Is Energy Efficiency Priced in the Housing Market? Some Evidence from the United Kingdom

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Abstract

This paper investigates whether energy performance ratings, as measured by mandatory Energy Performance Certificates (EPCs), are reflected in the sale prices of residential properties. This is the first large-scale empirical study of this topic in the UK involving approximately 400,000 dwellings in the period from 1995 to 2011. Applying hedonic regression and an augmented repeat sales regression, we find a positive relationship between the energy efficiency rating of a dwelling and the transaction price per square metre. The price effects of superior energy performance tend to be higher for terraced dwellings and flats compared to detached and semi-detached dwellings. The evidence is less clear-cut for house price growth rates but remains supportive of an overall positive association. Overall, the results of this study appear to support the hypothesis that energy efficiency levels are reflected in UK house prices, at least in recent years.

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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 and Wales. As part of a wider objective to reduce greenhouse gas emissions, one of the policy aims of energy labelling, such as Energy Performance Certificates (EPC), is to provide information to market participants about buildings' energy performance in order to aid the decision-making process for prospective buyers and tenants. In turn, it is implied that positive demand shifts will have positive effects on prices and supply and, ultimately, negative effects on the level of greenhouse gas emissions. Since they constitute the terms on which products are exchanged, prices are a fundamental element of markets and, while not always perfect, price signals are central to the operation of markets since they provide the information for the allocation of scarce resources. Research on price effects is, therefore, important to identifying the effectiveness of this type of policy intervention.

In order to investigate the relationship between energy performance and sale prices, details of transactions involving approximately 400,000 dwellings that took place in the period from 1995 to 2011 have been analysed including a large proportion of dwellings that were sold more than once (repeat sales). 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 UK residential property market.

Energy Labelling

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 eco-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.

Energy performance labels can broadly be interpreted as a form of eco-label. Over the last decade, both the commercial and the residential real estate sector have seen the introduction of a wide range of, what can be loosely termed, eco-labels. Although there is likely to be a drift towards harmonisation, at the international scale there are competing voluntary labels. Within national real estate markets, there can be a blend of compulsory and voluntary eco-labels. Indeed, as more and more local regulatory bodies make the attainment of a voluntary environmental label a requirement, labels such as BREEAM and LEED for commercial real estate, are becoming quasi-compulsory as the distinction between voluntary and compulsory becomes blurred.

As noted earlier, 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. While 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. From the occupiers' perspective, operating from a more energy efficient building may increase productivity, reduce running costs, meet corporate social responsibility objectives and attract financial incentives (or help avoid environmental taxes). For suppliers of commercial property space, prices act as the "invisible hand" steering production. When the market price of a product is higher than its cost of production, increasing production should be profitable, new producers should have incentives to enter the market and resources should be allocated to sectors where there is the highest willingness to pay.

In practice, there is evidence to suggest that the information provision role of energy labels may not be operating as expected. Firstly, for commercial real estate markets in the UK there is evidence of systematic non-compliance with regulations (see Banks, 2008 for a discussion of some early problems). Periodic surveys by organisations such as National Energy Services and Quidos have consistently found low (albeit improving) compliance rates with EPC requirements in the commercial property sector. Secondly, where these certificates are provided, it is often after the marketing stage. Anecdotal evidence suggests that Energy Performance Certificates tend to be given to commercial tenants well after Heads of Terms have been agreed and sometimes after completion. This may be indicative of the low weight that tenants attach to this information rather than any attempt to obfuscate by owners. Nevertheless, it is not possible for an EPC rating to be a price determinant if it is introduced after the price has been agreed. In terms of this research, there is little evidence of similar systematic problems in the residential sector.

In addition to non-compliance issues, 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 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. 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).

Data

The economic analysis of house price determination and the pricing of housing attributes require 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. Both of these concerns apply to our analysis of energy efficiency ratings and house price and were addressed by obtaining a large sample as well as maximum coverage of key control variables. More specifically, 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.

