Department of Energy & Climate Change

Final Project Report

An investigation of the effect of EPC ratings on house prices

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A report for the Department of Energy and Climate Change by:

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1. Executive Summary

- This report presents the results of an empirical investigation of the relationship between the energy performance ratings, as measured in Energy Performance Certificates (EPCs), and the sale prices of residential properties in England.

- This is the first large-scale empirical study of the effect of energy labelling on property residential property prices in England. Details of transactions involving 325,950 dwellings sold at least twice in the period from 1995 to 2011 are analysed using a unique database which incorporates sale prices, dwelling attributes, detailed information on EPC ratings and a host of socio-economic area variables.

- The data indicate that:

    - Nearly 93% of dwellings sold are in EPC bands C, D and E with 45.5% in band D alone.

    - On average, flats obtain the highest ratings with approximately half rated EPC band C (40%) or B (9.8%). Only 16% of flats were rated EPC E, F or G whereas the comparable figure for other dwellings types was 30%.

    - Unsurprisingly, there is a notable negative relationship between EPC rating and age of dwelling. Over half of dwellings built before 1929 have an EPC rating of E or worse. In contrast, the comparable figure for dwellings constructed since 1996 is less than 3%.

- There are certain property attributes that are important determinants of price; size, location and type of dwelling being the more obvious ones. Energy efficiency, although growing in importance, is undoubtedly a weaker determinant in comparison. A quick glance at summary statistics reveals that EPC ratings are correlated with several other attributes, notably age. To ensure that any energy efficiency price premium detected by the model is not simply due to differences in the underlying structure of dwellings (for example, modern properties might sell at a higher price regardless of their level of energy efficiency) we incorporate a large number of relevant dwelling attributes . Given that there is a negative relationship between age and EPC performance, we ensure that the complex interaction of age, size and type (detached, terraced etc.) on dwelling prices are carefully addressed by not only including these as explanatory variables but by measuring price on a square metre basis rather than the total price of a property .

- Hedonic regression modeling (the standard methodology for examining price or value determinants) is used to isolate the effect of EPC rating on price level and price appreciation. A well-known limitation of hedonic modeling of prices is the choice of an appropriate functional form along and problems to obtain data on all price determinants.

- The results suggest that there is a positive relationship between energy rating and dwelling price per square metre. Compared to dwellings rated EPC band G, dwellings with higher EPC ratings have sold at a statistically significant price premium and the pattern of the results is consistent and plausible. As expected, the price difference increases as EPC performance improves. We estimate that, compared to dwellings rated EPC G, dwellings rated EPC F and E sold for approximately 6%, dwellings rated D sold for 8% more and dwellings rated EPC band C for 10% and A/ B sold for 14% more. When the sample is disaggregated by dwelling type, there are notable differences. The price effects of superior energy performance tend to be higher for terraced dwellings and flats compared to detached and semi-detached dwellings.

- When investigating the relationship between *dwelling price appreciation* and EPC rating, the evidence is less clear-cut but remains generally supportive of a positive association. Compared to dwellings rated EPC G, the prices of detached and semi-detached dwellings EPC rated C and D appreciated at a significantly higher rate. However, it was also found that semi-detached and terraced dwellings rated EPC F appreciated at a significantly lower rate than dwellings rated EPC G. For dwellings sold with an EPC at the second transaction only, the results are stronger. There are significant positive effects on dwelling price appreciation per square metre for dwellings rated B, C and D compared to dwellings rated G. There are no statistically significant effects of an F rating for this sub-sample.

- Separate estimation of the house price effect of EPC ratings for each region reveals that the percentage premium commanded by properties with above-average EPC ratings is higher in regions where house price levels are low and vice versa. It is likely that this is due to the fact that broadly similar energy savings across regions had quite different relative effects on house prices.

2. Introduction

The purpose of this research is to investigate the relationship between the energy performance ratings and the sale prices of residential properties in the England. This report follows an initial literature review for the Department of Energy and Climate Change - Investigating the Effects of Voluntary and Compulsory Environmental Labelling on Real Estate Prices: A Review of the Literature. This review of existing empirical research found that nearly all studies examining the effects of voluntary and compulsory environmental certification on the prices of real estate assets had found a positive effect of superior environmental performance. However, a number of caveats were outlined. Many of the studies had not yet been through a rigorous peer review process.

In order to investigate the relationship between energy performance ratings and sale prices of dwellings in England, this report analyses repeat sales transactions involving 325,950 dwellings that took place in the period from 1995 to 2011. 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.

3. Energy Labelling and Real Estate Markets

Over the last decade, both the commercial and the residential real estate sector have seen the introduction of a wide range of energy and environmental labels. Within many real estate markets, there tends to be a blend of compulsory and voluntary energy and/or eco-labels with some environmentally friendly buildings collecting several labels. Boundaries between mandatory and voluntary environmental labels have become blurred as more and more urban planning authorities make labels such as Code for Sustainable Homes, BREEAM, LEED etc. a condition of permission to develop. In the European Union, the most widespread energy label has been the Energy Performance Certificate (EPC). 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. In the UK, certification comprises Energy Performance Certificates (EPCs) and the Display Energy Certificates (DECs). 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 as built. EPCs are similar to the mandatory energy labels used in many consumer products such as tumble dryers and washing machines. In the same vein as consumer products, buildings are rated on a scale A-G with band A being the most efficient.

A common direct aim of energy or environmental labels is to provide information to consumers or users about the environmental performance of a product with the indirect aim of influencing their consumption choices, suppliers' production outputs and, as a result, the level of environmentally harmful emissions. If goods with superior energy performance are not being priced efficiently, there may be sub-optimal consumption and production. Whilst the operation of the market pricing mechanism is central to the effectiveness of this type of market-based policy, there has been very little evaluation of the effectiveness of this type of approach. This is largely because the policy is relatively recent and there are well-documented problems of data availability (see Fuerst, McAllister, van der Wetering and Wyatt, 2010 for a detailed discussion).

Assuming that environmental or energy performance is salient information for consumers, labelling enables consumers to discriminate between products according to their environmental impact. This is implied to produce increased demand for products with reduced environmental impact and price differentials linked to energy performance. Price premiums, in turn, provide an economic incentive for producers to innovate and incur any additional production costs associated with improved energy performance.

For investors, superior risk-adjusted returns from energy efficient assets should provide a financial incentive to allocate investment to assets that are energy efficient.

