the dependent variable as price per square metre rather than total price, we largely eliminate the size effect of a property from the estimation. While this reduces the predictive power of the model and may not represent how the majority of buyers in the UK think about property prices, it presents a purer measure of prices. The bedroom coefficient then captures both the negative effect of smaller room sizes and possibly also diminishing marginal utility from consuming more space, i.e. all else equal, larger properties with more bedrooms command lower prices *per square metre* than smaller properties. 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 and detached properties. In contrast to semi-detached and terraced dwellings, detached properties constructed in the last three decades tend to sell for significantly less per square metre than dwellings constructed before 1900. The results for dwelling type are also in line with expectations. With terraced dwellings as the 'hold-out' category, semi-detached and detached properties achieve significantly higher prices per square metre, with the latter selling for approximately 19% more per square metre than terraced dwellings. The coefficients for deprivation and rural indexes also have the expected signs. Compared to leasehold, the coefficient for freehold is positive and significant.

Turning to the variable of interest, EPC rating, and using band D as the 'hold-out' category, the pattern of price effects reveals a positive relationship between energy performance rating and sale price. For the whole sample model, there are significant positive premiums for dwellings rated A/B (5%) or C (1.8%) compared to dwellings rated D. For dwellings rated E (-0.7%) and F (-0.9%), there are statistically significant discounts. The relative price effects are highest for terraced dwellings. All else equal, we estimate that a terraced dwelling rated B has sold for approximately 4.5% more per square metre than a terraced dwelling EPC rated D (see Column 4 in Table IV). The comparable figure for a flat is 1.6%. Compared to D rated dwellings, all dwelling types rated E, F and G sold at statistically significant discounts. In Table IV (Column 7) the results of the estimation when energy efficiency score, rather than band, is used as the independent variable and the expected positive relationship between energy efficiency and dwelling sale price is also found. A 1% increase in the energy efficiency score produces a 0.1% increase in predicted dwelling price. This price effect can be compared to two previous studies that examined the price effect of energy efficiency measured on a continuous scale. First Cajias and Piazolo (2013) found that a 1% increase in energy efficiency produced a 0.45% increase in market value and, second, Hyland *et al* (2013) reported a price fall of 1.3% for each 1-point decline in building energy rating as measured on a 15-point scale (i.e. a 1% fall in the energy rating produced a 0.2% fall in price).

With the exception of detached houses, a pattern of increasing price premiums with increasing energy performance is found for all the dwelling types. For detached dwellings, no significant price effects were observed. This apparent anomaly seems to be driven by a relatively small section of the sample consisting of just over 16,653 dwellings in rural areas. When the detached dwellings are separated into dwellings located in sparsely populated areas and dwellings located in densely populated areas, we find that the pattern of price discounts found in the rest of the sample is replicated for the detached dwellings in densely populated areas. More specifically, the pattern of price effects for the 68,354 detached dwellings in densely populated areas is very similar to the pattern of price discounts for the 106,793 semi-detached dwellings. It is also notable that the explanatory power of the hedonic model is lowest ($R^2 = 47\%$) for the sub-sample of 16,653 detached dwellings in sparsely populated areas. This is likely to be due to the greater heterogeneity of this particular group, which will include large country residences together with a wide range of rural dwellings, built in vernacular styles over several centuries.

[INSERT TABLE IV HERE]

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 salience 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 V provides estimates of the determinants of the dwelling price appreciation. We see that, for all types of dwelling, number of bedrooms has a significant positive effect on growth rate. Compared to dwellings built pre-1900, the prices of dwellings constructed between 1967 and 2007 have appreciated at a significantly lower rate. In contrast, dwellings constructed prior to 1949 have experienced slightly – but statistically significant – higher appreciation rates compared to the 'hold-out' category (dwellings constructed pre-1900), albeit the coefficients are not significant when the dwellings are disaggregated into types. Given the sample period and the over-supply of apartments in many markets, it is perhaps not surprising that, compared to terraced dwellings, flats have experienced significantly lower rates of price appreciation. It is likely that housing market sub-sectors may react differently to cyclical fluctuations, e.g. flats may experience more volatility compared to other sectors (see Costello *et al* (2000) for example). Our analysis at the sub-sector level is suitable to alleviate

such concerns as we also explicitly control for the time-specific effects within each sector. 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 sold for higher prices per square metre compared to leasehold dwellings and have experienced a significantly higher rate of price appreciation.

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 band, which have experienced significant price depreciation compared to D-rated dwellings. Dwellings in bands E and F are also estimated to have appreciated at significantly lower rates than properties in band D. When we look at the estimates for the dwelling type sub-samples, we see that the effects on price appreciation are largest for detached dwellings and that there is no significant effect on flats rated E and F. In Table V, Column 7 displays the results of the estimation when energy efficiency score, rating than band, is used as the independent variable. The expected positive relationship between energy efficiency and price appreciation is also found.

