Do Homebuyers Value Energy Efficiency? Evidence From an Information Shock*

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Abstract

We study the housing market response to a nationwide policy that mandated the provision of energy efficiency information with all marketing material at the time of listing. Using the near universe of housing sales in England and Wales, we match in the energy efficiency status of the property from Energy Performance Certificates at the time of sale. We provide causal evidence of households willingness to pay for a higher energy rated property, documenting a 1-3% premium to a higher energy efficiency rating at the national level, and a 3-6% premium in the London market.

Keywords— Hedonic Price Models, Energy Performance Certificates, Real Estate
JEL Codes— R38, Q48, K32

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1 Introduction

An increasingly warming earth represents one of the greatest global challenges today. With the 2050 goal to become net zero in greenhouse gas emissions and a more immediate cost of living crisis, the UK needs urgent attention to its housing sector energy efficiency. The UK has the largest stock of old houses in Europe (Sivarajah, 2021) – almost 31% of houses are built pre-1950.[1] Consequently, the housing sector in this country is more reliant on energy use than other European countries (Hodgkin and Sasse, 2022). Within this broader context, disclosing information on the energy efficiency of houses has attracted wide interest. The interest is arguably justified as housing accounts for approximately 40% of global energy consumption and a third of greenhouse gas emissions (World Economic Forum, 2021). As a result, many countries have introduced policies on mandatory disclosure of energy efficiency information for selling houses.

In this paper, we study the response of the housing market to a nationwide policy that required homeowners to prominently display the energy efficiency rating of the property with all marketing material when placing their home on the market. This was (and still is) typically done through providing the front page of the property's Energy Performance Certificate. The policy mandated that the energy efficiency information was prominently displayed at the outset of the buying process, and thus (i) a property's energy efficiency credentials were highly visible to all potential buyers and (ii) the salience of energy efficiency in general was heightened during the selling process.

Energy Performance Certificates were first introduced in the UK on 1 August, 2007 by the Housing Act 2004 and Energy Performance of Buildings (Certificates and Inspections) (England and Wales) Regulations (hereafter EPBR) of 2007. With this regulation, it became mandatory for sellers or landlords to provide any prospective buyer or tenant with a valid Energy Performance Certificate (hereafter EPC) at the earliest opportunity. All domestic properties in the entire England and Wales are assessed by accredited energy assessors and scored in a consistent manner, with assessment based on an exhaustive list of criteria, which serve as inputs into an energy efficiency score function.[2] The EPC ratings are categories based on these scores.

The policy we study – the EPBR 2011 amendment – was a response to the shortcomings of the original regulations. The market response to the original regulation of 2007 was tepid, and compliance with the regulations was poor (Ministry of Housing, Communities & Local Government, 2020). This was almost certainly due to the fact that although homeowners were mandated to supply potential buyers with an EPC, there was no requirement for this to be prominent or salient at the start of the process (Ministry of Housing, Communities & Local Government, 2012b). Thus for many buyers, the EPC may well have come right before sale was finalized. This is too late for the information on the building's energy efficiency to be priced in by the market (Ministry of Housing, Communities & Local Government, 2020, 2012a; Shepherd, 2012). The 2011 amendment addressed this directly.

We first investigate the house price effects of the EPBR 2011 amendment. To do so we

[1] The median energy efficiency rating band of UK houses is D (Office for National Statistics, 2021). As we show in Figure B1, older properties are typically less energy efficient.

[2] We cover the construction of the EPC scores in greater depth in Appendix D.

start with the near universe of all housing transactions in England and Wales, and match in information on the energy efficiency of the property at time of sale. With this data we estimate a hedonic house price model, using a regression-adjusted difference-in-differences (DD) specification. We consider all matched transactions with an energy efficiency rating of B, C or D[3] within a year window of the implementation of the EPBR 2011 amendment.

Our house price regression specifications are highly flexible across both space and time, in order to account for the current best practice when using DD specifications in a hedonic house price setting (Kuminoff et al., 2010; Kuminoff and Pope, 2014; Bishop et al., 2020). We specify the housing market as a local authority district (hereafter district). We interact all housing characteristics with district dummies in order to respect the "law of one price function" (Bishop et al., 2020). This allows the valuation of key property characteristics to vary across local housing markets. In addition, we allow the coefficients on all housing characteristics to differ in the pre and post periods, thereby allowing the hedonic price function to shift post-policy. We do so in order to avoid conflation bias – an issue where the DD estimate conflates the willingness to pay for more energy-efficient properties with a change in the hedonic price function over time (Kuminoff and Pope, 2014; Banzhaf, 2021). Recent work by Banzhaf (2021) asserts the suitability of using a difference-in-differences approach with a hedonic house price model in order to study welfare effects of policy changes.

We conceptualize the EPBR 2011 amendment as both (i) an information shock to the energy efficiency ratings of properties and (ii) a market-wide salience shock to the notion of energy efficiency as a key property attribute. Against this backdrop, we interpret our DD estimates as capturing the information shock-induced willingness to pay (WTP) of households for a higher EPC-rated property within a more energy efficiency aware market. In order to consider our estimates as the causal effects of the WTP for a higher EPC rating, we require two core assumptions to hold. First, the parallel trends assumption and second, that the composition of the groups we study are stable across our two time periods.[4]

We provide three pieces of evidence in support of the parallel trends assumption inherent in our DD approach – (i) placebo DD evidence from the years prior to the EPBR 2011 amendment implementation, (ii) we present the trends in house prices across the three EPC rating categories in the two years prior to the implementation of the amendment, and (iii) we implement the honest difference-in-differences approach of Rambachan and Roth (2022), in order to create worst-case treatment effect bounds for potential violations of the parallel trends assumption, based on pre-trends. Each piece of evidence provides support for the claim that the parallel trends assumption holds for our empirical specification in the sample period under consideration. In addition, with a series of balance tests, we present evidence that the composition of EPC category groups are stable across the pre and post periods.

We document significant premiums to higher EPC-rated properties – once the information on ratings is visible and salient at the start of the buying process, homebuyers pay 3.1% more for a B-rated property, and 1.3% less for a D-rated property, relative to our base rating category of C. We note significant heterogeneity in willingness to pay for more energy efficient properties across

[3]These three categories account for 71% of all properties. See Figure B2 for the EPC rating distribution.

[4]We require this second assumption as we use repeated cross-sectional data (Blundell and Dias, 2009).

the country, with the London region standing out as the housing market with particularly high valuation of energy efficiency. We proceed to focus on London, and document WTP for energy efficiency that are approximately twice of the national average, specifically a 6.5% premium for B-rated properties and a 3% penalty for D-rated properties.

We then investigate seller-responses to the EPBR 2011 amendments and ask two questions. First, do sellers attempt to game the inspection rating system by paying for multiple inspections in the hope of increasing their rating through assessor idiosyncrasies? Second, in the longer-run, do homeowners respond to the market incentives, and make energy efficiency enhancing improvements on their properties? We find no evidence of short-run gaming of the EPC assessment system, whilst we do find evidence that post-amendment, homeowners with lower rated properties are more likely to be reassessed within a two year period. These reassessments typically return higher energy efficiency scores, although we face small sample power-issues in this sub-analysis, so are limited with how strongly we can press upon this evidence.

In the final analysis, we seek to understand the mechanisms at playing in driving spatial variation in the WTP for higher energy efficiency ratings. We first focus on regional variation at the nationwide level, correlating regional DD estimates with various regional characteristics. We find no support for the hypothesis that those living in colder climates – therefore those with greater energy requirements – place a higher value on energy efficient homes. We then focus on London, and attempt to understand the district variation therein. We rule out political leanings or green credentials of districts as being important drivers of district-level WTP for higher EPC ratings. Instead we find that areas with a higher price-to-earnings ratio are the same areas with the highest DD estimates. We postulate that those living in higher price-to-earnings ratio areas may adopt a longer-term view of housing as an investment, and may thus pay more for a more energy efficient property to "future-proof" their investment. We find some supportive evidence for this idea – in areas with higher turnover, thus lower expected tenure at the property, we document larger EPC premiums.

Our study contributes to several strands of the literature and has important policy implications. First, by providing causal evidence on households' willingness to pay for a higher energy rate property we make a core contribution to a growing literature documenting the impact of energy performance certificates on housing markets. Much of the earlier work in this area was correlational (Fuerst et al., 2015; Jensen et al., 2016; Fuerst et al., 2020). Three recent papers are exceptions. Two of these papers study the housing market responses to a localized mandatory energy efficiency disclosure policy in a single US city (Myers et al., 2022; Cassidy, 2023). In an earlier paper, Aydin et al. (2020) follow an instrumental variable strategy to consider the house price responses to changes in energy efficiency levels of properties in the Netherlands.

Secondly, by studying the housing market responses to an energy efficiency information shock, we also contribute to a wider literature which focuses on the how the salience of available information shapes choices in a variety of domains, for e.g., information shocks on crime risk can adversely affect housing market (Linden and Rockoff, 2008). In this respect, our work is closest to that of Hussain (2022) who studies the housing market response to school quality ratings disclosure in England. Other research has also explored how more information on schools affect parental decision making (Greaves et al., 2021; Hastings and Weinstein, 2008), hospital report cards affect health-care provider behavior (Dranove et al., 2003), information on hygiene of restaurants influence consumer behaviors (Jin and Leslie, 2003), or gas pipeline explosions affect house prices (Herrnstadt and Sweeney, 2022).

In terms of policy implications, our study is relevant in that it deepens our understanding of the role that regulation-initiated, market-driven policy instruments can play in incentivizing more energy efficient homes. This places mandatory energy efficiency disclosure policies in company with other market-based regulatory approach to reducing carbon emissions. Examples of these other approaches include the cap and trade system of the EU Emissions Trading System (EUTS), and carbon taxation schemes (Hintermann and Zarkovic, 2020; Asen, 2021).[5]

2 Institutional Background and Data

2.1 Energy Performance Certificates and the EPBR 2011 Amendment

Energy Performance Certificates were introduced in the UK on 1 August, 2007 by the Housing Act 2004 and EPBR 2007.[6] With this regulation, it became mandatory for sellers or landlords to provide any prospective buyer or tenant with a valid EPC at the earliest opportunity. Moreover, landlords were obliged to commission an EPC before their properties were marketed for sale and to obtain the EPC within maximum 28 days by reasonable efforts.[7]

The EPBR 2011 amendment – the key regulatory policy we study in this work – came into force on 6th April, 2012, when a copy of the front page of the EPC *had to be* enclosed with all marketing materials of rental or sales properties. This meant that when one viewed a property online, the EPC would be prominent on the webpage. If one viewed a property in person, the front sheet of the EPC would be presented. Prior to the EPBR 2011 amendment, this was not the case. Instead, EPCs were available to all prospective buyers or tenants on request, but disclosure of EPCs was not mandatory at the outset of the selling process. Specifically, the 2011 amendment stated that landlords must obtain an EPC for all commercial or residential sales and lettings properties and include the first page of the certificate with all printed and electronic property particulars. At a minimum, in case the energy efficiency rating or the front page of the certificate were not included in all advertisement, a fine of £200 could be charged per advertisement.

It is noteworthy that the amendment was required at all. This reflects that the market response to the original regulation of 2007 was insufficient and that the level of compliance needed to be improved (Ministry of Housing, Communities & Local Government, 2020). This was al-

[5] Even though both policies have been somewhat successful in different contexts, their effectiveness are still under debate. Recent research suggest additional regulatory instruments are needed in addition to these market based solutions to address climate risk (Cullenward and Victor, 2020; Stavins, 2019). We see such regulatory-market interplay in the setting we study as well – the 2011 amendment to the original EPBR 2007 regulation was made due to the lack of initial market response.

[6] This law was implemented in response to the EU Directive 2002/91/EC. For further details on the relation between EU Directives and UK legislation, and for more context on the institutional background to the setting of our study, see Appendix D.

[7] An exemption would have applied only if the building in question were to be demolished.

most certainly due to the fact that although homeowners were mandated to supply potential buyers with an EPC, there was no requirement for this to be prominent and salient at the start of the process (Ministry of Housing, Communities & Local Government, 2012b). Thus for many buyers, the EPC may well have come right before sale was finalized. This is too late for the information on the building's energy efficiency to be priced in by the market (Ministry of Housing, Communities & Local Government, 2020, 2012a; Shepherd, 2012). The 2011 amendment addressed this directly.

2.2 Data and Sample Selection Criteria

Data We use two core datasets in our empirical work. The first is the Land Registry Price Paid data which covers almost every house sale in England and Wales.[8,9] Key variables we obtain from this data are sales price, final sale date, full address and some limited housing characteristics (indicators for whether the property is a leasehold, if the property is a new-build, as well as property type).

Second, we use the dataset "Energy Performance of Buildings Data: England and Wales".[10] These data are available from 2008 and include considerably more information on the property, including number of rooms, floor area, building age and a host of other property information. The data also provide us with information on the energy performance rating of the house, the date of inspection and full address of the property.