A number of intervening factors can effectively break any hypothesised link between energy performance and economic performance in the case of EPCs. Firstly, the fact that the EPC rating only indicates the intrinsic energy performance of the building based on its design, equipment and fabric may create uncertainty among tenants and buyers as to the cost savings potential in operation, which may in turn lead these market participants to discount the information expressed by the EPC rating. Secondly, any non-compliance in producing an EPC for a buyer or tenant will remove the information on which they can alter their behaviour. A further complicating issue is that, even if EPC ratings accurately expressed both the design-based and operational potential for cost savings, behavioural factors may effectively act to offset any gains from increased energy efficiency, commonly known as the rebound/backfire effects or “Jevons’ paradox”. Hanley et al (2009) find this to be the case in a computable general equilibrium application of energy efficiency measures in Scotland but on balance the empirical evidence on the existence and magnitude of these effects remains disputed (see, for example, Sorrell 2009).

In the 1980s, a body of work emerged investigating the relationship between energy efficiency (typically proxied by energy bills) and residential sale prices. Laquatra, Dacquisto, Emrath and Laitner (2002) provide a useful evaluation of this work. Among a range of limitations identified, probably the most important is that the studies typically involved small, highly localised samples consisting of dozens or hundreds of dwellings. However, they did 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). Similar to this paper, the body of research that has emerged over the last decade has largely focussed on the effects of intrinsic potential energy efficiency as measured in a certification or labelling process rather than realised performance outcomes. However, surprisingly few papers have been published in peer-reviewed journals and most are part of a ‘grey’ literature.

The largest body of work on the price effects of voluntary energy or environmental labels on prices has been on US commercial offices markets. Broadly focussed on rental and sale prices, the emerging stylized fact is of a positive relationship between environmental labels and prices (see Wiley, Benefield and Johnson, 2010; Eichholtz, Kok and Quigley, 2010 and 2011, Fuerst and McAllister, 2011a and 2011b; Reichardt, Fuerst, Rottke and Zietz, 2011; Deng, Li and Quigley, 2012). One of the first studies to investigate the price effect of mandatory energy labelling in a residential real estate market was carried out by the Australian Bureau of Statistics (2008). The study drew upon a database of residential sales in the Australian Capital Territory in the years 2005 (2,385 transactions) and 2006 (2,719 transactions). Using standard hedonic procedures to estimate the effect of Energy Efficiency Rating (EER) on house prices, they estimated five different model specifications. For 2005 sample, they estimate a premium of approximately 1% premium for every 0.5 increase in EER rating (EER ranges from 0-5).

For 2006 sample, they estimate a premium of approximately 2% for every 0.5 increase in EER. For 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 asset 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.

In the most closely related study to this research, Brounen and Kok (2011) examined the relationship between EPC ratings and sale price for 31,993 residential sale prices in 2008-9 in the Netherlands. Compared to D-rated homes, they estimate fairly substantial premiums of 10%, 5.5% and 2% for A, B and C respectively. For dwellings rated 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, the adoption rate of EPCs was low. For instance, in August 2009 this rate dropped to seven percent and never exceeded 25 percent throughout the study period. Although EPCs were supposed to be a mandatory requirement in the Netherlands, the policy regarding exemptions effectively made it optional. 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.

For the Netherlands office market, Kok and Jennen (2012) looked at the relationship between EPC rating and rental price for 1057 transactions in the period 2005-2010. Using standard hedonic techniques, they find a rental premium of approximately 4.7% for buildings rated C or lower compared to buildings rated D and above. However, it is possible that offices rated Class A, B and C may be better quality than buildings with inferior performance. Put simply, the level of energy efficiency may be correlated with other 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 property assets as at September 2010. They found no significant effect of EPC rating on appraised Market Rent and Market Value and some weak evidence of an effect on capitalisation rates.

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 extremely limited. Most work is focussed on commercial real estate markets. Nearly all studies apply a version of Rosen's hedonic model to estimate the price effect of the environmental label. Below, we use a large sample of dwelling transaction prices in the UK to investigate the effects of energy rating on dwelling prices and dwelling price appreciation.

4. Data and Descriptive Statistics

The economic analysis of house price determination and the pricing of housing attributes requires a large sample of properties to be 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 by obtaining a large sample as well as maximum coverage of key control variables. In the context of this study, a reliable hedonic estimation is 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 detailed below.

4.1 Data Procurement

Since no single source exists that provides information on all three areas, 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 an initial sample of 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 Postcode Directory 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 are a combination of postcode districts, Output Areas (urban-rural indicator) and Lower Level Super Output Areas (deprivation index). 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, was added to the database. This was carried out using address-matching software. Due to confidentiality requirements under the Data Protection Act, the research team was not permitted to know the identity of any individual EPCs. Consequently, all observations were anonymised by Landmark by removing or aggregating any information that would allow identification of a specific property before returning the merged data set to the research team. Transaction data from Wales was not matched with EPCs so the sample used for the analysis includes dwellings in England only. This, together with the removal of records due to input and administrative errors and duplicated EPCs, reduced the sample to 325,950 dwellings. It should also be noted that there was not a complete set of regressors for all of the observations and consequently sample size varies according to the nature of the analysis.

4.2 Descriptive Statistics

Before we estimate the capitalisation of energy efficiency into house prices with a regression model, we conduct an exploratory analysis of the general characteristics and distribution of values in our dataset. Descriptive statistics are provided in Tables 1 and 2 and there are a number of notable points (Tables 1 and 2).

- Of the 325,950 properties used in our analysis, over 92% are in EPC bands C, D or E. Nearly half (45%) of the properties are in band D. Only 7.25% of the properties are in the two highest (A and B) or two lowest bands (F and G).

- Terraced and semi-detached properties each account for approximately one third of the sample. Detached properties represent around a quarter with flats accounting for about 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, with 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 value of 85 square metres. In terms of energy efficiency, most dwellings (93%) are in the C, D or E bands. Only seven are in band A which is why we formed a combined A/B category for the purpose of this analysis. The mean energy rating is 60 and falls within Band D (see Appendix 1). Table 3 reveals that flats tend to be the most energy efficient category with 50% in EPC bands B and C. In contrast, 21% of detached properties were in bands B or C.
- There is a clear negative relationship between age of properties and energy rating. Albeit accounting for only 1% of the total sample, 92% of properties

built in the period 2007-2011 were in bands C (58%) or B (34%). In contrast, the comparable figure for properties built before 1949 (accounting for approximately 40% of the sample) is 10% of properties in band C or above.

- There is a clear negative relationship between mean price and energy efficiency, illustrating the importance of addressing the 'all else equal' issue.