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 transaction prices as submitted to and recorded by the Land Registry. To enable repeat-sales as well as pooled cross-sectional analysis, the sample contains the prices of all 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 in the database. 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 fully 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 comprising of a total 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 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 the appendix of this paper.

In the third step, EPC data as held 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. Random manual sample checks were also performed for quality control purposes. It should be noted that 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. Since not all properties in the original data set could be matched successfully with an EPC, our core database comprises of 433,584 dwellings and 867,168 transaction prices. However, since information on all the regressors was not available for the all of the observations, sample size varies according to the nature of the analysis.

Summary Statistics

Summary statistics are provided in Tables 1 to 3. There are a number of notable points.

- Of the 319,263 properties for which there are two sale prices, 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). In fact, there is a negligible number of properties in band A which means that it can be disregarded from interpretation of the results that follow.
- Both 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.
- 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: Mean Prices of Dwellings with Repeat Sales by EPC Rating

EPC Rating	*Sale1 Mean Price*	*Sale2 Mean Price*	*% price change*	*n*
A	£119,144	£172,771	45.01%	9
B	£172,449	£184,981	7.27%	4405
C	£158,249	£203,303	28.47%	76159
D	£153,420	£222,094	44.76%	145306
E	£169,756	£254,301	49.80%	74641
F	£198,179	£303,340	53.06%	15973
G	£160,464	£231,945	44.55%	2770
			Total	319,263

Source: Sample

Table 2: Dwelling Type by EPC Rating[1]

	Detached	Semi	Terraced	Flat
A	2	9	0	1
B	513	736	1790	3405
C	22147	29055	38319	13882
D	52184	62994	68362	11925
E	23403	36189	37437	4207
F	7542	6523	7401	1151
G	1180	1102	1896	218
Total	106,971	136,608	155,205	34,789

Source: Sample

[1] Statistics refer to entire sample, i.e. includes dwellings for which multiple EPCs were issued.

Table 3: Age of Dwellings and EPC Rating

	Pre-1900	1900-1929	1930-1949	1950-1966	1967-1975	1976-1982	1983-1990	1991-1995	1996-2002	2003-2006	2007 onwards
A	1	0	1	2	3	0	1	0	0	1	2
B	28	52	36	95	98	125	251	106	501	2167	1538
C	2631	4134	5119	8325	7869	6811	11405	6081	17651	14859	2647
D	16021	23793	22701	23559	20403	12093	18364	11286	14692	1363	241
E	16711	20777	15830	11494	8964	3519	3578	1469	621	218	77
F	5762	4693	2638	1973	1457	563	654	205	183	35	23
G	1314	934	545	419	237	86	47	17	11	4	19
Total	42468	54383	46870	45867	39031	23197	34300	19164	33659	18647	4547

Source: Sample

tend to be amongst the cheapest properties but they also tend to have the highest energy ratings.

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 dwellings from the data set.

Table 4 Relationship between Dwelling Age and Dwelling Size

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

Source: Sample

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, while 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.

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 intertemporal 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 A are omitted, we expect a negative coefficient since dwellings with inferior EPC ratings should, all else equal, sell for less. Conversely, if dwellings with EPC bandG 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 pointed out by Halvorsen and Palmquist (1980) and Giles (2011). Our simplified adjustment formula follows van Garderen and Shah (2002) 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 *cj* being the estimated coefficient of the dummy variable.

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

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

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.

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:

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

where the first and second sale periods are denoted by the superscripts 1 and 2 respectively. Assuming that most house characteristics remain the same between two sales of the same house, equation (4) simplifies to:

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

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, type etc.

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

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

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.

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. The results of the hedonic modelling 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 in 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. All age bands display significant negative price differences compared to dwellings built before 1900. 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, the 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 extremely large detached dwellings e.g. country homes, thatched cottages *inter alia.*

Table 5 Energy Rating and Price: Hedonic Estimations (dependent variable: price per sq.m.)