[INSERT TABLE V HERE]

7. 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 dwellings 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; dwellings that have been re-sold within a short period of time or dwellings exhibiting high levels of unexplained variance in the estimations for example. Firstly, we restrict the sample to dwellings sold where the EPC is known at time of sale. Second, we remove observations that had a relatively high level of unexplained variation in the full sample model. The rationale behind this test is that the dwellings that might have been improved are more likely to have a high level of unexplained price variation in our regression specification. Therefore, once we have run the full sample model, we then identified properties with a large discrepancy between the price predicted by the model and the observed price, and then re-estimate the model without those properties in the regression sample. This two-stage estimation is analogous to estimation techniques used in spatial econometrics to identify unobserved spatial effects (see for example Case *et al*, 2004), and should provide us with results from a sample of properties

whose price variations are reasonably explained by the observable information. Third, a related concern is the possibility of sample selection bias in our sample of transacted properties. A well-established literature argues that more frequently traded residential properties are of lower quality (Chernobai and Chernobai, 2013; Jansen *et al*, 2008; Bourassa *et al*, 2006; Costello and Watkins, 2002; Englund *et al*, 1999). In our context, it is likely that frequently transacted properties may have undergone energy efficiency-related improvements. However, our sample includes dwellings that have been sold twice in the time period under investigation, namely 17 years. According to the English Housing Survey (2014) the average holding period for an owner-occupied dwelling in 17.3 years. Given the long time period for inclusion in our sample, it is unlikely that the results will reflect any significant sample selection bias. However, in order to address such concern, we remove observations where the property had been sold again within two years.

It is reassuring that the results remain broadly stable. Details are presented in Table VI. For the cross-sectional price models the results of the three restricted sample models estimate similar patterns of premiums and discounts compared to EPC D as the full sample model with one exception; A/B rated dwellings in the sample restricted to dwellings where the EPC is known at time of both sales. It should be noted that this restriction resulted in a small sample size of 18,135 dwellings. Whilst restricting the sample to dwellings with low unexplained variance reduces the sample by approximately 80%, the estimates of price premiums and discounts remain indistinguishable from the full sample results. Although the outcome of this robustness test is supportive of the main findings, the caveat of omitted variable bias can still be significant to consider when interpreting the parameter estimates. Similarly, taking out dwellings that have been '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 very little variation in the estimated coefficients for the various restricted samples.

[INSERT TABLE VI HERE]

It was estimated above that the largest relative price effects associated with EPC rating were found with terraced dwellings. This may be due to the fact that terraced properties tend to be cheaper than other dwelling types. This, in turn, generates an expectation that the absolute value of energy savings associated with enhanced energy performance will have different relative price effects. Given marked regional variations in house prices, assuming that price premiums or discounts to some extent represent the present value of expected energy savings, there should also be a negative relationship between house prices and percentage price premium or discount. Table VII presents the results of the

hedonic estimations disaggregated by region[2]. The pattern of price effects is broadly as expected. The largest premiums and discounts related to dwellings rated D are in the region with the lowest house prices – the North East. In regions with the highest house prices (London, South East, South West and East Anglia) there are either lower or no statistically significant price premiums/discounts. Thus, the findings from a regional disaggregation are consistent with the expectation that similar absolute values of energy savings and other benefits associated with good energy ratings will have different relative effects on house prices.

[INSERT TABLE VII HERE]

8. Conclusion

Reflecting growing concern about man-made climate change, over the past decade there has been an increasing policy focus on improving the environmental performance of the housing stock. The core function of mandatory energy efficiency certification in the EU has been to change consumer behaviour by providing reliable information on the energy performance of dwellings to buyers. Given the quasi-credence attributes of residential property, it is often not feasible for consumers to directly measure some desired characteristics such as energy efficiency. The key assumption underpinning the introduction of market-based policy instruments such as certification is that energy efficient attributes will be capitalized which will, in turn, stimulate increased supply of new energy efficient dwellings and the refurbishment of existing dwellings to improve their energy performance.

Drawing upon a large sample of dwellings with mandatory energy certificates, we find that the vast majority of dwellings are clustered in the middle EPC bands (C, D and E). Nearly half of all dwellings are rated D. Only eight out of 333,095 (twice) sold dwellings were in band A. Given the careful approach taken to select the sample, there is no reason to suspect that this breakdown of ratings is significantly different from the population of transacted dwellings over the relevant time period in this study. Not surprisingly, there is a clear relationship between energy efficiency and age. Only 6% of dwellings built before 1900 had a rating of C or better. The comparable figure for dwellings constructed since 2007 is 94%. We find evidence of a positive association between price per square metre and energy performance rating. We estimate that, compared to dwellings rated D, those in bands A and B sold at a premium of 5% and those in band C for a premium of 1.8%. Dwellings rated F and E sold for approximately 1% less and dwellings rated G sold for nearly 7% less. Apart from the dwellings in the highest EPC band, the findings for price growth are broadly similar.