Table 1: Descriptive statistics for key categorical variables (n=325,950)

Variable	Categories	Frequency	% of total
Property type	Detached	83,151	25.51%
	Semi-detached	104,163	31.96%
	Terraced	113,477	34.81%
	Flat	25,159	7.72%
Tenure	Freehold	285,419	87.57%
	Leasehold	40,531	12.43%
Age of dwelling	Missing	48,319	14.82%
	Before 1900	31,985	9.81%
	1900-1929	40,389	12.39%
	1930-1949	36,164	11.09%
	1950-1966	35,132	10.78%
	1967-1975	30,001	9.20%
	1976-1982	17,346	5.32%
	1983-1990	26,518	8.14%
	1991-1995	14,699	4.51%
	1996-2002	27,582	8.46%
	2003-2006	14,747	4.52%
	2007 onwards	3,068	0.94%
Number of bedrooms	0	8,474	2.60%
	1	11,700	3.59%
	2	93,452	28.67%
	3	142,014	43.57%
	4	55,856	17.14%
	5	11,919	3.66%
	5+	2,535	0.78%

Energy efficiency band	A	7	0.00%
	B	4,434	1.36%
	C	78,204	23.99%
	D	148,665	45.61%
	E	75,778	23.25%
	F	16,068	4.93%
	G	2,791	0.86%

Table 2: Descriptive statistics for key continuous variables (n=325,950)

Variable	Median	Range	Mean	SD
Price (P1)	£134,000	£5,000 to £4,900,000	160,330	130,941
Price (P2)	£179,995	£11,000 to £6,635,000	226,189	189,629
Compound annual growth rate	5%	-30% to +40%	5%	6%
Total floor area (m2)	85	9 - 3,309	95	45
Energy efficiency rating	62	0 - 100	60	12

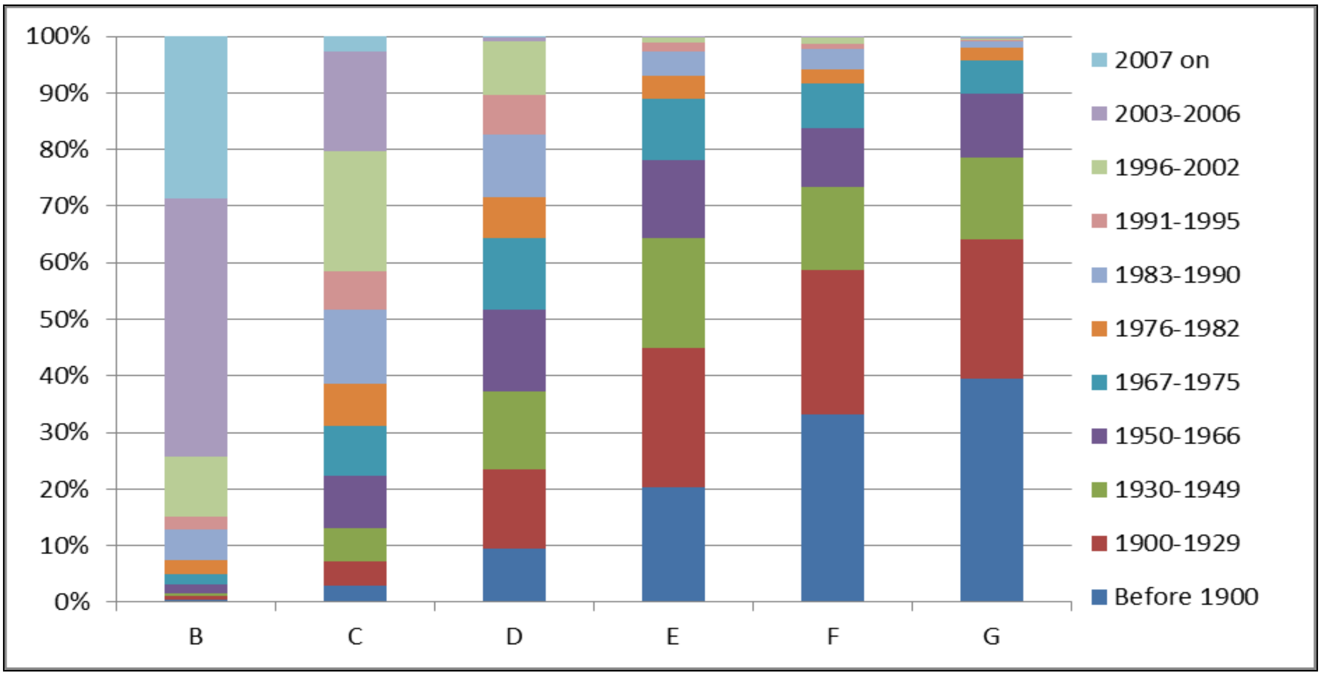
Table 3: Cross tabulation between dwelling type and EPC rating

EPC rating	Detached	Semi-detached	Terraced	Flat
A/B	288	489	1,200	2,457
C	17,315	22,298	28,402	10,189
D	41,169	48,424	50,439	8,636
E	18,007	27,584	27,237	2,950
F	5,555	4,696	5,026	791
G	816	667	1,173	135
All	83,151	104,163	113,477	25,159

The impact of age on EPC band is shown in Figure 1; 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.

Figure 1: Dwellings in each EPC band (B to G) classified by age band



5. Econometric Models: Estimation Strategy

We apply two main econometric techniques to the analysis of the data. The underlying premise of hedonic analysis is that the utility obtained from the numerous attributes of a multi-faceted "economic good" are reflected in the price paid. In the case of housing, occupiers receive utility from each of the attributes that a dwelling might offer such as location, number of bedrooms, age or energy efficiency. Dwelling prices are hedonic in that they represent a payment for this 'bundle' of attributes. The number of hedonic attributes could, theoretically at least, be large in number but usually a small number of characteristics tend to be the key price determinants. When examining the impact that EPC ratings might have on prices, it is essential that other price determinants, particularly the key ones, are identified and controlled for. Therefore, to conduct the hedonic regression analysis, data on the following attributes are required:

- transaction price
- transaction date
- size (floor area and/or number of bedrooms)
- type (detached, semi, terraced etc.)
- age (year built or suitably constructed age bands)
- location postcode
- changes (inflation/deflation) in house prices
- location area attributes

A potentially significant variable that is missing from the list above is property condition. It is possible that older dwellings, which have been refurbished or are well maintained, are going to have higher EPC ratings than poorly maintained buildings. Data on condition is not generally available in the UK at the dwelling level other than via the sample-based English Housing Survey. The Valuation Office Agency, widely regarded as the custodian of the most comprehensive set of dwelling attribute data, does not have up to date, detailed information on condition. In addition, it is difficult to obtain information on a number of other variables that may affect prices and that may, more importantly, be related to the EPC rating. For instance, older and more attractive houses may tend to have lower EPC ratings. If the control for age does not adequately capture perceived attractiveness of assets, then an aesthetic effect may be identified as an EPC effect if the variables are correlated: in other words there may be a positive or negative relationship between aesthetic quality and EPC rating.