	(1) Full sample	(2) Detached	(3) Semi-detached	(4) Terraced	(5) Flat	(6) Detached dense	(7) Detached Sparse
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 (0.52)	-0.0927*** (-13.21)	-0.0115 (-1.74)	0.0475*** (8.67)	0.0276* (2.12)	-0.0447*** (-4.88)	-0.113*** (-8.73)
2007-	0.00655 (1.05)	-0.0451*** (-4.12)	-0.0169 (-1.21)	0.0698*** (5.40)	-0.0201 (-1.09)	-0.000362 (-0.03)	-0.0637** (-2.81)
Age (unknown)	-0.0563*** (-23.50)	-0.110*** (-17.35)	-0.0806*** (-16.12)	-0.0334*** (-10.08)	-0.0451*** (-3.72)	-0.0660*** (-7.69)	-0.138*** (-13.17)
Freehold	0.0659*** (21.20)	0.0301*** (4.22)	0.0405*** (7.84)	0.0850*** (16.42)	0.0827*** (7.13)	0.0260*** (3.61)	0.0987** (2.84)
Deprivation score	-0.00908*** (-155.35)	-0.00514*** (-32.19)	-0.00920*** (-95.88)	-0.00887*** (-95.17)	-0.00702*** (-30.90)	-0.00539*** (-32.63)	-0.000669 (-0.94)
EPC A-B	0.138*** (16.00)	0.0213 (0.96)	0.101*** (4.75)	0.182*** (12.64)	0.116*** (4.07)	0.0917** (3.09)	-0.0494 (-1.18)
EPC C	0.0991*** (14.12)	0.0129 (0.97)	0.0768*** (6.01)	0.155*** (14.59)	0.104*** (3.75)	0.0779*** (3.51)	-0.0385* (-2.11)
EPC D	0.0760*** (10.93)	0.0130 (0.99)	0.0675*** (5.33)	0.135*** (12.92)	0.0933*** (3.38)	0.0749*** (3.39)	-0.0201 (-1.18)
EPC E	0.0655*** (9.39)	0.00260 (0.20)	0.0512*** (4.03)	0.114*** (10.78)	0.0803** (2.88)	0.0598** (2.70)	-0.0155 (-0.93)
EPC F	0.0596*** (8.16)	-0.0009 (-0.07)	0.0403** (3.04)	0.0816*** (7.27)	0.0555 (1.90)	0.0503* (2.23)	-0.0205 (-1.18)
EPC G	Hold-out	Hold-out	Hold-out	Hold-out	Hold-out	Hold-out	Hold-out
Urban level Category 1	Hold-out	Hold-out	Hold-out	Hold-out	Hold-out	Hold-out	Hold-out

Urban level Category 2	-0.0173	0.00428	0.0136	-0.113*	0.164	0.0948	.
	(-0.73)	(0.13)	(0.28)	(-1.98)	(1.23)	(1.56)	.
Urban level Category 3	0.0861***	0.0961**	0.0650	0.0688	0.266*	.	0.0287
	(3.93)	(3.06)	(1.51)	(1.27)	(2.14)	.	(1.40)
Urban level Category 4	0.104***	0.103**	0.0829	-0.0290	.	.	0.0298
	(3.91)	(2.98)	(1.28)	(-0.44)	.	.	(1.20)
Urban level Category 5	-0.0513*	-0.0505	-0.00136	-0.110*	0.0545	0.0565	.
	(-2.27)	(-1.59)	(-0.03)	(-1.97)	(0.47)	(0.94)	.
Urban level Category 6	-0.0379	-0.0307	0.00652	-0.0845	0.0393	0.0765	.
	(-1.67)	(-0.97)	(0.14)	(-1.52)	(0.34)	(1.27)	.
Urban level Category 7	0.0355	0.0477	0.0599	-0.0183	0.0751	.	-0.0321***
	(1.57)	(1.50)	(1.28)	(-0.33)	(0.64)	.	(-4.92)
Urban level Category 8	0.0626**	0.0792*	0.0798	-0.0251	0.0620	.	.
	(2.73)	(2.47)	(1.69)	(-0.44)	(0.52)	.	.
Terraced	0.00668		.	.	.		
	(1.83)		.	.	.		
Detached	0.195***						
	(50.31)						
Semi-detached	0.0962***						
	(25.90)						
Flat	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 * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

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 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 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.