We merge these two datasets to yield a combined dataset with house price, property characteristics, and energy efficiency information for the property.[11] We are able to match EPC data to the vast majority of house sales during our sample period (86.8%). Table B1 presents summary statistics for the key variables in our analysis.

Sample Selection We restrict our analysis to properties with EPC ratings of B, C and D, which comprise over 70% of the properties in our matched EPC-transaction sample.[12] We do not consider new-build properties, as the EPC distribution for these properties is completely different to the existing housing stock. We drop properties with multiple inspections in the run-up to a sale in order to rule out sellers gaming the EPC rating system by "shopping around" for better ratings, which reduces the sample by 1%.

[8] Source: `https://www.gov.uk/government/statistical-data-sets/price-paid-data-downloads`, HM Land Registry.

[9] The Land Registry list reasons for the minority of sales that are not registered at `https://www.gov.uk/guidance/about-the-price-paid-#data-excluded-from-price-paid-data`.

[10] Source: `https://epc.opendatacommunities.org/`, Energy Performance of Buildings Register.

[11] Details on the data and merging process is included in appendix D.

[12] Figure B2 presents the distribution of EPC ratings in our matched data. A-rated properties are so rare that we do not use these. Properties rated E-G evolved with different time trends in the pre-period, hence given that we are using difference-in-differences, we consider properties rated B-D.

3 Empirical Specification

Our empirical approach takes the form of a hedonic house price model, using a regression-adjusted difference-in-differences (DD) specification as follows:

$$Price_{it} = \sum_{k \neq C}^{K} \alpha_k Category_k + \sum_{k \neq C}^{K} \beta_k (Post_t \times Category_k) + \sum_{d=1}^{D} (District_d \times Post_t \times X_i^{'} \gamma_d)$$
$$+ \sum_{w=1}^{W} \tau_w (Wider\, Neighborhood_w \times time_t) + \pi_{r \times t} + \theta_n + \epsilon_{it} \ , \tag{1}$$

where $Price_{it}$ is the house price of house i, sold in period t (measured at the month-level). $Category_k$ denotes EPC rating category k, $Post_t$ is a dummy for properties sold post-EPBR 2011 amendment, and β_k are our parameters of interest. These are the DD parameters. We conceptualize the EPBR 2011 amendment as both (i) an information shock regarding the energy efficiency ratings of properties and (ii) a market-wide salience shock to the notion of energy efficiency as a key property attribute. Against this backdrop, we interpret our DD estimates as capturing the information shock-induced willingness to pay (WTP) of households for a higher EPC-rated property within a more energy efficiency aware market. X_i is a vector of property characteristics including a dummy for leasehold, a dummy for gas being the main fuel, property type dummies, quintiles of floor area of the property, number of habitable rooms categories and categories for construction year bands. $\pi_{r \times t}$ captures month-by-year regional shocks to house prices, τ_w accounts for wider neighborhood trends in house price determinants, θ_n is a neighborhood fixed effect and captures local unobservables and ϵ_{it} is an error term. The treatment occurs at the household-level and we implement a repeated cross-sectional DD approach, hence we use heteroskedasticity-robust standard errors throughout (Abadie et al., 2023).

We specify the housing market as a local authority district (hereafter district). We interact the vector of housing characteristics, X_i, with district dummies in order to respect the "law of one price function" (Bishop et al., 2020). This allows the valuation of key property characteristics to vary across local housing markets.

We allow the coefficients on all housing characteristics to differ in the pre and post periods, thereby allowing the hedonic price function to shift post-policy. We do so in order to avoid conflation bias (Kuminoff and Pope, 2014; Banzhaf, 2021). Given this flexibility, the regression specifications in (1) is, in the nomenclature of Kuminoff et al. (2010), a generalized DD estimator.

3.1 Identification

The key identifying assumption underpinning our empirical approach is that properties with different EPC ratings experience common house price trends. Taking into account the recent critique to canonical pre-trends testing made by Roth (Forthcoming), we provide a battery of evidence using multiple approaches in support of parallel trends in our setting.

We first implement a set of placebo DD regressions. We shift all key dates one year back in time, and re-estimate Equation 1. We do not estimate any significant placebo DD parameters for either England and Wales combined (Table A1), or for the London region (Table A2). Next we inspect the trends in house prices across the three EPC rating categories in the two years prior to the implementation of EPBR 2011. We cannot reject the null of equality of trends in any case. Finally we implement the honest difference-in-differences approach of Rambachan and Roth (2022), in order to create worst-case treatment effect bounds for potential violations of the parallel trends assumption, based on pre-trends. We discuss these results in Section A.1.3. Taken together, the evidence we present here is strongly supportive of parallel trends in house prices across the different EPC categories under consideration.

Given that we are using repeat cross-sectional data for our empirical analysis, we also provide evidence for a second identifying assumption – that the composition of EPC category groups are stable across the pre and post periods. In order to assess the stability of groups over time, we present the results from a series of balance tests in Table A4 for England and Wales, and Table A5 for London. In both cases, we find strong support for stability of group composition in our sample period.

4 The Value of Energy Efficiency Information

4.1 England and Wales

We present the DD parameter estimates from Equation (1) in Column 6 of Table 1. The five preceding columns present DD estimates for less stringent variants of our baseline regression specification, in order to show parameter stability as we (i.) increase the resolution of the spatial fixed effects and (ii.) include local time trends at different levels of spatial resolution. In column 1 we take the housing market as the Travel To Work Area (TTWA) – analogous to Commuting Zones in the US, we account for time invariant at the TTWA level, and we do not include local time trends. With this specification, we document that the heightened salience of EPC rankings due to the EPBR 2011 amendment lead to B-rated properties selling for 5.3% higher prices ((B Rating $\times$ Post)/$\overline{Y}_{C,PRE}$ at the base of Table 1), and a 1.3% penalty ((D Rating $\times$ Post)/$\overline{Y}_{C,PRE}$) for D-rated properties, when compared to C-rated properties.

In Column (2) we include spatial effects at a lower spatial resolution, but keep fixed the rest of the specification. Moving from Column (2) to (3) we change our definition of the housing market from TTWA to district, which impacts the X interactions term. Both of these changes reduce the premium of a B rating, yet do little to change the D rating penalty, which suggests that high energy efficiency properties are non-uniformly located across housing markets. Moving from Column (3) to Column (7) does very little to change either of the two DD parameters estimates. Column (7) presents the DD estimates for our baseline specification, which features neighborhood fixed effects, wider neighborhood time trends, and district-by-period-by-X interactions for all controls. In this specification, we document that by making energy efficiency more salient to home-buyers, the EPBR 2011 amendment led to a 3.1% premium for B rating properties, and a 1.3% penalty for D rating property, relative to the base category of C rated houses.

Table 1: DD Estimates from Introduction of EPC certificates – England and Wales

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
B Rating × Post	11052**	8473**	6363*	6364**	6400**	6422**	6528**
	(4418)	(4133)	(3476)	(3191)	(3190)	(3062)	(3095)
D Rating × Post	–2758**	–2692***	–3016***	–2659***	–2662***	–2612***	–2591***
	(1090)	(1001)	(816)	(769)	(769)	(775)	(780)
$\overline{Y}_{C,PRE}$	208098	208098	208098	208098	208098	208098	208098
(B Rating × Post)/$\overline{Y}_{C,PRE}$	.0531**	.0407**	.0306*	.0306**	.0308**	.0309**	.0314**
(D Rating × Post)/$\overline{Y}_{C,PRE}$	-.0133**	-.0129***	-.0145***	-.0128***	-.0128***	-.0126***	-.0125***
Spatial FEs	TTWA	District	District	Wider NH	Wider NH	NH	NH
Local Time Trends					District		Wider NH
X Interactions	TTWA× Post×X	TTWA× Post×X	District× Post×X	District× Post×X	District× Post×X	District× Post×X	District× Post×X
Adjusted R^2	.458	.559	.691	.737	.737	.76	.76
Observations	705,179	705,179	705,182	705,182	705,182	705,086	705,086

Notes: *** denotes significance at 1%, ** at 5%, and * at 10%. The dependent variable in all regressions is the house price in £. The estimation sample is based on a +/-1 year window of sales dates around April 6, 2012. We restrict our attention to EPC ratings of B-D, which comprise the majority (.719) of the full sample.

4.2 London-Specific Estimates

Given the national scope of our data, one may wonder about the spatial heterogeneity of our results. We present region-specific DD estimates for the ten regions in England and Wales in Figure B4. London is a stand-out region for at least two reasons. First, the sheer magnitude of the estimated DD parameters. Second, London is the only region with statistically significant DD estimates for both B and D ratings. This is not just a power-related artifact of London's size – other regions are larger in terms of transaction volume, or of a similar size. We thus focus our attention on London in this sub-section[13], presenting estimates for a London-specific variant of Equation (1) in Table 2.

We note three key points in the London-specific results. First, house prices are considerably higher in London, thus it is instructive to consider the DD estimates in percentage terms relative to the base category in the pre-period – these are presented in the fourth and fifth rows of the table. Second, the patterns of coefficients as one moves rightwards across specifications mirrors what we saw in Table 1 – large parameters movements from Columns (1) to (3), followed by a stabilization of DD estimates. Third, in our main specification we find a premium for B rating properties of 6.5%, and a D rating penalty of 3.0%. These premiums are double the magnitude of the DD estimates we document at the national level. We consider a range of candidates to explain for the spatial variation in energy efficiency information capitalization across areas in Section 6.

4.3 Cost Benchmarks

As part of an energy assessment, the assessor will recommend a set of improvements that the homeowner could make to reach the "potential efficiency rating" for the property. There are

[13]In Section B.2.2 we present the complementary results for England and Wales without London.

Table 2: DD Estimates from Introduction of EPC certificates – London Only

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
B Rating × Post	39585**	29670*	25277*	22598*	22535*	22904**	22676*
	(16879)	(15724)	(13361)	(12119)	(12115)	(11631)	(11781)
D Rating × Post	–15201**	–12746**	–11230**	–9490**	–9553**	–10837**	–10552**
	(7033)	(6376)	(5057)	(4784)	(4779)	(4946)	(4995)
$\overline{Y}_{C,PRE}$	351311	351311	351311	351311	351311	351311	351311
(B Rating × Post)/$\overline{Y}_{C,PRE}$	.113**	.0845*	.0719*	.0643*	.0641*	.0652**	.0645*
(D Rating × Post)/$\overline{Y}_{C,PRE}$	-.0433**	-.0363**	-.032**	-.027**	-.0272**	-.0308**	-.03**
Spatial FEs	TTWA	District	District	Wider NH	Wider NH	NH	NH
Local Time Trends					District		Wider NH
X Interactions	TTWA× Post×X	TTWA× Post×X	District× Post×X	District× Post×X	District× Post×X	District× Post×X	District× Post×X
Adjusted R^2	.298	.447	.642	.697	.697	.718	.719
Observations	94,111	94,111	94,104	94,104	94,104	94,091	94,091

Notes: *** denotes significance at 1%, ** at 5%, and * at 10%. The dependent variable in all regressions is the house price in £. The estimation sample is based on a +/-1 year window of sales dates around April 6, 2012. We restrict our attention to EPC ratings of B-D, which comprise .716 of the full sample.

on average 4 recommendations per assessment, and each recommendation is supplied with an estimated cost interval. Some recommendations are relatively cheap (changing to low energy lighting, installing loft insulation) whereas others can exceed £5,000 (external wall insulation, upgrading the home's heating system).

In this section, we use the recommendations data to calculate the cost of increasing the energy rating category of a property based on the recommendations of the energy assessor.[14] These calculations serve as a useful benchmark against which to gauge the magnitude of our DD estimates from the sections above. We present costings for achieving a higher EPC category via retrofitting in Table 3 below.

Table 3: The Cost of Increasing a Property's Rating via Retrofit Far Exceeds our DD Estimates

	(1)	(2)	(3)	(4)
	England and Wales		**London Only**	
	Current Score to Lowest Score in Next Category	Current Category Mean Score to Next Category Mean Score	Current Score to Lowest Score in Next Category	Current Category Mean Score to Next Category Mean Score
C to B Rating	76,000	83,467	40,253	43,838
	[54,041 - 97,959]	[59,402 - 107,533]	[26,236 - 54,270]	[28,637 - 59,039]
D to C Rating	41,679	69,316	49,032	72,868
	[28,510 - 54,847]	[47,837 - 90,795]	[31,727 - 66,336]	[47,087 - 98,649]

Notes: We display mean cost estimates associated with moving up a rating category via retrofitting, and the lower and upper bound cost estimates in brackets. All cost estimates are based on energy improvement steps from inspection. Data: EPC Certificate and Recommendation Data, 6 April 2011-5 April 2012.

Using the "current score to lowest score in next category" approach, we document that in order to move up one EPC category, it would cost on average £42,000 and £76,000 for a D-rated and C-rated property respectively. For the London region, the equivalent cost estimates are £49,000

[14]We describe the specifics of how we create the cost benchmarks in Appendix B.4.

and £42,000 – a difference most likely due to the different stock of housing in the capital. Our key take-away from Table 3 is that these retrofit costs far exceed the DD estimates we document in the previous sections.