It is worth noting that, until recently, dwelling size has not been available to researchers. In the UK, the standard approach has been to use number of bedrooms as a proxy for size in econometric modelling. However, it is possible that different vintages of dwellings may have different sizes but the same number of bedrooms. In the last decade size of dwelling has been recorded by a number private and public sector organisations. Most pertinently for this research, it is recorded as part of the EPC assessment process. A potential problem is that dwellings with different levels of energy performance may also have different sizes. Roy (2008) illustrated that the average size of English dwellings had decreased throughout the twentieth century before starting to increase around 1990. In particular, semi-detached properties recorded the largest decrease with average size falling from approximately 100 square metres in 1919 to approximately 80 square metres in 1990. Our sample is consistent with Roy's findings. Table 4 presents the average size of all dwellings from the data set.

Table 4 Relationship between Dwelling Age and Dwelling Size for all Dwelling Types

Age Band	Size (square metres)
Pre-1900	102
1900-1929	96
1930-1949	96
1950-1966	91
1967-1975	90
1976-1982	84
1983-1990	79
1991-1995	84
1996-2002	100
2003-2006	102
2007 onwards	106
Mean	95

It is possible that failure to control for size differences between different vintages of dwelling could bias the findings. Since there is a strong link between energy performance and age, if dwelling size is not accounted for, it is possible that the positive price effect of typically higher space levels in older dwellings may conceal the negative price effects of poor energy performance. In the results below we report the effect of EPC rating on price per square metre. We have produced comparable estimates of the effect of energy performance rating on 'raw' price. However, whilst the results suggest positive price effects of good energy performance, there are a number of anomalies (for example, the price effect tends to become smaller as energy performance improves) and this suggests that dwelling size needs to be incorporated.

As noted above, hedonic regression modeling is the standard methodology for examining price or value determinants in real estate research. We use this method in our study primarily to isolate the effect of EPC rating on price. The quintessential hedonic rent model takes the following form:

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

Where P_{it} is the transaction price of a property (measured in our study as the natural logarithm of the price in £ per square metre), X_i is a vector of several explanatory locational and physical characteristics, β_i is a vector of parameters 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 a variance of σ^2_e. The hedonic weights assigned to each variable are equivalent to its overall contribution to the price (Rosen, 1974). However, hedonic models are rarely a cross-sectional snapshot and typically have a time dimension as sales transactions are collected and analysed over a period of months, quarters or years.

To allow for inter-temporal variation, the model is then expanded with a set of binary variables that capture the average effect of each time period separately in the following form (see Bailey et al, 1963; Gatzlaff and Haurin, 1997):

$$P_{it} = \sum_{j=1}^{J} \beta_j X_{jit} + \sum_{t=1}^{T} c_t D_t + e_{it} \qquad (2)$$

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 also use a set of binary variables to indicate the EPC band of each dwelling at the relevant transaction date. The expected coefficient is dependent upon which rating is omitted i.e. the 'hold-out' category. If dwellings with EPC band G are omitted, we expect a positive coefficient. 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 our semi-logarithmic specification, 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.

A summary specification of our semi-logarithmic model is as follows:

$$\ln Price_i = C_0 + \beta_1 \sum_{n=1}^{N} EPCvariables + \beta_2 \sum_{n=1}^{N} AGEvariables + \beta_3 \sum_{n=1}^{N} PHYSICALvariables + \beta_4 \sum_{n=1}^{N} LOCATIONvariables + \beta_5 \sum_{n=1}^{N} TIMINGvariables + \varepsilon_t$$
(3)

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 that can arise from the local area. If these unobserved effects are correlated to the observed attributes, then the estimates are biased. One way to address the issue is to include local area fixed effects (specified as dummy variables) in the model specification under the assumption that correlated unobservables are time-invariant. In our cross-section model, we explicitly control for such unobserved effects by using fairly fine-grained postcode area dummy variables.

A second problem is that a number of dwellings in the sample may have undergone physical changes due to renovation. A renovation may affect both the price and the EPC rating. In the absence of information on improvements, refurbishments and extensions of individual dwellings, we assume that upgrading activities are relatively common but evenly distributed throughout the stock of dwellings. To measure eco-labelling effects on price appreciation, we also perform a hedonic analysis with the repeat sales transactions only. Specifically, difference in sales prices between two transaction dates are regressed on a set of dwelling attributes including the EPC ratings in the following form:

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

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 (4) simplifies to:

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

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:

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

Thus price changes in 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 robust framework we are able to estimate the extent to which growing awareness of EPC ratings and energy efficiency has affected prices of residential dwellings.

6. Findings

Following the analytical strategy outlined above, we first fit regression models to both the full set of observations and the sub-samples of the different types of dwelling to estimate whether energy efficiency is capitalised into house prices. All else equal, we expect that the cost savings associated with a more energy-efficient home should be reflected in the price, provided that buyers have at least a rough idea of average electricity and heating costs in the property.

EPC ratings and house prices

The results of the hedonic regression model are presented in Table 5. 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 energy performance ratings. The overall explanatory power of the model is good with an adj. R^2 in excess of 70% for the whole sample and the coefficients of the independent variables 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. Compared to dwellings constructed pre-1900, dwellings constructed between 1983 and 2002 have sold for small but statistically significant price premiums. When we look at the results across dwelling types, it is apparent that this price premium is being driven by terraced housing. For all terraced dwellings constructed since 1983, there are significant price premiums compared to terraced housing constructed pre-1900. This is likely to be due to the presence of modern amenities in modern terraces. The largest discounts compared to dwellings constructed pre-1900 are observed in dwellings built before 1982. The results for dwelling type are also in line with expectations. With flats as the 'hold-out' category, terraced, semi-detached and detached properties all achieve significantly higher prices, with the latter category selling for an average 21% more than the flats. The coefficients for deprivation and rural indexes are also of the expected signs. Compared to leasehold, the coefficient for freehold is positive and significant.

Turning to the variable of interest, using EPC band G as the 'hold-out' category, a consistent pattern of positive price effects can be seen. For the whole sample model, there is a gradual increase in the estimated coefficient as the energy rating improves. It is estimated that, compared to dwellings rated G, dwellings rated F sell for nearly 6% more, dwellings rated D and E sell for approximately 6% and 8% more, C rated dwellings sell for around 10% more and dwellings rated A or B sell for approximately 14% more (see Column 1 in Table 5). The premiums are highest for terraced dwellings. All else equal, we estimate that a terraced dwelling rated C has sold for nearly 16% more per square metre than a terraced dwelling EPC rated G (see Column 4 in Table 5). The comparable figure for semi-detached dwellings is 7%. It is possible that buyers of terraced dwellings put a higher price on energy efficiency when measured as a percentage of the price per square metre. However, we cannot rule out that the prices of terraced dwellings are influenced more than other property types by the unobserved effects of refurbishment and modernisation.