Appendix 1 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. The earliest lodgement date of an EPC certificate in our data set is 22nd 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 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 6 Energy Rating and Price Appreciation: Repeat Sales Estimations (dependent variable: change in price per sq.m.)

	(1) Full Sample	(2) Detached	(3) Semi-detached	(4) Terraced	(5) Flats
Regional price Index	2.381*** (965.59)	2.215*** (451.01)	2.428*** (595.70)	2.491*** (575.01)	2.306*** (233.53)
No. of Bedrooms	0.0114*** (23.52)	0.0081*** (9.45)	0.0155*** (17.51)	0.0111*** (12.60)	0.0090*** (4.03)
1900-29	0.0050** (2.81)	0.0099 (1.69)	0.0052 (1.35)	-0.0005 (-0.24)	0.0111 (1.20)
1930-49	0.0021 (1.11)	0.0011 (0.21)	-0.0042 (-1.17)	-0.0046 (-1.50)	0.0122 (1.27)
1950-66	-0.0023 (-1.22)	-0.0045 (-1.94)	-0.0160*** (-4.41)	0.0010 (0.30)	0.0176* (1.98)
1967-75	-0.0366*** (-20.04)	-0.0472*** (-9.88)	-0.0527*** (-14.31)	-0.0308*** (-10.80)	-0.0099 (-1.15)
1976-82	-0.0539*** (-27.01)	-0.0743*** (-14.83)	-0.0642*** (-15.99)	-0.0431*** (-14.02)	-0.0294** (-3.27)
1983-90	-0.0723*** (-39.85)	-0.0937*** (-19.58)	-0.0783*** (-20.41)	-0.0569*** (-21.63)	-0.0518*** (-6.23)
1991-95	-0.0903*** (-43.18)	-0.1060*** (-20.86)	-0.0925*** (-21.48)	-0.0713*** (-22.36)	-0.0755*** (-8.35)
1996-2002	-0.125*** (-62.82)	-0.133*** (-27.62)	-0.124*** (-29.65)	-0.110*** (-34.48)	-0.124*** (-13.82)
2003-2007	-0.116*** (-48.08)	-0.120*** (-20.90)	-0.134*** (-28.70)	-0.116*** (-31.44)	-0.118*** (-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***	-0.0005***	0.0006***	0.0007***	0.0002
	(12.71)	(-4.01)	(6.95)	(9.16)	(1.36)
EPC A	-0.0340	0.0273	-0.0529	-	0.0570
	(-0.70)	(0.34)	(-0.71)		(1.77)
EPC B	-0.0033	0.1010***	-0.0108	0.0060	-0.0110
	(-0.49)	(4.21)	(-0.76)	(0.55)	(-0.46)
EPC C	0.0235***	0.0583***	0.0263*	0.0105	-0.0079
	(4.18)	(5.65)	(2.51)	(1.14)	(-0.34)
EPC D	0.0110*	0.0371***	0.0124	0.0056	-0.0066
	(1.97)	(3.67)	(1.20)	(0.61)	(-0.28)
EPC E	-0.0070	0.0092	-0.0125	-0.0085	-0.0062
	(-1.25)	(0.91)	(-1.20)	(-0.93)	(-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	0.0142	0.0352	0.0169	-0.0969
	(0.75)	()0.55	(1.10)	(0.46)	(-1.35)
Urban level Category 3	0.0618***	0.0443	0.105***	0.0802*	-0.016
	(3.91)	(1.83)	(3.39)	(2.28)	(-0.78)
Urban level Category 4	0.0619**	0.0556*	0.0831	0.0927	-0.133
	(3.28)	(2.11)	(1.81)	(2.03)	(-1.09)
Urban level Category 5	-0.0033	-0.0343	0.0404	0.0457	-0.0354
	(-0.20)	(-1.41)	(1.22)	(1.23)	(-0.68)
Urban level Category 6	0.0021	-0.0329	0.0483	0.0551	-0.0054
	(0.013)	(-1.35)	(1.47)	(1.49)	(-0.10)
Urban level Category 7	0.0188	-0.0046	0.0665*	0.0514	-0.0252
	(1.16)	(-0.19)	(2.02)	(1.39)	(-0.47)
Urban level Category 8	0.0271	0.0449	0.0789*	0.0525	-0.0277
	(1.65)	(0.18)	(2.35)	(1.40)	(-0.50)
Intercept	-0.0640***	-0.0113	-0.0464**	-0.0003	0.0145
	(-8.16)	(-0.77)	(-3.13)	(-0.02)	(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 $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$