5 The Short- and Medium-Run Response From Homeowners

In this section, we consider the supply side[15], and answer two related questions. First, do homeowners respond to the heightened importance of EPCs post-April 6, 2012 by "shopping around" for better ratings? The short answer to this question is no.[16] This is somewhat surprising given the premiums we document in Section 4. One explanation for this finding is that the uniform and prescribed nature of EPC inspections leaves no scope for the same property to receive a different rating without key improvements to the energy efficiency of the property being implemented.

Second, in the longer run, do homeowners respond to buyers' (EPBR 2011 amendment-induced) increased energy efficiency awareness by making energy efficiency enhancing improvements to their properties? To answer this, second question, we focus solely on the EPC data, and make use of the panel element of this data. Through unique property identifiers, we can track all EPC inspections conducted on a property over time. The empirical set-up is the same as before, except now we use the inspection date to anchor our data in time. Our empirical specification amounts to a less onerous variant of Equation (1)[17]:

$$Repeat^d_{it} = \sum_{k \neq C}^{K} \alpha_k Category_k + \sum_{k \neq C}^{K} \beta_k (Post_t \times Category_k) + X_i^{'}\gamma + \pi_{r \times t} + \theta_n + \epsilon_{it} \ , \qquad (2)$$

where $Repeat_{it}$ is an indicator for a follow-up inspection within a given time frame, d, and all other variables are as defined when describing Equation (1). We present the corresponding results in Table 4, and present the placebo analogue of these results in Table C1.

In the period after the EPBR 2011 Amendment, owners of properties initially D-rated are more likely to have a repeat inspection in the medium-run. This effect kicks in a year after the initial inspection and increases with time since first inspection. Post-EPBR 2011 Amendment, we see that properties initially D-rated are 16% and 15% more likely (than a C-rated property) to have a follow-up inspection with 24 months, for England and Wales, and London respectively. We find no statistically significant change in the re-inspection behavior of B-rated properties. Our interpretation of these findings is that given (i.) the timeframe and (ii.) the fact that the effects are concentrated almost exclusively on D-rated properties in the post period, these results reflect

[15] We note that irrespective of what we find in this section, our core results presented in Section 4 are insulated against any supply side responses, as we consider only properties that have a single inspection in the run-up to a sale.

[16] We present related results in Section C.2.

[17] In the hedonic house price model specification we estimate in Equation (1) we specify such a rich model in order to guard against conflation bias, and to respect the law of one price.

Table 4: Owners of D-Rated Properties are More Likely to Get Another Inspection in the Medium-Run

	(1)	(2)	(3)	(4)
	Repeat Inspection Within:			
	6 Months	12 Months	18 Months	24 Months
A.) England and Wales				
B Rating × Post	.00274**	.0028*	.00251	.00259
	(.00132)	(.00164)	(.00195)	(.00214)
D Rating × Post	.000477	.00171***	.00329***	.00383***
	(.000361)	(.000485)	(.000569)	(.000637)
$\overline{Y}_{C,PRE}$	.00835	.0145	.0192	.0233
(B Rating × Post)/$\overline{Y}_{C,PRE}$	.328**	.193*	.131	.111
(D Rating × Post)/$\overline{Y}_{C,PRE}$	.0571	.118***	.172***	.164***
Observations	1,052,927	1,052,927	1,052,927	1,052,927
B.) London Only				
B Rating × Post	.00318	.00313	.00424	.00592
	(.00329)	(.00399)	(.00466)	(.00503)
D Rating × Post	.00187	.00312**	.004**	.00448**
	(.00123)	(.00157)	(.0018)	(.00197)
$\overline{Y}_{C,PRE}$	.0137	.0212	.0263	.0304
(B Rating × Post)/$\overline{Y}_{C,PRE}$	.233	.147	.161	.195
(D Rating × Post)/$\overline{Y}_{C,PRE}$	.137	.147**	.152**	.147**
Observations	132,332	132,332	132,332	132,332

Notes: *** denotes significance at 1%, ** at 5%, and * at 10%. The estimation sample is based on properties assessed for an EPC within a +/-1 year window around April 6, 2012. We restrict our attention to EPC ratings of B-D, which respectively comprise and of the National and London samples.

homeowners making energy efficiency improvements on their properties. The front page of the EPC itself prominently displays a set of ways in which prospective homebuyers could improve the energy efficiency of the property under consideration.[18] Several of these, are relatively cheap ways in which poorly insulated UK homes can be made more energy efficient.

In Section C.3 we present results from analogous specifications to Equation (2), but where the dependent variable is either $\Delta EPC\ Score_{it}$ or $\Delta EPC\ Rating_{it}$, in order to assess if medium-run inspections are associated with improvements in EPC scores or ratings. This would provide direct evidence that homeowners improve the energy efficiency of their properties in light of the EPBR 2011 amendment. The hurdle we face in this analysis is one of power – once we condition on having a repeat inspection, the sample becomes very small. We do see that for properties initially D-rated, there is a consistent improvement in EPC scores (Table C3) and ratings (Table C4) following a repeat inspection in the post period, yet this effect is not statistically significantly different from zero at conventional levels.

6 What Drives Spatial Heterogeneity in EPC Premiums?

We now explore correlates of area-specific DD estimates. The aim of this exploratory analysis is to better understand what drives the spatial heterogeneity in WTP for energy efficiency,

[18]See the lower part of the EPC template shown in Figure D1.

both across the country, and within the London region. We start with regional variation in our DD estimates at the nationwide-scale, presenting the results from bivariate regressions of our regional-specific DD estimates on various regional in Figure 1a. We first make use of the climatic variation across England and Wales – we document a $2°C$ or $4°F$ range in climate across regions – to explore the relationship between climate and the policy-induced change in EPC premiums across EPC rating categories. The logic behind this starting point is simple – all else equal, a colder climate should mean a higher WTP for energy efficiency in order to offset higher energy spending. And yet the estimates are opposite-signed to this what this logic would suggest – warmer climates are associated with a larger B-rating premium and a large D-rating penalty. Sensitivity analysis indicates an outsized role of London in these regressions, hence panel ii.) of Figure 1a repeats the analysis removing London. This analysis indicates no meaningful correlation between our region-specific DD estimates and any area characteristics.

These null findings leads us to conclude that the drivers of the heterogeneity in WTP for energy efficiency do not lie in the domains of climate, which we use to proxy for energy consumption, or in the realm of area differences in price or income levels. Given the importance of this regional housing market, we now zoom in on London, and present a set of analyses based at the level of district, which in the case of London coincides with London boroughs. Not only is the London housing market more dense, thereby allowing us to drop down to the spatial level of district, but we have considerably more district-level data available to us for London than for the country as a whole. This enables us to consider a richer set of district-level correlates.[19]

We document that transport- and politics-related variables, which may proxy for the "green" credentials of the area, do not correlate with our DD estimates. We find some relationship between our DD estimates and both (i) highest levels of education and (ii) occupation-based socioeconomic status categories, but these variables do not correlate in an internally consistent fashion for both B- and D-rating DD estimates. Where we do find internally consistent correlates is in the house price-earnings ratio (as well as the inputs to the ratio). These financial variables are the only set of district-level characteristics that correlate with both our DD estimates in a logical manner.

Why is it that our DD estimates are higher in areas with higher price/earnings ratios? Are homebuyers in different areas internalizing house prices relative to earnings when making purchasing decisions? Specifically when house prices are high relative to their earnings do buyers choose to invest in more energy efficient homes, possibly in order to avoid the need to do further work on the property, or to "future-proof" their housing investment? Without matched buyer-transaction data it is difficult to comprehensively answer this question.

In the final piece of analysis we correlate area-specific turnover in the property market with area-specific DD estimates, controlling for the house price-earnings ratio in that area. If it is the case that areas where turnover is lower, and thus property tenure is higher, are also areas where the EPC ratings premiums are higher, this would provide some support for the idea that buyers are more forward-looking with their housing investments when faced with a higher relative price housing market. We find some supportive evidence for this hypothesis, both at the regional level

[19] Figure B6 maps house prices for C-rated properties in the pre EPBR 2011 period. This orients us in terms of the spatial-price topology of London – prices are highest in the center and the west.

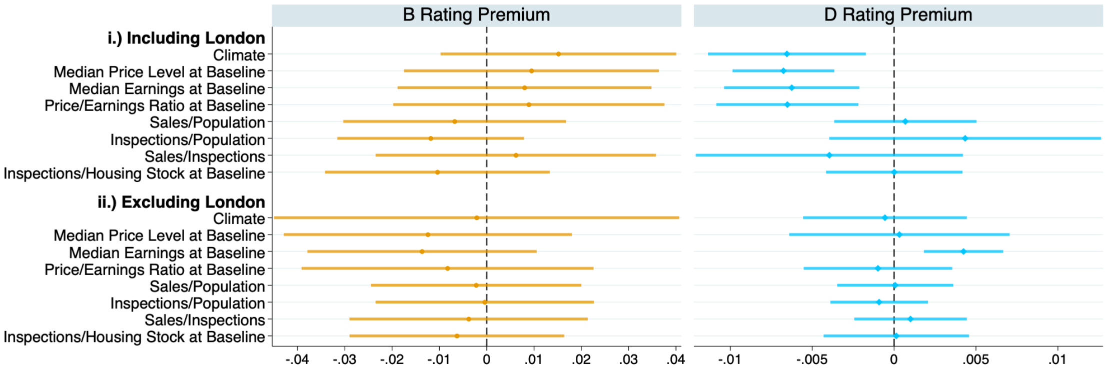
across England and Wales (Figure 1c). In both cases we document a negative partial correlation between ex-ante turnover in the market and subsequent EPC ratings premiums, which in turn implies a positive relationship between ex-ante tenure expectations and our DD estimates.

7 Conclusion

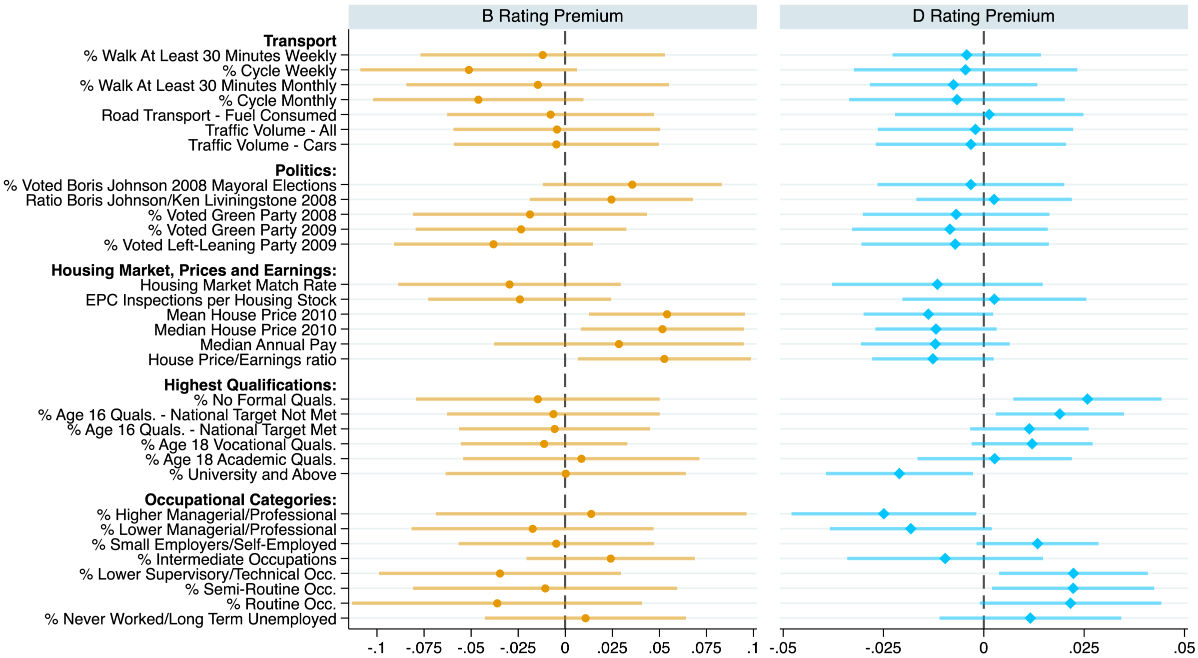
In this paper we study a nationwide policy that mandated the provision of energy efficiency information of a property at listing. Using a generalized difference-in-differences specification, we provide causal evidence of the WTP of households for higher energy efficiency ratings. We document that homebuyers value energy efficiency, paying a premium of 1-3% more for a higher EPC rating nationwide, and 3-6% more in London. We find considerable spatial heterogeneity in our estimates – both at the country-level, but also within London. We probe both the regional- and district-level WTP estimates in order to understand the correlates of the spatial variation. The only consistent correlate for both spatial levels is the house price-to-earnings ratio – areas with a larger ratio also have higher WTP for energy efficiency ratings. We speculate this may be the result of higher relative house prices causing homebuyers to consider their housing investment over a longer time horizon, and thus invest in more energy efficient housing. We provide supporting evidence for this hypothesis. Our work also documents of homeowner-response to the policy we study, albeit over a longer timeframe.