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 15,300 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 premiums 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 63,399 detached dwellings in densely populated areas is very similar to the pattern of price premiums for the 97,431 semi-detached dwellings. It is also notable that the explanatory power of the hedonic model is the lowest (R^2 = 48%) for the sub-sample of 15,300 detached dwellings in sparsely populated areas. This is likely to be due to the greater heterogeneity of this particular sub-sample which will include large country residences together with a wide range of rural dwellings built in vernacular styles over several centuries.

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

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Full sample	**Detached**	**Semi-detached**	**Terraced**	**Flat**	**Detached dense**	**Detached sparse**
EPC A/B	0.138***	0.0213	0.101***	0.182***	0.116***	0.0917**	-0.0494
	(16.00)	(0.96)	(4.75)	(12.64)	(4.07)	(3.09)	(-1.18)
EPC C	0.0991***	0.0129	0.0768***	0.155***	0.104***	0.0779***	-0.0385*
	(14.12)	(0.97)	(6.01)	(14.59)	(3.75)	(3.51)	(-2.11)
EPC D	0.0760***	0.0130	0.0675***	0.135***	0.0933***	0.0749***	-0.0201
	(10.93)	(0.99)	(5.33)	(12.92)	(3.38)	(3.39)	(-1.18)
EPC E	0.0655***	0.00260	0.0512***	0.114***	0.0803**	0.0598**	-0.0155
	(9.39)	(0.20)	(4.03)	(10.78)	(2.88)	(2.70)	(-0.93)
EPC F	0.0596***	-0.0009	0.0403**	0.0816***	0.0555	0.0503*	-0.0205
	(8.16)	(-0.07)	(3.04)	(7.27)	(1.90)	(2.23)	(-1.18)
EPC G	Hold-out	Hold-out	Hold-out	Hold-out	Hold-out	Hold-out	Hold-out
No. of bedrooms	-0.0420***	-0.0342***	-0.0410***	-0.0395***	-0.0443***	-0.0353***	-0.0310***
	(-68.20)	(-33.55)	(-36.01)	(-34.62)	(-14.72)	(-31.44)	(-14.06)
Pre-1900	Hold-out	Hold-out	Hold-out	Hold-out	Hold-out	Hold-out	Hold-out

1900-29	-0.0848***	-0.0629***	-0.0790***	-0.0682***	-0.0428***	-0.0245**	-0.0661***
	(-37.77)	(-8.38)	(-15.75)	(-26.05)	(-3.52)	(-2.58)	(-4.25)
1930-49	-0.0520***	-0.0467***	-0.0799***	-0.0352***	-0.0504***	-0.0039	-0.0697***
	(-22.60)	(-6.92)	(-17.39)	(-10.27)	(-4.02)	(-0.44)	(-4.92)
1950-66	-0.0574***	-0.0184**	-0.0856***	-0.0970***	-0.130***	0.0234**	-0.0454***
	(-24.21)	(-2.87)	(-18.12)	(-25.99)	(-11.17)	(2.70)	(-4.14)
1967-75	-0.0577***	-0.0776***	-0.0502***	-0.102***	-0.137***	-0.0333***	-0.112***
	(-23.79)	(-12.09)	(-10.04)	(-28.43)	(-11.78)	(-3.85)	(-10.36)
1976-82	-0.0321***	-0.0949***	-0.0391***	-0.0220***	-0.0669***	-0.0509***	-0.130***
	(-12.04)	(-14.15)	(-7.21)	(-5.31)	(-5.48)	(-5.75)	(-10.07)
1983-90	0.0189***	-0.0854***	0.0125*	0.0702***	-0.00185	-0.0422***	-0.111***
	(7.61)	(-13.28)	(2.37)	(19.03)	(-0.16)	(-4.92)	(-8.93)
1991-95	0.0319***	-0.0771***	0.0195***	0.104***	0.0123	-0.0382***	-0.0708***
	(11.39)	(-11.67)	(3.37)	(23.04)	(0.99)	(-4.39)	(-5.13)
1996-2002	0.0144***	-0.0811***	0.0206***	0.0823***	0.0378**	-0.0352***	-0.107***
	(5.65)	(-12.98)	(3.78)	(19.20)	(3.06)	(-4.15)	(-9.74)
2003-2006	0.00163	-0.0927***	-0.0115	0.0475***	0.0276*	-0.0447***	-0.113***
	(0.52)	(-13.21)	(-1.74)	(8.67)	(2.12)	(-4.88)	(-8.73)

2007-	0.00655	-0.0451***	-0.0169	0.0698***	-0.0201	-0.000362	-0.0637**
	(1.05)	(-4.12)	(-1.21)	(5.40)	(-1.09)	(-0.03)	(-2.81)
Age (unknown)	-0.0563***	-0.110***	-0.0806***	-0.0334***	-0.0451***	-0.0660***	-0.138***
	(-23.50)	(-17.35)	(-16.12)	(-10.08)	(-3.72)	(-7.69)	(-13.17)
Freehold	0.0659***	0.0301***	0.0405***	0.0850***	0.0827***	0.0260***	0.0987**
	(21.20)	(4.22)	(7.84)	(16.42)	(7.13)	(3.61)	(2.84)
Deprivation score	-0.00908***	-0.00514***	-0.00920***	-0.00887***	-0.00702***	-0.00539***	-0.000669
	(-155.35)	(-32.19)	(-95.88)	(-95.17)	(-30.90)	(-32.63)	(-0.94)
Urban level Category 1	Hold-out	Hold-out	Hold-out	Hold-out	Hold-out	Hold-out	Hold-out
Urban level	-0.0173	0.00428	0.0136	-0.113*	0.164	0.0948	.
Category 2	(-0.73)	(0.13)	(0.28)	(-1.98)	(1.23)	(1.56)	.
Urban level	0.0861***	0.0961**	0.0650	0.0688	0.266*	.	0.0287
Category 3	(3.93)	(3.06)	(1.51)	(1.27)	(2.14)	.	(1.40)
Urban level	0.104***	0.103**	0.0829	-0.0290	.	.	0.0298
Category 4	(3.91)	(2.98)	(1.28)	(-0.44)	.	.	(1.20)
Urban level	-0.0513*	-0.0505	-0.00136	-0.110*	0.0545	0.0565	.
Category 5	(-2.27)	(-1.59)	(-0.03)	(-1.97)	(0.47)	(0.94)	.