Conclusions

- For the sample of dwellings under investigation, the vast majority are in EPC bands C, D and E. Nearly half of all dwellings are EPC rated D. Only nine out of 319,263 (twice) sold dwellings were in EPC 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.
- Flats tend to be the most energy efficient with approximately half rated EPC C (40%) or B (9.8%).
- There is a clear relationship between EPC rating 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 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. The price effect is consistent with expectations in that the price differences increase as the energy performance rating improves.
- In terms of change in price per square metre, the results are less clear-cut. While 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.

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Appendix 1 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***	-0.0372***
	(-6.72)	(-6.72)
Age unknown	-0.0152***	-0.0350***
	(-18.76)	(-18.76)
Detached	0.0106***	0.0245***
	(8.69)	(8.69)
Semi-detached	0.0182***	0.0420***
	(15.89)	(15.89)
Terraced	0.0170***	0.0391***
	(15.21)	(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 Category 7	0.0110 (1.54)	0.0253 (1.54)
Urban level Category 8	0.0149* (2.06)	0.0343* (2.06)
Deprivation index	0.000281*** (12.90)	0.000646*** (12.90)
EPC A	-0.00668 (-0.31)	-0.0154 (-0.31)
EPC B	0.00757* (2.40)	0.0174* (2.40)
EPC C	0.0181*** (6.84)	0.0416*** (6.84)
EPC D	0.0122*** (4.66)	0.0281*** (4.66)
EPC E	0.00362 (1.38)	0.00834 (1.38)
EPC F	-0.00317 (-1.17)	-0.00729 (-1.17)
EPC G	Hold-out	Hold-out
Intercept	-0.0186* (-2.42)	-0.0428* (-2.42)

quarterly fixed effects	Yes	Yes
adj. R^2	0.788	0.788
N	307483	307483

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

Appendix 2 List of database variables

Calnea Data
First transaction price First transaction date Regional Land Registry HPI at first transaction date Second transaction price Second transaction date Regional Land Registry HPI at second transaction date Postcode Postal Districts Property type Tenure Old or new Year of construction Number of bedrooms Percentage change in price between P1 and P2 Number of days between D1 and D2 Compound annual growth rate
Office for National Statistics Postcode Directory
Output Area code Output Area classification Urban / rural indicator (England and Wales) Lower Super Output Area Code Medium Super Output Area Code Local authority code Region code Index of Multiple Deprivation score All people aged 16 - 74 in employment Households:Owner occupied
Landmark data
Energy efficiency rating Energy efficiency band (A-G) Environmental impact rating Environmental impact band (A-G) Period of construction EPC inspection date (in date format) EPC lodgement date (in date format)