Our study highlights the importance of regulatory adjustment with market-oriented policies such as the regulation underpinning Energy Performance Certificates. When the regulation was first introduced, the design was insufficient for the market to adequately respond to EPCs. The 2011 EPBR amendment made the energy rating information more visible, more salient and made it available at the right time – when properties are first listed. In this way the market could better respond to the regulations. In this manner Energy Performance Certificates share commonalities with other market-based regulatory instruments that aim to lower emissions, such as carbon taxes and cap and trade schemes. The more we can collectively understand about the strengths and weaknesses of such approaches, the better we can implement market-facing regulatory instruments in the fight to stave off a climate emergency.

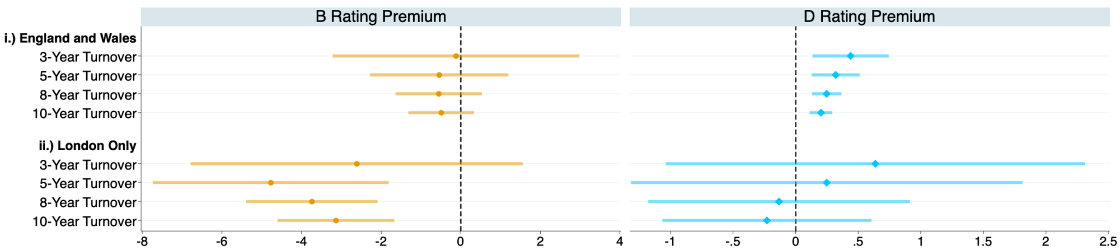
Figure 1: Few District Characteristics Substantively Correlate with Both B- and D-Rating District-Specific DD Estimates.



(a) Correlates of Regional-Level DD Estimates – England and Wales



(b) Correlates of District-Level DD Estimates – London



(c) Turnover and DD Estimates

Notes: The figure present point estimates and 95% confidence intervals. Region and district observations are weighted by the number of transactions in the sample period. We standardize variables to present the coefficients on a single scale. As we are comparing across regions with different price levels, we normalize the area-specific DD estimates by the average house price for C-rated properties (the base category) in the area prior to the EPBR 2011 amendment. Additional data used in Figure 1a includes climate data (source: HadUK-Grid, Met Office), data on the housing stock (source: Department for Levelling Up, Housing & Communities for England, and StatsWales for Wales), and data on earnings (source: Annual Survey of Hours and Earnings (ASHE)). For the London-specific analysis in Figure 1b, additional data include information on transport and politics (source: London Datastore), and data on qualifications and occupation (source: Census 2011, nomis). The turnover data used in Figure 1c is based on the main housing transaction data we use in the paper (source: HM Land Registry), with the period under consideration based purely on the pre-period. For example, the 10-year turnover statistic is constructed based on property-level turnover in the period April 6 2002-April 5 2012.

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Appendix

A Support for the Identifying Assumptions

A.1 Parallel Trends

A.1.1 Placebo Regressions

In this section, we run placebo versions of our baseline specification – Equation (1) – where we shift all key dates one year back in time. Here the $Post_t$ term takes value zero for the period 6 April 2010-5 April 2011, and one for the period 6 April 2011-5 April 2012. We control for the same variables, and include the same fixed effects. The aim of this section is to check for pre-trends. The key assumption of the DD model is one of parallel trends, hence any significant coefficients here is a warning that this assumption is not met.

We do not estimate any significant placebo DD parameters for either England and Wales combined, or for the London region. We take this as the first piece of evidence in support of the parallel trends assumption holding.

Table A1: DD Estimates from Introduction of EPC certificates – England and Wales – Placebo

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
B Rating × Post	5744*	5191	4577*	3444	3301	2452	2750
	(3445)	(3234)	(2704)	(2505)	(2504)	(2343)	(2318)
D Rating × Post	–730	–1006	–784	–682	–640	–815	–669
	(886)	(804)	(664)	(617)	(616)	(626)	(634)
$\overline{Y}_{C,PRE}$	208948	208948	208948	208948	208948	208948	208948
(B Rating × Post)/$\overline{Y}_{C,PRE}$	.0275*	.0248	.0219*	.0165	.0158	.0117	.0132
(D Rating × Post)/$\overline{Y}_{C,PRE}$	-.00349	-.00482	-.00375	-.00326	-.00306	-.0039	-.0032
Spatial FEs	TTWA	District	District	Wider NH	Wider NH	NH	NH
Local Time Trends					District		Wider NH
X Interactions	TTWA× Post×X	TTWA× Post×X	District× Post×X	District× Post×X	District× Post×X	District× Post×X	District× Post×X
Adjusted R^2	.499	.596	.709	.752	.752	.774	.774
Observations	645,059	645,059	645,057	645,057	645,057	644,890	644,890

Notes: *** denotes significance at 1%, ** at 5%, and * at 10%. The dependent variable in all regressions is the house price in £. The estimation sample is based on a +/-1 year window of sales dates around April 6, 2011. We restrict our attention to EPC ratings of B-D, which comprise the majority (.692) of the full sample.

A.1.2 Graphical Evidence of Parallel Trends

Figure A1 shows the pre-trends in residualized house prices for the pre-policy period of 6 April 2010-5 April 2012. In order to residualize the data, we run the following regression, and then extract the residuals.

$$Price_{it} = \sum_{d=1}^{D}(District_d \times X_i^{'}\gamma) + \sum_{w=1}^{W}\tau_w(Wider\,Neighborhood_w \times time_t) + \theta_n + \epsilon_{it}\ , \quad (3)$$

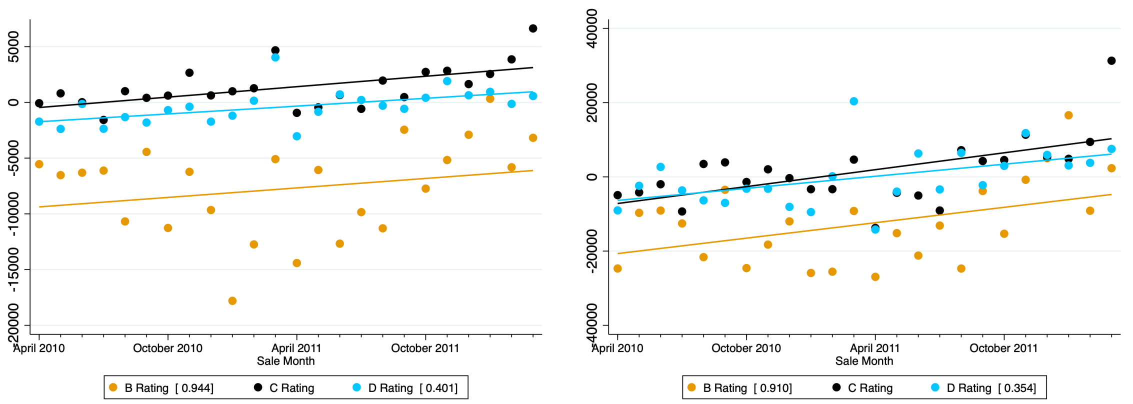
Table A2: DD Estimates from Introduction of EPC certificates – London Only – Placebo

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
B Rating × Post	13285	9404	3029	2186	1566	572	1832
	(13154)	(12237)	(10009)	(9154)	(9147)	(8548)	(8364)
D Rating × Post	71.4	–2217	–1528	–1833	–1656	–2079	–1173
	(5364)	(4770)	(3706)	(3434)	(3423)	(3588)	(3658)
$\overline{Y}_{C,PRE}$	349205	349205	349205	349205	349205	349205	349205
(B Rating × Post)/$\overline{Y}_{C,PRE}$	.038	.0269	.00867	.00626	.00448	.00164	.00525
(D Rating × Post)/$\overline{Y}_{C,PRE}$	.000205	-.00635	-.00437	-.00525	-.00474	-.00595	-.00336
Spatial FEs	TTWA	District	District	Wider NH	Wider NH	NH	NH
Local Time Trends					District		Wider NH
X Interactions	TTWA× Post×X	TTWA× Post×X	District× Post×X	District× Post×X	District× Post×X	District× Post×X	District× Post×X
Adjusted R^2	.331	.486	.671	.721	.721	.739	.74
Observations	87,446	87,446	87,439	87,439	87,439	87,417	87,417

Notes: *** denotes significance at 1%, ** at 5%, and * at 10%. The dependent variable in all regressions is the house price in £. The estimation sample is based on a +/-1 year window of sales dates around April 6, 2011. We restrict our attention to EPC ratings of B-D, which comprise .686 of the full sample.

The p-value presented in the legend of each graph is based on a test of equality of trends in the pooled data (i.e. testing the trends for B and D rated properties against category C properties). The large p-values reinforce the visual patterns, confirming that the trends in house prices between EPC ratings groups are indeed parallel in the run-up to the policy change in April 2012.

Figure A1: Pre-trends



(a) England and Wales

(b) London

Notes: The p-values presented in square brackets in the legend of both graphs is based on a test of equality of trends between the control rating category (C) and the treatment categories (B and D) using pooled, transaction-level data. Period: 6 April 2010-5 April 2012

A.1.3 Honest Difference-in-Differences – Rambachan and Roth (2022)

Finally, we implement the honest difference-in-differences approach of Rambachan and Roth (2022), in order to create worst-case treatment effect bounds for potential violations of the parallel trends assumption, based on pre-trends. In order to operationalize this approach, we use data for sales that occur in the three years between 6 April 2010 and 5 April 2013, and create

3 periods: 1.) An initial period of 6 April 2010 - 5 April 2011 that is prior to the pre-period used in the main analysis, 2.) the pre-period of 6 April 2011 - 5 April 2012 and 3.) the post-period of 6 April 2012 - 5 April 2013. We then implement our core DD model, but based on the extended data and a 3 period approach, as follows:

$$
\begin{aligned}
Price_{it} = & \sum_{j=1,\neq 2}^{3} \sum_{k \neq C}^{K} \beta_{jk}(Period_j \times Category_k) + \sum_{j=1,\neq 2}^{3} \sum_{d=1}^{D} (District_d \times Period_j \times X_i^{'}\gamma) + \pi_{r\times t} \\
& + \sum_{w=1}^{W} \tau_w(Wider\,Neighborhood_w \times time_t) + \theta_n + \epsilon_{it} \ , \qquad (4)
\end{aligned}
$$

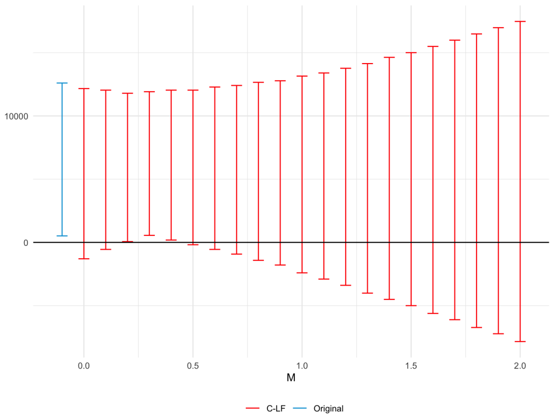
The coefficients presented in Table A3 below, and accompanying variance-covariance matrices are the required inputs into the R package (HonestDiD) that implements the Rambachan and Roth (2022) approach.

Table A3: The Inputs For the Honest DD Approach Highlight The Large Ratio Between Placebo and Actual Treatment Effects From a Pooled Estimation

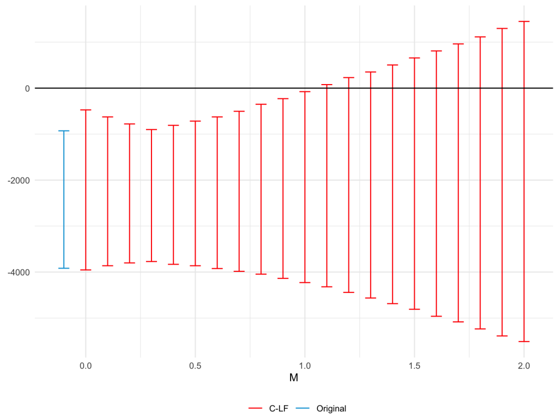
	(1)	(2)
	England and Wales	London
B Rating $\times$Period$_1$	–2638	–1674
	(2407)	(8813)
B Rating $\times$Period$_3$	6558**	22461*
	(3084)	(11767)
D Rating $\times$Period$_1$	788	1362
	(626)	(3597)
D Rating $\times$Period$_3$	–2423***	–9746**
	(763)	(4839)
$\overline{Y}_{C,PRE}$	208098	351311
Adjusted R^2	.766	.728
Observations	1,003,344	135,061

Notes: *** denotes significance at 1%, ** at 5%, and * at 10%. We restrict our attention to EPC ratings of B-D. The variables Period$_1$ and Period$_3$ are dummies corresponding resepctively to the earlist pre-period of 6 April 2010-5 April 2011, and the post-policy period of 6 April 2012-5 April 2013. The pre-policy period of 6 April 2011-5 April 2012 is the omitted period.