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[2] There are nine regions in England; London, South East, South West, East Midland, West Midlands, East of England, Yorkshire and Humberside, North East and North West.

In order to put the percentage premiums into context, it is useful to consider the average dwelling price in England and Wales. In August 2014 this was £177,824 according to Land Registry data[3]. For the full sample, dwellings in EPC bands A and B sold for a 5% premium, all else equal; a monetary equivalent of approximately £8,900 in relation to the average house price. For dwellings in band C the premium was 1.8%, a monetary equivalent of approximately £3,200. In comparison to the cost of energy efficiency measures, these premiums seem broadly plausible. For example, the combined cost of typical energy efficiency measures that include loft and wall cavity insulation, boiler and space-heating controls, and low energy lighting (but not renewable power generation such as photovoltaic panels) would be approximately £6,100 for a two-bedroom Victorian end-of-terrace dwelling and £7,300 for a three-bedroom semi-detached dwelling built in the mid twentieth century (BPF, 2013).

In the UK, as in most residential real estate markets, house price is driven in the main by location, size and dwelling type. But price is also influenced by other attributes that determine the condition and quality of the accommodation. Many of these attributes, such as double-glazing, modern space and water heating systems, improve energy efficiency and so it is not surprising that there is a positive relationship between price and the energy efficiency of a dwelling. We should acknowledge that there are significant empirical challenges in estimating the equilibrium prices of the component attributes in house price models. For example, it is not practical to include the full range of price determining variables in the model and, thus, hedonic studies are afflicted by omitted variable and endogeneity problems. In this study specifically, it is possible that dwellings with higher energy ratings are also superior in terms of other attributes such as more modern kitchens and bathrooms, which may impact upon the results of our cross-sectional estimation. However, by combining the cross-sectional analysis with an augmented repeat-sales approach, a consistent pattern emerges that is robust across model specifications, sub-groups and time periods. While the causality behind the energy efficiency price premium may be subject to debate, this research has established the existence of such a premium in the English housing market.

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[3]

https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/357080/HPIReport20140922.pdf

References

Australian Bureau of Statistics. 2008. Energy Efficiency Rating and House Prices in the ACT, Report for Department of the Environment, Water, Heritage and Arts.

Bajari, P., Benkard, C., 2005. Demand Estimation with Heterogeneous Consumers and Unobserved Product Characteristics: A Hedonic Approach. J. Polit. Econ. 113(6), 1239-1276.

Bartik, T., 1987. The Estimation of Demand Parameters in Hedonic Price Models. J. Polit. Econ. 95(1), 81-88.

Bailey, M., Muth, R., Nurse, H., 1963. A regression method for real estate price index construction. J. Am. Stat. Assoc. 58(304), 933-942.

Blomquist, G., Berger, M., Hoehn, J., 1988. New Estimates of Quality of Life inUrban Areas. Am. Econ. Rev. 78, 89-107.

BPF., 2013. Energy Efficiency and the Private Rented Sector, British Property Federation, http://www.bpf.org.uk/en/files/event_related_documents/Energy_Efficiency_and_the_Private_Rented _Sector.pdf

Brounen, D., Kok, N., 2011. On the Economics of Energy Labelling in the Housing Market. J. Environ. Econ. Manag. 62, 166-179.

Bourassa, S., Hoesli, M., Sun, J., 2006. A Simple Alternative House Price Index Method. J. Hous. Econ. 15, 80–97.

Cajias, M., Piazolo, D., 2013. Green performs better: energy efficiency and financial return on buildings. J. Corp. Real Estate. 15(1), 53-72.

Case, B., Clapp. J., Dubin, R., Rodriguez, M., 2004. Modeling Spatial and Temporal House Price Patterns: A Comparison of Four Models. J. Real Estate Financ. Econ., 29(2), 167–91.

Chernobai, A., Chernobai, E., 2013. Is Selection Bias Inherent in Housing Transactions? An Equilibrium Approach. Real Estate Econ. 41(4), 887–924.

Costello, G., Watkins, C., 2002. Towards a System of Local House Price Indices. Hous. Stud. 17, 857–873.

Costello, G., 2000. Pricing size effects in housing markets. J. Property Res. 17(3), 203-219.

Deng, Y., Li, Z., Quigley, J., 2011. Economic Returns to Energy-Efficient Investments in the Housing Market: Evidence from Singapore. Reg. Sci. Urban Econ. 42, 685-694.

Dinan, T., Miranowski, J., 1989. Estimating the implicit price of energy efficiency improvements in the residential housing market: A hedonic approach. J. Urban Econ. 25(1), 52-67.