Urban level	-0.0379	-0.0307	0.00652	-0.0845	0.0393	0.0765	.
Category 6	(-1.67)	(-0.97)	(0.14)	(-1.52)	(0.34)	(1.27)	.
Urban level	0.0355	0.0477	0.0599	-0.0183	0.0751	.	-0.0321***
Category 7	(1.57)	(1.50)	(1.28)	(-0.33)	(0.64)	.	(-4.92)
Urban level	0.0626**	0.0792*	0.0798	-0.0251	0.0620	.	.
Category 8	(2.73)	(2.47)	(1.69)	(-0.44)	(0.52)	.	.
Terraced	0.00668		.	.	.		
	(1.83)		.	.	.		
Detached	0.195***						
	(50.31)						
Semi-detached	0.0962***						
Flat	(25.90) Hold-out						
Constant	7.828***	8.024***	7.894***	7.849***	7.874***	7.832***	7.985***
	(320.26)	(216.51)	(159.69)	(136.00)	(61.47)	(118.81)	(157.75)
quarterly fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
postcode fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes

N	300618	78734	97431	102815	21638	63399	15335
adj. R^2	0.701	0.568	0.661	0.793	0.734	0.600	0.483

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

EPC ratings and house price growth

We also apply a similar regression specification with dwelling price *appreciation* per square metre as the dependent variable. 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 6 provides estimates of the determinants of the dwelling price appreciation. We see that, for all types of dwelling, number of bedrooms has a 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 between 1900 and 1929 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 time period and the over-supply of apartments in many markets, it is perhaps not surprising that, compared to flats, all other dwelling types have experienced significantly higher 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 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 differ notably from those of the total price model. Both C and D-rated dwellings have indeed experienced significantly higher price appreciation than the least energy-efficient dwellings but this is not the case for any of the other EPC bands. However, when we look at the estimates for the dwelling type sub-samples, we see that this is being largely driven by detached dwellings. For this category, there is a significant 'growth premium' for dwellings rated A, B, C and D relative to dwellings rated G. Furthermore, we also find that, compared to dwellings rated G, dwellings rated F have grown at a significantly lower rate.

Table 6 Energy Rating and Price Appreciation: Repeat Sales Estimations (dependent variable: change in price per square metre)

	(1) Full Sample	(2) Detached	(3) Semi-detached	(4) Terraced	(5) Flats
Regional price	2.381***	2.215***	2.428***	2.491***	2.306***
Index	(965.59)	(451.01)	(595.70)	(575.01)	(233.53)
No. of	0.0114***	0.0081***	0.0155***	0.0111***	0.0090***
Bedrooms	(23.52)	(9.45)	(17.51)	(12.60)	(4.03)
1900-29	0.0050**	0.0099	0.0052	-0.0005	0.0111
	(2.81)	(1.69)	(1.35)	(-0.24)	(1.20)
1930-49	0.0021	0.0011	-0.0042	-0.0046	0.0122
	(1.11)	(0.21)	(-1.17)	(-1.50)	(1.27)
1950-66	-0.0023	-0.0045	-0.0160***	0.0010	0.0176*
	(-1.22)	(-1.94)	(-4.41)	(0.30)	(1.98)
1967-75	-0.0366***	-0.0472***	-0.0527***	-0.0308***	-0.0099
	(-20.04)	(-9.88)	(-14.31)	(-10.80)	(-1.15)
1976-82	-0.0539***	-0.0743***	-0.0642***	-0.0431***	-0.0294**
	(-27.01)	(-14.83)	(-15.99)	(-14.02)	(-3.27)
1983-90	-0.0723***	-0.0937***	-0.0783***	-0.0569***	-0.0518***
	(-39.85)	(-19.58)	(-20.41)	(-21.63)	(-6.23)
1991-95	-0.0903***	-0.1060***	-0.0925***	-0.0713***	-0.0755***
	(-43.18)	(-20.86)	(-21.48)	(-22.36)	(-8.35)
1996-2002	-0.125***	-0.133***	-0.124***	-0.110***	-0.124***
	(-62.82)	(-27.62)	(-29.65)	(-34.48)	(-13.82)
2003-2007	-0.116***	-0.120***	-0.134***	-0.116***	-0.118***
	(-48.08)	(-20.90)	(-28.70)	(-31.44)	(-12.51)

2007-2011	-0.0378*** (-7.14)	-0.0086 (-0.76)	-0.0731*** (-7.29)	-0.0667*** (-8.22)	-0.0825*** (-6.58)
Pre-1900	Hold-out	Hold-out	Hold-out	Hold-out	Hold-out
Age unknown	-0.0346*** (-19.05)	-0.0584*** (-12.14)	-0.0319*** (-8.48)	-0.0241*** (-9.41)	-0.0352*** (-4.02)
Detached	0.0246*** (8.90)				
Semi-detached	0.0409*** (15.78)				
Terraced	0.0379*** (15.03)				
Freehold	0.0171*** (7.94)				
Deprivation Index	0.0006*** (12.71)	-0.0005*** (-4.01)	0.0006*** (6.95)	0.0007*** (9.16)	0.0002 (1.36)
EPC A/B	-0.0033 (-0.49)	0.1010*** (4.21)	-0.0108 (-0.76)	0.0060 (0.55)	-0.0110 (-0.46)
EPC C	0.0235*** (4.18)	0.0583*** (5.65)	0.0263* (2.51)	0.0105 (1.14)	-0.0079 (-0.34)
EPC D	0.0110* (1.97)	0.0371*** (3.67)	0.0124 (1.20)	0.0056 (0.61)	-0.0066 (-0.28)
EPC E	-0.0070 (-1.25)	0.0092 (0.91)	-0.0125 (-1.20)	-0.0085 (-0.93)	-0.0062 (-0.26)
EPC F	-0.0180**	-0.0064	-0.0237*	-0.0201*	-0.0034

	(-3.09)	(-0.61)	(-2.18)	(-2.08)	(-0.14)
Urban level Category 1	Hold-out	Hold-out	Hold-out	Hold-out	Hold-out
Urban level Category 2	0.0125 (0.75)	0.0142 ()0.55	0.0352 (1.10)	0.0169 (0.46)	-0.0969 (-1.35)
Urban level Category 3	0.0618*** (3.91)	0.0443 (1.83)	0.105*** (3.39)	0.0802* (2.28)	-0.016 (-0.78)
Urban level Category 4	0.0619** (3.28)	0.0556* (2.11)	0.0831 (1.81)	0.0927 (2.03)	-0.133 (-1.09)
Urban level Category 5	-0.0033 (-0.20)	-0.0343 (-1.41)	0.0404 (1.22)	0.0457 (1.23)	-0.0354 (-0.68)
Urban level Category 6	0.0021 (0.013)	-0.0329 (-1.35)	0.0483 (1.47)	0.0551 (1.49)	-0.0054 (-0.10)
Urban level Category 7	0.0188 (1.16)	-0.0046 (-0.19)	0.0665* (2.02)	0.0514 (1.39)	-0.0252 (-0.47)
Urban level Category 8	0.0271 (1.65)	0.0449 (0.18)	0.0789* (2.35)	0.0525 (1.40)	-0.0277 (-0.50)
Intercept	-0.0640*** (-8.16)	-0.0113 (-0.77)	-0.0464** (-3.13)	-0.0003 (-0.02)	0.0145 (0.40)
quarterly fixed effects	Yes	Yes	Yes	Yes	Yes
adj. R^2	0.79	0.76	0.81	0.80	0.79
N	315605	80757	100899	109737	24212