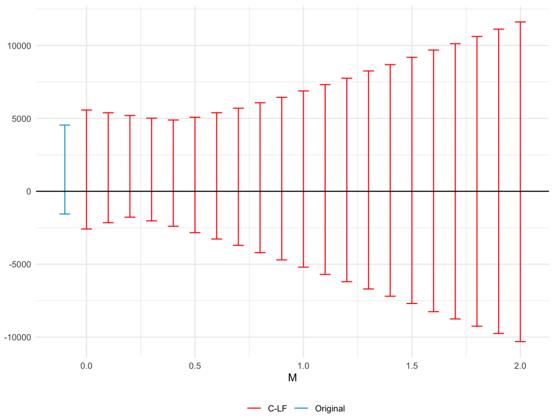
Figure A2: Pre-trends



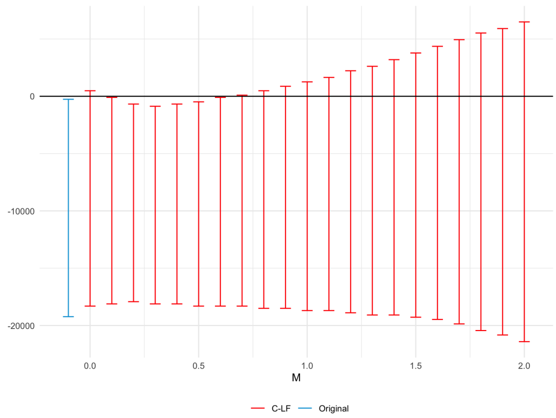
(a) B Rating - England and Wales



(b) D Rating - England and Wales



(c) B Rating - London Only



(d) D Rating - London Only

Notes: The blue bands ("Original") are the respective 90% confidence interval of the DD treatment effect estimates ($Period_3 \times Category_k$ in Table A3). The red bands ("C-LF") are the robust confidence intervals for the Rambachan and Roth (2022) Relative Magnitude-based bounds. These vary with the x-axis – $\overline{M}$ – which designates factors of the maximum pre-treatment violation of parallel trends. Thus a confidence interval that does not intersect 0 when $\overline{M} = 1$ informs us that when we allow any parallel trend violations in the post-period to be as large as the maximum pre-treatment violation, the 90% confidence intervals for the bounded treatment effect do not include zero. Period: 6 April 2010 and 5 April 2013.

The graphical outputs from the Rambachan and Roth (2022) approach, where we use the Relative Magnitude approach for bounding, are presented in Figure A2. Although the ratio of the period 3 to period 1 rating coefficients in Table A3 are large, the "breakdown values" of $\overline{M}$ – the factor of the pre-trends at which the bounds on the estimated treatment effect overlap with zero – are surprisingly low in some cases. This appears to be more a factor of the imprecisely estimated period 1 ratings premiums, rather that the point estimates being excessively large of these premiums. Put differently, the confidence interval of the worst-case bounds include zero for three out of the four cases at $\overline{M} = 1$.

A.2 Stable Group Composition

In order to use difference in differences with repeat cross-sectional data, we also require stability of the composition of the groups across time. If treatment group composition varies over time, the DD estimator will not identify the ATT, but rather some other parameter (Blundell and

Dias, 2009) – we will conflate compositional changes with the ATT.

In order to assess the stability of groups over time, we present the results from a series of balance tests in Table A4 for England and Wales, and Table A5 for London. In this analysis, we account for spatiotemporal variables, but not property characteristics. We do so to account for the fact that properties with different rating categories will not be randomly distributed across areas, and that different areas may experience different housing market cycles. We do not want to conflate these spatiotemporal factors with property characteristics.

Of the 54 balance tests we present, 3 are significant at the 5% level. Given that 3/54=.056, we ascribe this to sampling error, and conclude that the group composition is stable for both England and Wales, and London.

Table A4: Balance Tests - England and Wales

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Control Group			**Treatment Groups**					
	Category C			**Category B**			**Category D**		
	Pre Period	Post Period	*p*-value: Difference	Pre Period	Post Period	*p*-value: Difference	Pre Period	Post Period	*p*-value: Difference
Sample Size	109785	107074		9577	7863		228036	243652	
Property Type:									
Detached	.191	.168	[.029]	.0138	.0112	[.722]	.255	.261	[.376]
	(.00529)	(.00542)		(.00343)	(.00411)		(.00378)	(.00354)	
Semi-Detached	.235	.237	[.854]	.0337	.0205	[.265]	.322	.322	[.976]
	(.00563)	(.00578)		(.00559)	(.00649)		(.00426)	(.00399)	
Terraced	.292	.309	[.191]	.0871	.104	[.527]	.305	.311	[.449]
	(.00626)	(.00642)		(.0121)	(.0143)		(.00398)	(.00373)	
Flat	.281	.286	[.640]	.865	.865	[.980]	.118	.106	[.015]
	(.00505)	(.00519)		(.0125)	(.0148)		(.00258)	(.00241)	
Leasehold	.326	.329	[.817]	.878	.882	[.890]	.162	.153	[.089]
	(.00539)	(.00553)		(.0127)	(.015)		(.00294)	(.00275)	
Building Age	1976	1975	[.153]	1999	2000	[.786]	1950	1950	[.238]
	(.419)	(.431)		(.748)	(.872)		(.333)	(.313)	
Number of Rooms	4.35	4.28	[.100]	2.97	3.01	[.674]	4.69	4.72	[.311]
	(.0234)	(.024)		(.0504)	(.0596)		(.0141)	(.0132)	
Total Floor Area	87.5	83.5	[.002]	64.9	69.7	[.268]	91.5	91.7	[.805]
	(.64)	(.654)		(2.01)	(2.39)		(.356)	(.333)	
Main Fuel is Gas	.886	.89	[.613]	.664	.696	[.548]	.917	.919	[.580]
	(.00427)	(.00437)		(.0246)	(.029)		(.00222)	(.00208)	

Notes: Means and standard erors (in parentheses) are shown. *p*-values are based on OLS regressions with Eicker-Huber-White standard errors. We do not control for any household-level characteristics in the balance test regressions, but we do account for the following spatiotemporal variables: Neighborhood Fixed Effects, Wider Neighborhood Time Trends and Region-by-Month-by-Year Fixed Effects.

Table A5: Balance Tests - London

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Control Group			**Treatment Groups**					
	Category C			**Category B**			**Category D**		
	Pre Period	Post Period	p-value: Difference	Pre Period	Post Period	p-value: Difference	Pre Period	Post Period	p-value: Difference
Sample Size	15285	15022		2295	2020		28987	30638	
Property Type:									
Detached	.0134	.0271	[.092]	.00137	.00146	[.870]	.0419	.0402	[.865]
	(.00404)	(.00418)		(.000546)	(.000623)		(.00525)	(.00498)	
Semi-Detached	.0458	.0556	[.455]	.00361	.00314	[.599]	.18	.168	[.502]
	(.00658)	(.00673)		(.000777)	(.000779)		(.01)	(.00946)	
Terraced	.188	.223	[.186]	.00558	.0216	[.600]	.366	.398	[.182]
	(.0133)	(.0136)		(.0146)	(.0162)		(.0126)	(.012)	
Flat	.753	.695	[.037]	.989	.974	[.610]	.412	.394	[.449]
	(.0141)	(.0144)		(.0147)	(.0163)		(.0123)	(.0116)	
Leasehold	.76	.712	[.083]	.982	.986	[.847]	.418	.415	[.923]
	(.0138)	(.0141)		(.0116)	(.013)		(.0123)	(.0116)	
Building Age	1959	1959	[.927]	1995	1993	[.419]	1926	1929	[.264]
	(1.54)	(1.57)		(1.39)	(1.49)		(1.09)	(1.03)	
Number of Rooms	3.37	3.36	[.913]	2.71	2.68	[.884]	4.18	4.2	[.828]
	(.0496)	(.0505)		(.0902)	(.099)		(.0435)	(.0413)	
Total Floor Area	75.5	71.5	[.189]	67.3	63.9	[.657]	86.3	86.4	[.936]
	(1.53)	(1.55)		(3.7)	(3.98)		(1.11)	(1.05)	
Main Fuel is Gas	.82	.84	[.487]	.706	.606	[.259]	.939	.931	[.461]
	(.0141)	(.0143)		(.0429)	(.0465)		(.00568)	(.00541)	

Notes: Means and standard erors (in parentheses) are shown. p-values are based on OLS regressions with Eicker-Huber-White standard errors. We do not control for any household-level characteristics in the balance test regressions, but we do account for the following spatiotemporal variables: Neighborhood Fixed Effects, Wider Neighborhood Time Trends and Region-by-Month-by-Year Fixed Effects.

B Summary Statistics and Ancillary Results

B.1 Summary Statistics

Figure B1: Energy Efficiency Score by Age Bands

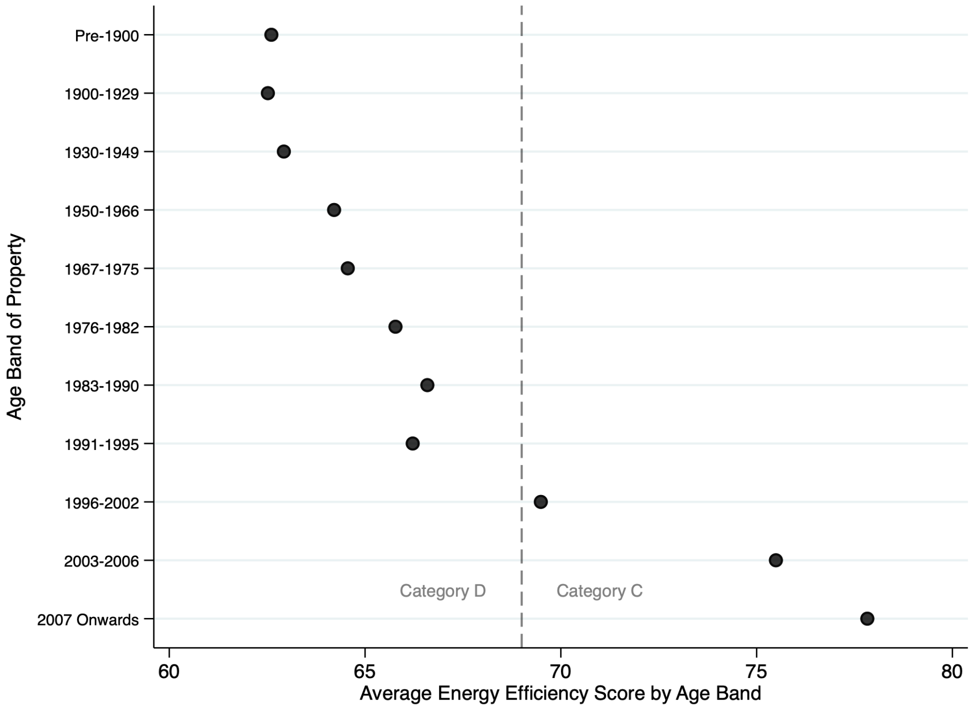


Table B1: Summary Statistics

	England and Wales		London	
	Mean	Standard Deviation	Mean	Standard Deviation
Sale Price (£s)	222811	230842	400445	484138
EPC Category:				
B Rating	0.02	0.16	0.05	0.21
C Rating	0.31	0.46	0.32	0.47
D Rating	0.67	0.47	0.63	0.48
Property Type:				
Detached	0.23	0.42	0.03	0.18
Semi-Detached	0.29	0.45	0.13	0.33
Terraced	0.30	0.46	0.31	0.46
Flat	0.18	0.39	0.53	0.50
Leasehold	0.23	0.42	0.54	0.50
Building Age	1959	41	1941	47
Number of Rooms	4.55	1.64	3.86	1.59
Total Floor Area	89.19	40.59	81.31	40.06
Main Fuel is Gas	0.90	0.30	0.89	0.31

Notes: Time Period: 6 April 2011 - 5 April 2013.