Edlefson, L., 1981. The Comparative Statics of Hedonic Price Functions and Other Nonlinear Constraints. Econometrica. 49, 1501-20.

Eichholtz, P., Kok, N., Quigley, J., 2010. Doing Well By Doing Good? Green Office Buildings. Am. Econ. Rev. 100, 2492-2509.

Eichholtz, P., Kok, N., Quigley, J., 2013. The economics of green building. Rev. Econ. Stat. 95(1), 50-63.

Englund, P., Quigley, J., Redfearn, C., 1999. The Choice of Methodology for Computing Housing Price Indexes: Comparisons of Temporal Aggregation and Sample Definition. J. Real Estate Financ. Econ. 19: 91–112.

English Housing Survey. 2014. Headline Report 2012-13. Department for Communities and Local Government.
https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/284648/English_Housing_Survey_Headline_Report_2012-13.pdf .

Epple, D., 1987. Hedonic Prices and Implicit Markets: Estimating the Demand and Supply Functions for Differentiated Products. J. Polit. Econ. 95, 59-80.

Fuerst, F., McAllister, P., 2011a. Green Noise or Green Value: Measuring the Price Effects of Environmental Certification in Commercial Buildings. Real Estate Econ. 39, 46-69.

Fuerst, F., McAllister, P., 2011b. Eco-labeling in Commercial Real Office Markets: Do LEED and Energy Star Offices Obtain Multiple Premiums? Ecol. Econ. 70, 1220-30.

Fuerst, F., McAllister, P., 201lc. The Impact of Energy Performance Certificates on the Rental and Capital Values of Commercial Property Assets. Energy Policy. 39, 6608-6614.

Gatzlaff, D., Haurin, D., 1997. Sample selection bias and repeat-sales index estimates. J. Real Estate Financ. Econ. 14, 33-50.

Giles, D., 2011. Interpreting Dummy Variables in Semi-logarithmic Regression Models: Exact Distributional Results (Working Paper). Victoria, B.C.: University of Victoria, Department of Economics.

Halvorsen, R., Pollakowski, H., 1981. The effects of fuel prices on house prices. Urban Stud. 18, 205–211.

Halvorsen, R., Palmquist, R., 1980. The Interpretation of Dummy Variables in Semilogarithmic Equations. Am. Econ. Rev. 70(3), 474

Hyland, M., Lyons, R., Lyons, S., 2013. The Value of Domestic Building Energy Efficiency: Evidence from Ireland. Energy Econ. 40, 943-952.

Jansen, S., de Vries, P., Coolen, H., Lamain, C., Boelhouwer, P., 2008. Developing a House Price Index for the Netherlands: A Practical Application of Weighted Repeat Sales. J. Real Estate Financ. Econ. 37: 163–186.

Johnson, R., Kaserman, D., 1983. Housing Market Capitalization of Energy-Saving Durable Good Investments. Econ. Inq. 21(3), 374-386.

Kok, N., Jennen, M., 2012. The impact of energy labels and accessibility on office rents. Energy Policy. 46, 489-497.

Land Registry, 2013. House Price Index, March 2013. Released 29 April 2013.

Laquatra, J., 1986. Housing market capitalization of thermal integrity. Energy Econ. 8(3), 134-138.

Laquatra, J., Dacquisto, D., Emrath, P., Laitner, J., 2002. Housing Market Capitalization of Energy Efficiency Revisited. ACEEE Summer Study of Energy Efficiency in Buildings, Teaming for Efficiency, Proceedings, 8.

Malpezzi, S., 2003. Hedonic Pricing Models: A Selective and Applied Review, in Housing Economics and Public Policy: Essays in Honor of Duncan Maclennan, T. O. Sullivan and K. Gibbs (Eds.), Blackwell.

Quigley, J., 1984. The production of housing services and the derived demand for residential energy. RAND J. Econ. 555-567.

Quigley, J., Rubinfeld, D., 1989. Unobservables in consumer choice: Residential energy and the demand for comfort. Rev. Econ. Stat. 416-425.

Reichardt, A., Fuerst, F., Rottke, N., Zietz, J., 2011. The business case of sustainable building certification: A panel data approach. J. Real Estate Res. 34, 99-126.

Roback, J., 1982. Wages, Rents, and the Quality of Life. J. Polit. Econ. 90: 1257-1278.

Rosen, S., 1974. Hedonic prices and explicit markets: production differentiation in pure competition. J. Polit. Econ. 82, 34–55.

Van Garderen, K. J., Shah, C., 2002. Exact interpretation of dummy variables in semilogarithmic equations. Econometrics J., 5, 149-159.

Wiley, J., Benefield, J., Johnson, K., 2010. Green Design and the Market for Commercial Office Space. J. Real Estate Financ. Econ. 41, 228-243.