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

Regional breakdown of price effects

House prices vary widely across regions. The average transaction price for a property in London is almost four times higher than the price paid for a property located in the North east of England (Land Registry, 2013). Hence, it seems likely that savings from energy efficiency are not capitalised into house prices uniformly, at least as a percentage of total price and possibly even in absolute terms. Table 7 explores the regional variation in the effect of EPCs on property prices. Using the same model specification used for the results reported in Table 5, we find noticeable difference in estimates across the regions. Broadly, there appears to be a north-south divide in size and significance of parameter estimates between northern and southern regions.

Perhaps surprisingly, we do not find any significant premium for EPC ratings on house prices in the South East. A possible explanation is that house prices in the South East are predominantly drive by the availability and quality of transport links to London. The price effect of EPC ratings, although statistically significant, is considerably smaller in East England, London and the South West compared to the North and the Midlands.

There are several possible reasons for these regional variations. Firstly, the observed regional variation might be driven by the variation in climatic conditions as it can be expected that energy efficiency is valued more highly in regions with a greater number of heating degree days as is the case in the north of England.

Secondly, property prices vary considerably across regions. Hence, the capitalisation of a fixed amount of annual energy savings, say £300, will make for a smaller fraction of the total property price in expensive regions compared to lower-priced regions.

Thirdly, demand for housing is generally higher in the southern regions and supply is more severely constrained than it is in northern regions. It is possible that a general shortage in housing supply may impede the full capitalisation of energy efficiency where buyers are principally concerned about finding a property that meets the most important criteria such as location and size.

In regions with more ample supply of housing, lower ranked search criteria, such as the EPC rating of a house, may attract more attention from prospective buyers and hence be capitalised more fully into house prices. Finally, buyers who are more income-constrained may attach more importance to the potential cost savings indicated by the EPC rating. To the extent that average household incomes vary across space, the heterogeneity in the energy efficiency premium found in our analysis may also be reflective of this relationship.

Single EPC only

Appendix 2 contains a further variation of the hedonic model that only includes observations where the first sale of the dwelling occurred before the introduction of EPCs. This sub-sample should allow us to separate the 'information value' of the EPC from the capitalisation of energy efficiency. The rationale for introducing this constraint is to test the assumption that it was arguably difficult for the average buyer to ascertain the level of energy efficiency of a property *before* the introduction of mandatory EPCs. If this is indeed the case, we expect that buildings with higher energy efficiency will command relatively higher prices *after* the introduction of mandatory EPCs (holding market conditions and building characteristics constant) as buyers now possess information on this criterion which might hitherto not have been available to the majority of buyers. In the present dataset, the earliest lodgement date of an EPC certificate set is 22 April 2007 which is defined as the cut-off date for the occurrence of the first sale. All dwellings that were first sold after this date are not included in this subset estimation. This reduces the sample by about 15,000 observations. The results show that A, B, C and D ratings appreciated by a small but significant margin compared to G-rated properties but no significant effect is found for other rating bands. It is notable that the estimated effects of energy performance on price appreciation are noticeably higher in this 'single EPC' sample. Further, in contrast to the whole sample findings, no statistically significant difference in price appreciation is identified for F rated dwellings

Table 7: Energy Rating and Dwelling Prices: Regional Variation (dependent variable: log(price/sqm))

	ALL	North East	North West	Yorkshire & Humberside	East Midlands	West Midlands	East of England	London	South East	South West
EPC A/B	0.138***	0.382***	0.265***	0.244***	0.162***	0.165***	0.0738***	0.122***	0.0275	0.116***
	(16.00)	(7.19)	(9.55)	(9.1)	(5.11)	(5.85)	(3.51)	(4.86)	(1.42)	(5.45)
EPC C	0.0991***	0.260***	0.210***	0.158***	0.105***	0.100***	0.0531**	0.118***	0.0152	0.0690***
	(14.12)	(5.58)	(9.59)	(7.92)	(4.27)	(5.04)	(2.93)	(5.86)	(0.91)	(4.33)
EPC D	0.0760***	0.227***	0.177***	0.138***	0.0746**	0.0691***	0.033	0.119***	-0.0053	0.0427**
	(10.93)	(4.90)	(8.15)	(6.99)	(3.05)	(3.52)	(1.84)	(5.97)	(-0.32)	(2.72)
EPC E	0.0655***	0.204***	0.157***	0.115***	0.0493*	0.0533**	0.0298	0.114***	-0.0047	0.0360*
	(9.39)	(4.38)	(7.17)	(5.79)	(2.02)	(2.71)	(1.66)	(5.67)	(-0.28)	(2.28)
EPC F	0.0596***	0.147**	0.124***	0.0859***	0.0305	0.0502*	0.0388*	0.103***	0.0171	0.0268
	(8.16)	(2.97)	(5.36)	(4.04)	(1.2)	(2.43)	(2.08)	(4.92)	(0.99)	(1.61)
adj. R^2	0.701	0.547	0.567	0.556	0.443	0.512	0.569	0.701	0.530	0.400
N	300,618	11,711	31,966	27,286	29,336	27,164	44,184	29,110	62,821	37,040

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

We have only reported parameter estimates of the variable of interest i.e. EPC ratings. Models include other control variables as in Table 5.

7. Main Conclusions

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 good 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 is clustered in the middle EPC bands (C, D and E). Nearly half of all dwellings are rated D. 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. Flats tend to be the most energy efficient with approximately half rated EPC C (40%) or B (9.8%). Not surprisingly, there is 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 is 92%.

The analysis of the descriptive statistics reinforces the importance of controlling for other price determinants in estimating the relationship between house prices and EPC rating. It is particularly important to control for property type because flats, which tend to have the lowest prices, also have the highest EPC rated dwellings. There is a positive association between price per square metre and energy performance rating. We estimate that, compared to dwellings rated EPC G, dwellings rated F and E sold for approximately 6% more, dwellings rated D sold for 8% more and dwellings in band C for 10% and A/ B sold for 14% more. It is notable that there were quite large differences in the price premium when the sample was categorised by dwelling type. Turning to price growth, the findings are less clear-cut. Both C and D-rated dwellings experienced significantly higher price growth compared to than the least energy-efficient dwellings. However, this effect is strongest for detached dwellings.