Figure B2: EPC Rating Distribution

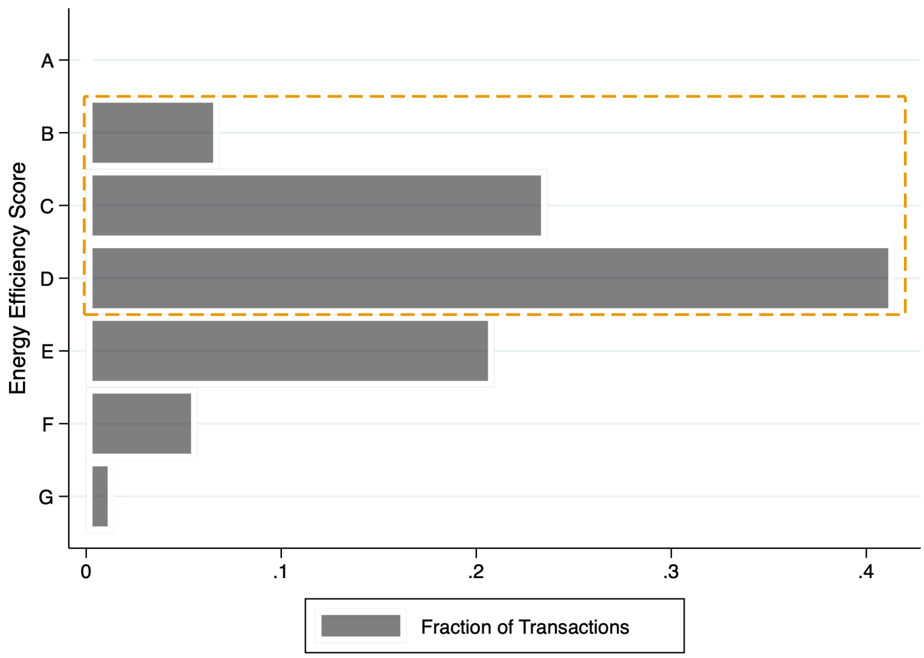
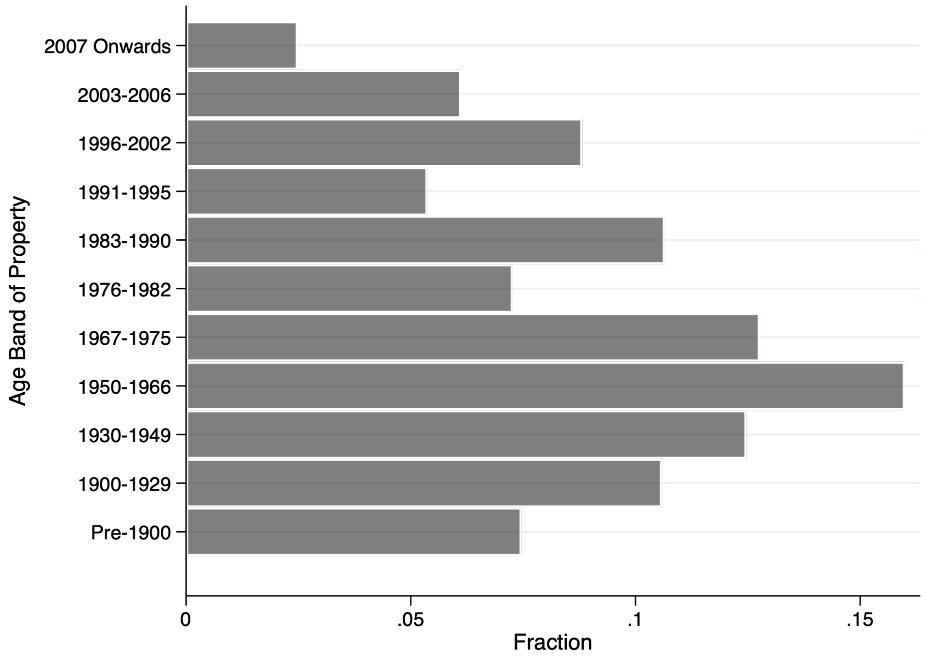


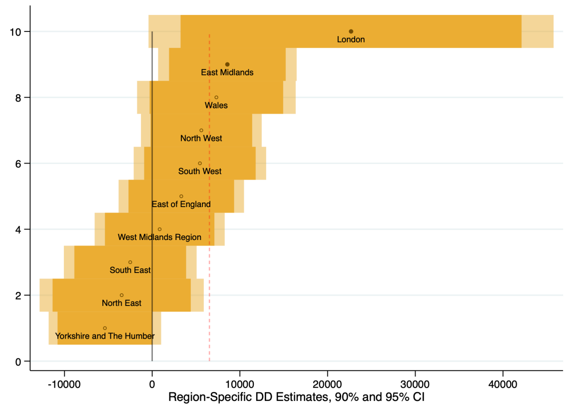
Figure B3: Building Age Bands



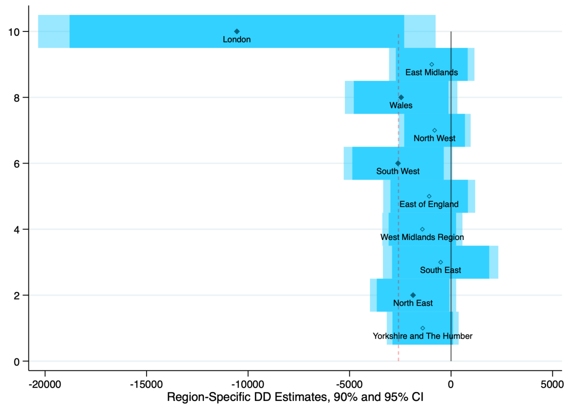
B.2 Region-Specific Estimates

B.2.1 Region-Specific DD Estimates

Figure B4: Region-specific Main DD estimates

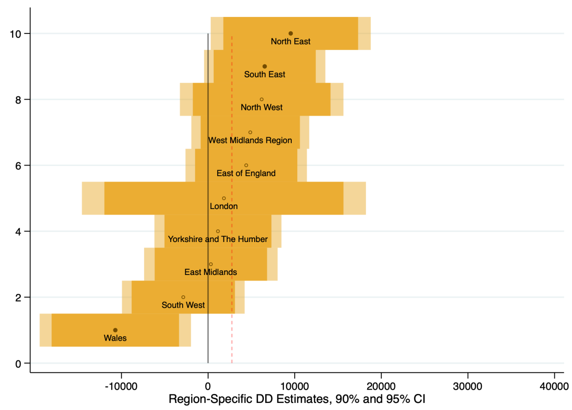


(a) B rating

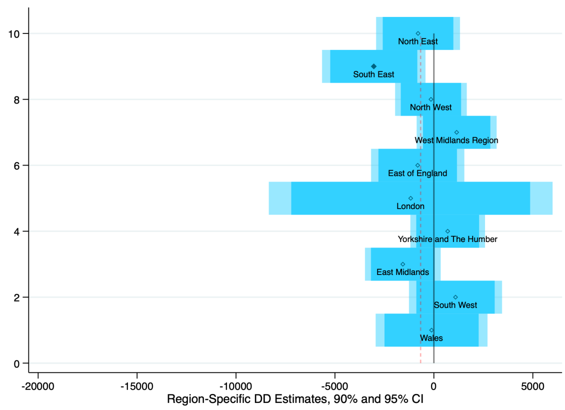


(b) D rating

Figure B5: Region-specific Placebo DD estimates



(a) B rating



(b) D rating

B.2.2 Country-wide Analysis With the London Region Removed

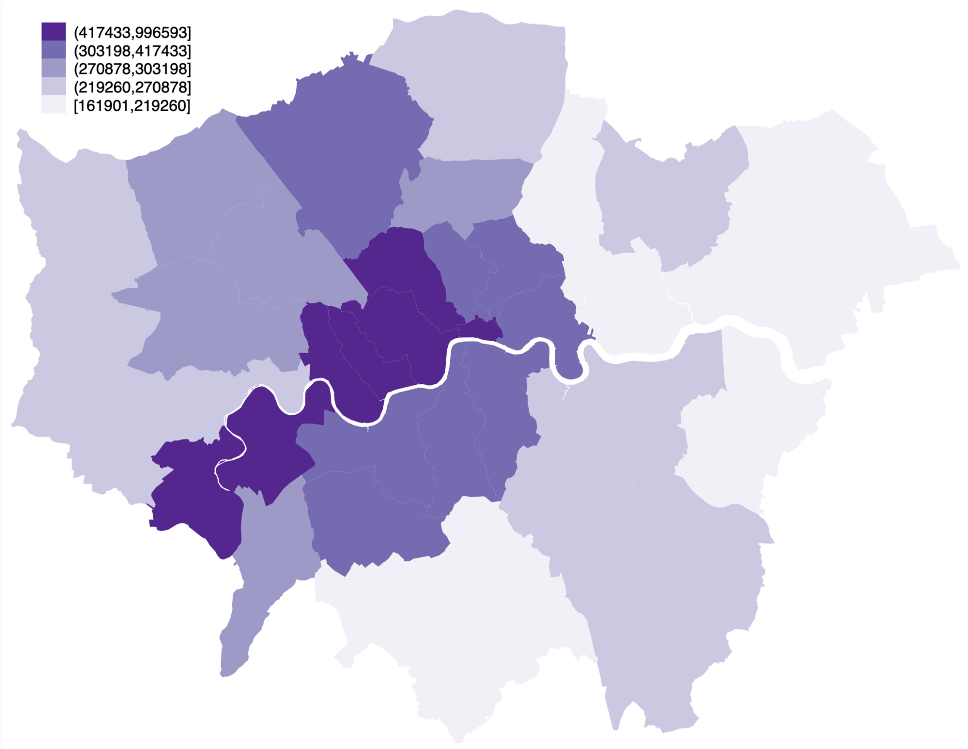
Table B2: DD Estimates from Introduction of EPC certificates – All Regions Except London

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
B Rating × Post	137	363	503	1431	1486	1247	1501
	(1892)	(1820)	(1723)	(1648)	(1646)	(1564)	(1577)
D Rating × Post	−1185**	−1312**	−1657***	−1474***	−1468***	−1191**	−1221***
	(571)	(546)	(524)	(490)	(490)	(466)	(469)
$\overline{Y}_{C,PRE}$	184934	184934	184934	184934	184934	184934	184934
(B Rating × Post)/$\overline{Y}_{C,PRE}$	.000742	.00196	.00272	.00774	.00804	.00674	.00812
(D Rating × Post)/$\overline{Y}_{C,PRE}$	-.00641**	-.00709**	-.00896***	-.00797***	-.00794***	-.00644**	-.0066***
Spatial FEs	TTWA	District	District	Wider NH	Wider NH	NH	NH
Local Time Trends					District		Wider NH
X Interactions	TTWA×	TTWA×	District×	District×	District×	District×	District×
	Post×X	Post×X	Post×X	Post×X	Post×X	Post×X	Post×X
Adjusted R^2	.628	.663	.687	.733	.733	.764	.764
Observations	611,068	611,067	611,077	611,077	611,077	610,994	610,994

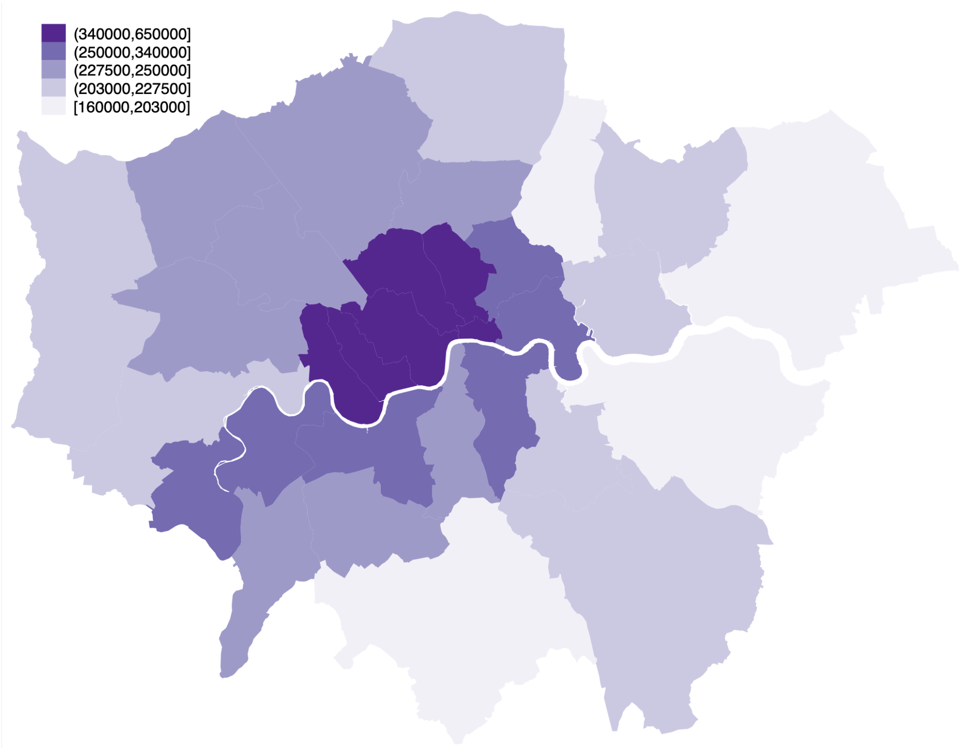
Notes: *** denotes significance at 1%, ** at 5%, and * at 10%. The dependent variable in all regressions is the house price in £. The estimation sample is based on a +/-1 year window of sales dates around April 6, 2012. We restrict our attention to EPC ratings of B-D, which comprise .72 of the full sample.

B.2.3 Mapping District-Level House Prices in London

Figure B6: Mapping District-Level House Prices in London



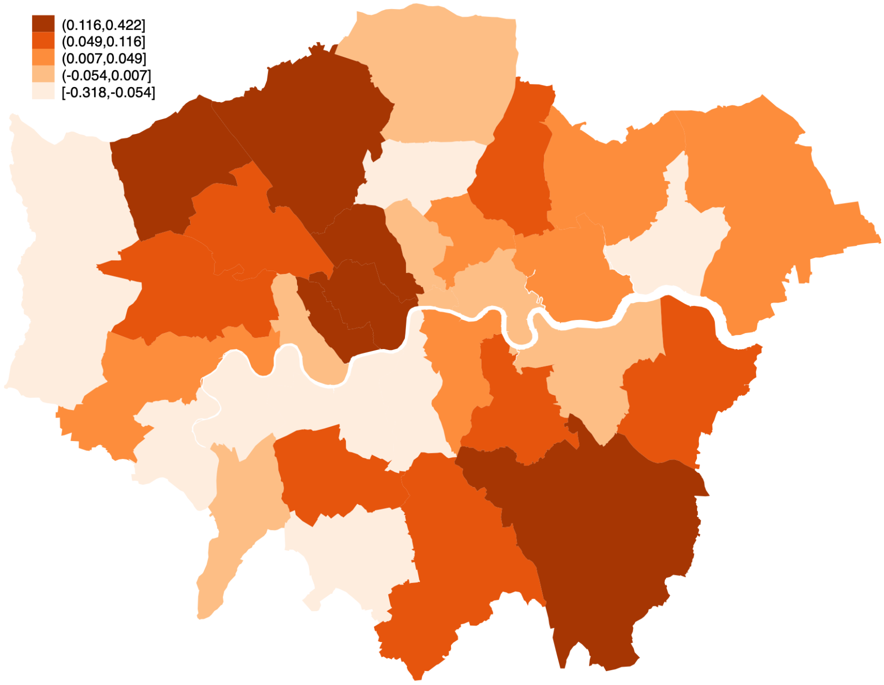
(a) Mean Prices



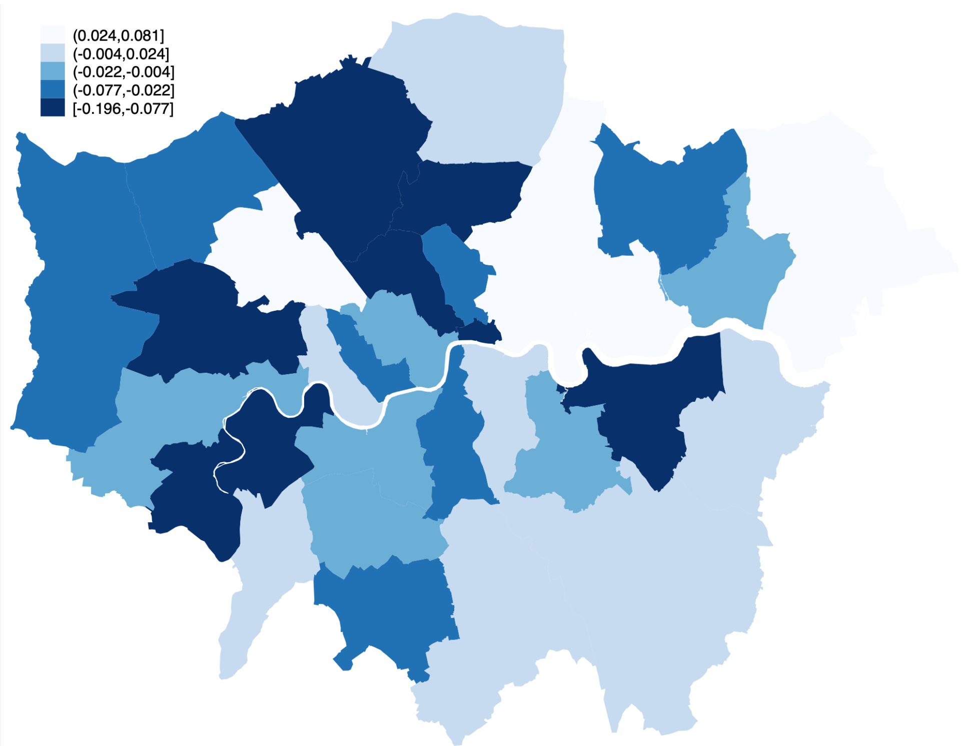
(b) Median Prices

B.2.4 Mapping District-Level DD Estimates in London

Figure B7: Mapping District-Level House Prices in London



(a) District-Specific DD Estimates: B-Rating



(b) District-Specific DD Estimates: D-Rating

B.3 Sensitivity Analysis

B.3.1 Sensitivity Analysis – EPBR 2012

The EPBR 2012 amendment came into force on 9 January 2013. This amendment obviated the need for sellers to display the entire frontpage of the EPC in marketing material, but still required any marketing material to display the EPC letter rating and numerical score.[20] If we assume houses are marketed once the EPC inspection is lodged on the EPC register, we find that only 1.19% of post-period transactions in our main sample are marketed after the introduction of the 2012 amendment. In the analysis below we repeat our core analysis, but remove sales in the post period where the EPC inspection was lodged on or after January 9 2013. As we are working with a repeat cross section DD specification, we are ever mindful of the need to impose symmetric restrictions in both periods. Hence, in addition to the sample restriction we note for the post period, we additionally remove pre-period transactions where the EPC inspection was lodged on or after January 9 2012. We present the results of this sensitivity analysis both for England and Wales in Table B3 and for London in Table B4. None of our core results change.

Table B3: DD Estimates from Introduction of EPC certificates – England and Wales

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
B Rating × Post	11681***	8888**	6482*	6430**	6462**	6450**	6600**
	(4443)	(4158)	(3476)	(3194)	(3193)	(3071)	(3103)
D Rating × Post	–2715**	–2618***	–3005***	–2685***	–2690***	–2629***	–2641***
	(1099)	(1010)	(826)	(779)	(779)	(787)	(793)
$\overline{Y}_{C,PRE}$	208176	208176	208176	208176	208176	208176	208176
(B Rating × Post)/$\overline{Y}_{C,PRE}$	.0561***	.0427**	.0311*	.0309**	.031**	.031**	.0317**
(D Rating × Post)/$\overline{Y}_{C,PRE}$	-.013**	-.0126***	-.0144***	-.0129***	-.0129***	-.0126***	-.0127***
Spatial FEs	TTWA	District	District	Wider NH	Wider NH	NH	NH
Local Time Trends					District		Wider NH
X Interactions	TTWA× Post×X	TTWA× Post×X	District× Post×X	District× Post×X	District× Post×X	District× Post×X	District× Post×X
Adjusted R^2	.458	.558	.69	.737	.737	.759	.759
Observations	694,795	694,795	694,795	694,795	694,795	694,795	694,795

Notes: *** denotes significance at 1%, ** at 5%, and * at 10%. The dependent variable in all regressions is the house price in £. The estimation sample is based on a +/-s year window of sales dates around April 6, 2012. We restrict our attention to EPC ratings of B-D, which comprise the majority (.718) of the full sample.

[20] Source: `https://www.legislation.gov.uk/uksi/2012/3118/regulation/11/made`.

Table B4: DD Estimates from Introduction of EPC certificates – London Only

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
B Rating × Post	41734**	30848*	25788*	22568*	22428*	22611*	22357*
	(16985)	(15827)	(13356)	(12125)	(12120)	(11663)	(11808)
D Rating × Post	–14662**	–12260*	–10773**	–9395*	–9454*	–10992**	–10872**
	(7079)	(6427)	(5116)	(4852)	(4846)	(5022)	(5085)
$\overline{Y}_{C,PRE}$	351,492	351,492	351,492	351,492	351,492	351,492	351,492
(B Rating × Post)/$\overline{Y}_{C,PRE}$	.119**	.0878*	.0734*	.0642*	.0638*	.0643*	.0636*
(D Rating × Post)/$\overline{Y}_{C,PRE}$	-.0417**	-.0349*	-.0307**	-.0267*	-.0269*	-.0313**	-.0309**
Spatial FEs	TTWA	District	District	Wider NH	Wider NH	NH	NH
Local Time Trends					District		Wider NH
X Interactions	TTWA× Post×X	TTWA× Post×X	District× Post×X	District× Post×X	District× Post×X	District× Post×X	District× Post×X
Adjusted R^2	.298	.446	.641	.696	.696	.717	.718
Observations	92,710	92,710	92,710	92,710	92,710	92,710	92,710

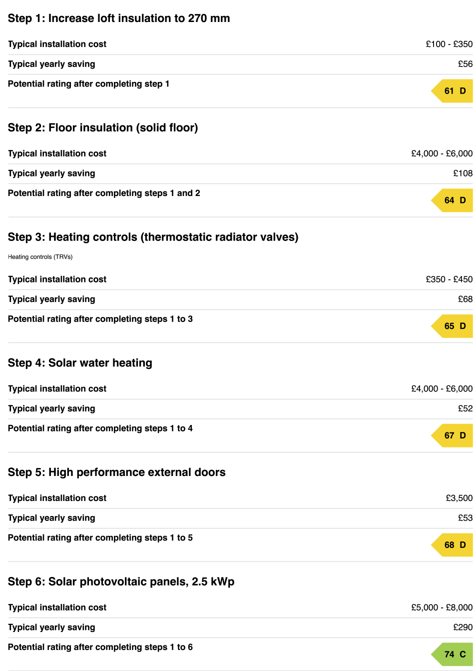
Notes: *** denotes significance at 1%, ** at 5%, and * at 10%. The dependent variable in all regressions is the house price in £. The estimation sample is based on a +/-s year window of sales dates around April 6, 2012. We restrict our attention to EPC ratings of B-D, which comprise .715 of the full sample.

B.4 Cost Benchmark Construction

We calculate the costs as follows. We sum the cost estimates for all assessor recommendations – if all of these recommendations were implemented, the proeprty would move from the current to the potenital energy efficiency score. We then calculate the distance between the property's potential and current energy efficincy score. Dividing the sum of the cost estimates by the energy score gap yields a property-specific estimated cost per additional energy efficiency score. We consider all D-rated and C-rated properties respectively, and calculate two different measures for improving the rating of these properties – moving from the current score to the lowest score in the next category, and moving from the current category midpoint to the next category midpoint. With the estimated cost per score improvement, we can cost the two score improvements we consider in Table 3, namely: (i) moving from ones current score to the lowest score in the next EPC category and (ii) moving from the mean score of one's current EPC category to the mean score of the next EPC category.

To elucidate these steps, take the EPC excerpt from a property in South London suburbia, listed in Figure B8 below. The property has an EPC score of 60 – a low scoring D-rated property – and a potential EPC score of 74 – a mid-range score for category C. The energy score gap in this case is 14, and the mid-range cost estimate required to achieve the potential EPC score for the property (which entails making all of the improvements as suggested below) totals £20,625 (minimum estimate:£16,950, maximum estimate: 24300). This means estimated cost per score improvement for this property is (£20,625 / 14 = £1,473.21). Tka We calculate the estimated

Figure B8: Suggested Energy Efficiency Improvements from the EPC


Step 1: Increase loft insulation to 270 mm

Typical installation cost	£100 - £350
Typical yearly saving	£56
Potential rating after completing step 1	61 D

Step 2: Floor insulation (solid floor)

Typical installation cost	£4,000 - £6,000
Typical yearly saving	£108
Potential rating after completing steps 1 and 2	64 D

Step 3: Heating controls (thermostatic radiator valves)

Heating controls (TRVs)

Typical installation cost	£350 - £450
Typical yearly saving	£68
Potential rating after completing steps 1 to 3	65 D

Step 4: Solar water heating

Typical installation cost	£4,000 - £6,000
Typical yearly saving	£52
Potential rating after completing steps 1 to 4	67 D

Step 5: High performance external doors

Typical installation cost	£3,500
Typical yearly saving	£53
Potential rating after completing steps 1 to 5	68 D

Step 6: Solar photovoltaic panels, 2.5 kWp

Typical installation cost	£5,000 - £8,000
Typical yearly saving	£290
Potential rating after completing steps 1 to 6	74 C

cost per score improvement for each property, as well as the distance to the next EPC category, and then take the average, by area and by initial EPC category. This yields the key inputs to create the costings presented in Table 3.

C Homeowner Responses – Additional Results

C.1 Placebo Tests – Medium-Run Repeat Inspections

In this sub-section we provide evidence that the parallel trends assumption hold for the medium-run inspection outcomes. We present placebo regressions in , where we shift all key dates one year back in time. Here the $Post_t$ term takes value zero for the period 6 April 2010-5 April 2011, and one for the period 6 April 2011-5 April 2012. We control for the same variables, and include the same fixed effects.

We find one coefficient (out of sixteen) to be significant at the ten percent level in these regressions. We interpret the overall pattern as supportive of the parallel trends assumption.