In terms of change in price per square metre, the results are less clear-cut. Whilst there is evidence that, compared to dwellings rated EPC G, the prices of detached and semi-detached dwellings EPC rated C and D appreciated at a significantly higher rate, it was also found that semi-detached and terraced dwellings rated EPC F appreciated at a significantly lower rate than dwellings rated EPC G. The estimations for the sample of 300,000 dwellings with a single EPC (approximately 5% of the sample had an EPC at two separate transactions) indicated significant positive price appreciation effects for dwellings rated B, C and D compared to dwellings rated G. Separate estimation of the house price effect of EPC ratings for each region reveals that the percentage premium commanded by properties with above-average EPC ratings is higher in regions where house price levels are low and vice versa.

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 many 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. While our findings are robust to model specification and choice of sample and sub-periods, 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 e.g. more modern kitchens, bathrooms which may bias the results of our cross-sectional estimation but is less likely to affect our augmented repeat-sales estimation. Our analysis of sub-samples also revealed considerable variation in the capitalisation of energy efficiency ratings by region, property type and price category which we intend to explore in future research.

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Appendix 1 Database variables

Variable name	Variable description
P1	First transaction price
D1	First transaction date
RP1	Regional Land Registry House Price Index at first transaction date
P2	Second transaction price
D2	Second transaction date
RP2	Regional Land Registry House Price Index at second transaction date
Percentage	Percentage change in price between P1 and P2
Days_betwe	Number of days between D1 and D2
CAGR	Compound annual growth rate
lnp2	Log of P2
lnp1	Log of P1
lnbtwn	Log of number of days between D1 and 2
Propertyty	Property type (detached, semi-detached, terraced, flat)
Tenure	Tenure (freehold or leasehold)
Age category	0 Invalid or missing 0.5 Before 1900 1 1900-1929 2 1930-1949 3 1950-1966 4 1967-1975 5 1976-1982 6 1983-1990 7 1991-1995 8 1996-2002 9 2003-2006 10 2007 onwards
Beds	Number of bedrooms
Total_floor_area	Total floor area in square metres
URINDEWN	Urban / rural indicator for Output Area (OA) in which dwelling is located: 1 Urban ≥ 10k – sparse: OA falls within Urban

	settlements with a population of 10,000 or more and the wider surrounding area is sparsely populated; 2 Town and Fringe – sparse: OA falls within the Small Town and Fringe areas category and the wider surrounding area is sparsely populated; 3 Village – sparse: OA falls within the Village category and the wider surrounding area is sparsely populated; 4 Hamlet and Isolated Dwelling – sparse: OA falls within the Hamlet & Isolated Dwelling category and the wider surrounding area is sparsely populated; 5 Urban ≥ 10k – less sparse: OA falls within Urban settlements with a population of 10,000 or more and the wider surrounding area is less sparsely populated; 6 Town and Fringe – less sparse: OA falls within the Small Town and Fringe areas category and the wider surrounding area is less sparsely populated; 7 Village – less sparse: OA falls within the Village category and the wider surrounding area is less sparsely populated; 8 Hamlet and Isolated Dwelling – less sparse: OA falls within the Hamlet & Isolated Dwelling category and the wider surrounding area is less sparsely populated; 9 (pseudo) Scotland/NI/Channel Is/IoM; null no information available
IMD	Index of Multiple Deprivation score
Energy_rating	Energy efficiency rating, measured on an index of ‘Standard Assessment Procedure or SAP points where 1-20 is band G, 21-38 is band F, 39-54 is band E, 55-68 is band D, 69-80 is band C, 81-91 is band B and 92-100 is band A
Energy_rating_band	Energy efficiency band (A-G)

Appendix 2 Energy Rating and Dwelling Prices: Single EPC only

	(1) Change in Total Price	(2) Change in Price per sq.m.
Regional house price index	1.035***	2.384***
	(957.80)	(957.80)
No. of bedrooms	0.00507***	0.0117***
	(23.63)	(23.63)
Pre-1900	Hold-out	Hold-out
1900-1929	0.00211**	0.00486**
	(2.71)	(2.71)
1929-1949	0.000665	0.00153
	(0.80)	(0.80)
1950-1966	-0.00141	-0.00325
	(-1.68)	(-1.68)
1967-1975	-0.0164***	-0.0378***
	(-20.36)	(-20.36)
1976-1982	-0.0239***	-0.0550***
	(-27.12)	(-27.12)
1983-1990	-0.0319***	-0.0734***
	(-39.80)	(-39.80)
1991-1995	-0.0398***	-0.0917***
	(-43.18)	(-43.18)
1996-2002	-0.0552***	-0.127***
	(-62.82)	(-62.82)
2003-2006	-0.0515***	-0.119***
	(-48.19)	(-48.19)

2007-	-0.0161*** (-6.72)	-0.0372*** (-6.72)
Age unknown	-0.0152*** (-18.76)	-0.0350*** (-18.76)
Detached	0.0106*** (8.69)	0.0245*** (8.69)
Semi-detached	0.0182*** (15.89)	0.0420*** (15.89)
Terraced	0.0170*** (15.21)	0.0391*** (15.21)
Flat	Hold-out	Hold-out
Freehold	0.00743*** (7.80)	0.0171*** (7.80)
Urban level Category 1	Hold-out	Hold-out
Urban level Category 2	0.00750 (1.02)	0.0173 (1.02)
Urban level Category 3	0.0303*** (4.34)	0.0697*** (4.34)
Urban level Category 4	0.0306*** (3.64)	0.0704*** (3.64)
Urban level Category 5	0.000928 (0.13)	0.00214 (0.13)
Urban level Category 6	0.00337 (0.47)	0.00776 (0.47)
Urban level	0.0110	0.0253

Category 7	(1.54)	(1.54)
Urban level	0.0149*	0.0343*
Category 8	(2.06)	(2.06)
Deprivation index	0.000281***	0.000646***
	(12.90)	(12.90)
EPC A	-0.00668	-0.0154
	(-0.31)	(-0.31)
EPC B	0.00757*	0.0174*
	(2.40)	(2.40)
EPC C	0.0181***	0.0416***
	(6.84)	(6.84)
EPC D	0.0122***	0.0281***
	(4.66)	(4.66)
EPC E	0.00362	0.00834
	(1.38)	(1.38)
EPC F	-0.00317	-0.00729
	(-1.17)	(-1.17)
EPC G	Hold-out	Hold-out
Intercept	-0.0186*	-0.0428*
	(-2.42)	(-2.42)
quarterly fixed effects	Yes	Yes
adj. R^2	0.788	0.788
N	307483	307483

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

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