Table C1: Owners of D-Rated Properties are More Likely to Get Another Inspection in the Medium-Run

	(1)	(2)	(3)	(4)
	Repeat Inspection Within:			
	6 Months	12 Months	18 Months	24 Months
A.) England and Wales				
B Rating × Post	-.00108	-.00152	-.00078	-.00161
	(.00119)	(.00154)	(.00184)	(.00203)
D Rating × Post	-.000324	-.000927*	-.000497	.000339
	(.000385)	(.000529)	(.000624)	(.000702)
$\overline{Y}_{C,PRE}$	.00813	.0161	.0238	.031
(B Rating × Post)/$\overline{Y}_{C,PRE}$	-.133	-.0944	-.0328	-.0521
(D Rating × Post)/$\overline{Y}_{C,PRE}$	-.0398	-.0574*	-.0209	.011
Observations	1,097,226	1,097,226	1,097,226	1,097,226
B.) London Only				
B Rating × Post	-.00071	.00086	-.000066	-.00107
	(.00301)	(.00369)	(.00424)	(.00463)
D Rating × Post	-.000474	-.00147	-.00176	-.000238
	(.00129)	(.00169)	(.00194)	(.00214)
$\overline{Y}_{C,PRE}$	.0114	.0199	.0271	.0349
(B Rating × Post)/$\overline{Y}_{C,PRE}$	-.0623	.0432	-.00245	-.0308
(D Rating × Post)/$\overline{Y}_{C,PRE}$	-.0416	-.0737	-.0648	-.00683
Observations	139,199	139,199	139,199	139,199

Notes: *** denotes significance at 1%, ** at 5%, and * at 10%. The estimation sample is based on properties assessed for an EPC within a +/-1 year window around April 6, 2011. We restrict our attention to EPC ratings of B-D, which respectively comprise and of the National and London samples.

C.2 Short-Run Repeat Inspections

If homeowners preparing to market their property were to attempt to game the EPC inspection system, we would expect to see multiple inspections within a short timeframe. In response to a borderline EPC score that falls below a rating threshold, a seller may be willing to pay for a second inspection soon after, in the hope of achieving a slightly higher score. We investigate the possibility of such "shopping around" for a better rating in Table C2. We find no evidence that sellers attempt to game the EPC inspection system.

Table C2: The Lack of a Short-Run Response Suggests Homeowners do not Shop Around for a Better EPC Rating

	(1)	(2)	(3)	(4)	(5)
	Repeat Inspection Within:				
	7 Days	10 Days	14 Days	21 Days	28 Days
A.) England and Wales					
B Rating × Post	.000586	.000703	.000869	.00106	.00112
	(.00053)	(.000551)	(.000604)	(.000678)	(.000723)
D Rating × Post	4.1e-06	.000079	.000098	.000043	-.000056
	(.000139)	(.000151)	(.000164)	(.000182)	(.000195)
$\overline{Y}_{C,PRE}$	.00114	.00138	.00161	.00195	.00221
(B Rating × Post)/$\overline{Y}_{C,PRE}$	.514	.508	.541	.544	.509
(D Rating × Post)/$\overline{Y}_{C,PRE}$	.00361	.0568	.0611	.0221	-.0255
Observations	1,052,927	1,052,927	1,052,927	1,052,927	1,052,927
B.) London Only					
B Rating × Post	-.000517	-.000283	.000514	.000936	.000745
	(.00124)	(.00126)	(.00142)	(.00152)	(.00171)
D Rating × Post	-.000178	.000068	3.5e-06	.00056	.000686
	(.000508)	(.000546)	(.000598)	(.000653)	(.000702)
$\overline{Y}_{C,PRE}$	.00198	.00232	.00275	.00348	.0041
(B Rating × Post)/$\overline{Y}_{C,PRE}$	-.261	-.122	.187	.269	.181
(D Rating × Post)/$\overline{Y}_{C,PRE}$	-.0898	.0295	.00126	.161	.167
Observations	132,332	132,332	132,332	132,332	132,332

Notes: *** denotes significance at 1%, ** at 5%, and * at 10%. The estimation sample is based on properties assessed for an EPC within a +/-1 year window around April 6, 2012. We restrict our attention to EPC ratings of B-D, which respectively comprise and of the National and London samples.

C.3 Medium Run Score and Ratings changes

In Table 4 we document that homeowners of D-rated properties are more likely to have their property reassessed in the medium run – up to two years after a given inspection. A key reason for a repeat inspection within this timeframe is that homeowners have made energy efficiency enhancing improvements of their properties. In this section, we focus on properties that are assessed twice within a two year timeframe, and investigate whether we find evidence of home improvements – specifically we look at changes in EPC ratings, as well as the scores that underlie these rating bands.

To do so, we estimate a specification of the form:

$$\Delta EPC_{it} = \sum_{k \neq C}^{K} \alpha_k Category_k + \sum_{k \neq C}^{K} \beta_k (Post_t \times Category_k) + X_i^{'} \gamma + \pi_{r \times t} + \theta_n + \epsilon_{it} \ , \qquad (5)$$

where ΔEPC_{it} is equal to either $\Delta EPC\,Score_{it}$ or $\Delta EPC\,Rating_{it}$. We present the results for score changes in Table C3 and for ratings changes in Table C4. Given that we only consider properties with repeat assessments in a short time-frame here, we have very small samples compared to the main analysis, and we run into power-related issues here. Given these hurdle, we are unable to say anything with much statistical certitude. We do however note, that the score changes we document for D-rated properties are highly consistent and positive over the various inspection windows that we consider. Hence homeowners of lower rated properties may well be making energy efficient investments on their properties – we just cannot conclude as such with strong statistical certainty.

Table C3: EPC Score Changes as a Result of an Additional Inspection

	(1)	(2)	(3)	(4)
	EPC Score Change | Repeat Inspection Within:			
	6 Months	12 Months	18 Months	24 Months
A.) England and Wales				
B Rating × Post	-.0966	-.431	.521	-.478
	(5.25)	(3.18)	(2.19)	(1.71)
D Rating × Post	.0704	.459	.538	.212
	(2.29)	(1.01)	(.679)	(.494)
$\overline{\text{Score}}_{C,PRE}$	73	72.9	73	72.9
(B Rating × Post)/$\overline{Y}_{C,PRE}$	-.00132	-.00591	.00713	-.00656
(D Rating × Post)/$\overline{Y}_{C,PRE}$	.000964	.0063	.00737	.00291
Observations	7,445	13,924	19,696	25,297
B.) London Only				
B Rating × Post	.158	.726	2.59	2.85
	(6.51)	(4.37)	(3.43)	(2.68)
D Rating × Post	-.595	.287	1.73	1.3
	(3.37)	(2.11)	(1.6)	(1.28)
$\overline{\text{Score}}_{C,PRE}$	73.6	73.5	73.5	73.5
(B Rating × Post)/$\overline{Y}_{C,PRE}$	.00214	.00989	.0353	.0389
(D Rating × Post)/$\overline{Y}_{C,PRE}$	-.00808	.0039	.0236	.0177
Observations	1,339	2,252	3,036	3,731

Notes: *** denotes significance at 1%, ** at 5%, and * at 10%. The estimation sample is based on properties assessed for an EPC within a +/-1 year window around April 6, 2012. We restrict our attention to EPC ratings of B-D, which respectively comprise and of the National and London samples.

Table C4: EPC Rating Changes as a Result of an Additional Inspection

	(1)	(2)	(3)	(4)
	EPC Rating Change | Repeat Inspection Within:			
	6 Months	12 Months	18 Months	24 Months
A.) England and Wales				
B Rating × Post	-.0575	-.0147	.06	-.00535
	(.533)	(.284)	(.19)	(.146)
D Rating × Post	-.0487	.0164	.0438	.0111
	(.191)	(.0831)	(.0551)	(.0407)
$\overline{\text{Rating}}_{C,PRE}$	C	C	C	C
Observations	7,445	13,924	19,696	25,297
B.) London Only				
B Rating × Post	-.0133	.0276	.186	.16
	(.623)	(.397)	(.301)	(.232)
D Rating × Post	-.149	-.019	.0931	.0376
	(.276)	(.167)	(.125)	(.1)
$\overline{\text{Rating}}_{C,PRE}$	C	C	C	C
Observations	1,339	2,252	3,036	3,731

Notes: *** denotes significance at 1%, ** at 5%, and * at 10%. The estimation sample is based on properties assessed for an EPC within a +/-1 year window around April 6, 2012. We restrict our attention to EPC ratings of B-D, which respectively comprise and of the National and London samples.

D Data Appendix

D.1 Details on Institutional Background

Within the EU the main directive to monitor energy performance of buildings is the Energy Performance of Buildings Directive (EPBD). Influenced by the Kyoto protocol, the first version of the directive (2002/91/EC) was implemented in December, 2002 (The European Parliament and the Council of the Europian Union, 2003). The objective of this directive was to foster improvement of energy efficiency of buildings allowing for the outdoor and local climatic conditions along with the indoor climatic requirement and budget constraints. This directive was later replaced by the EPBD Directive (2010/31/EU) which was implemented on 18th of June, 2010 (The European Parliament and the Council of the Europian Union, 2010). This directive requires energy performance certificates (EPC) to be displayed in the advertising for all real estate sales or rentals across the EU and it is the primary legal framework for improving housing energy efficiency in the EU (Committee on Industry, Research and Energy: European Parliament, 2021).[21] However the member states have implemented energy performance ratings requirements in different times. For example, Denmark was one of the first country to adopt the EPBD 2002 directive (Jensen et al., 2016), however brought in the mandatory disclosure of EPC ratings only in July 2012 (Thomsen et al., 2016). France has implemented the mandatory inclusion of EPC information in property marketing on 1st of January, 2011 (Bordier et al., 2016). In Germany the requirement to include energy performance ratings in advertisement came in effect on 2013 (Schettler-Köhler et al., 2016). The policy we study in this paper is not an isolated one, but similar policies have been implemented across Europe.[22] Crucially, the EPBR 2007 in the UK was implemented in response to the EPBD 2002 directive (Department for Levelling Up, Housing and Communities and Ministry of Housing, Communities & Local Government, 2007) and similarly EPBR 2011 was response to the EPBD 2010.[23]

At this point, it is important to note that EPCs are an intriguing hybrid of both a regulatory- and a market-based approach to improving the energy efficiency of buildings. The EPBR 2007 established the regulatory framework that mandated the provision of detailed energy efficiency information to potential buyers. The 2011 amendment was important in that the amended regulations required this information to be prominent and salient at the *start* of the home-buying process. With the regulatory framework in place, the market could respond to the new information – owners of energy efficient homes would be rewarded by the market, and owners of inefficient homes would be penalized. This created incentives for owners of energy inefficient properties to invest in energy efficient upgrades in their properties.

We now briefly detail the process of obtaining EPCs and the energy rating scales in the context of the UK. EPCs are required to contain information on property address, property type,

[21]There has been two major revisions to this amendment, i.e., Directive 2012/27/EU and Directive (EU) 2018/844, both on long term actions to renovate national building stocks in the member states.

[22]It is important to note here that the EPBD 2010 directive provided a two year time frame in which member states needed to implement the laws (European Union Law, 2021), however member states in reality implemented this at different points in time and sometimes with regional responsibilities within the country (like Belgium) (Concerted Action: Energy Performance of Buildings, European Union, 2013).

[23]Explanatory Note: `https://www.legislation.gov.uk/uksi/2011/2452/made`

date of inspection, certificate date and serial number, total floor area, as well as recommendations on ways to improve the property's energy efficiency. The energy assessment, which is a non-invasive procedure, is required to be performed by a qualified and accredited energy assessor. The assessor visits the property and notes the key characteristics such as boiler, cavity walls, floor insulation, radiator, heating, glazing of windows etc. These observations are used to calculate the rating of energy efficiency through a software programme. This survey is paid for by the householder and costs (for a typical four bedroom house) approximately £60 -£120, depending on locations. The EPCs assign a number to the property ranging from 1-100, higher number denotes that the property is more energy efficient. The numbers are categorized in 7 scale ratings. The ratings range from A (most energy efficient) to G (least energy efficient). The scale below shows the relation between the EPC scores and rating scales. EPC regulations have been subjected to many criticisms and controversy as the procedure is non-invasive and often relies on the assessor's subjective judgements. Moreover, as improvements in listed buildings are often barred, it poses problems to rectify low EPC ratings.

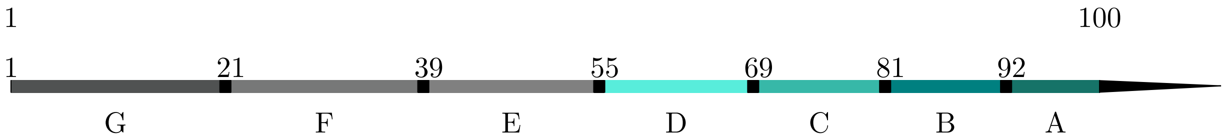


Table D1: Time line of EPC regulations for England and Wales

2007	01 August: EPC mandatory for marketed sales of houses in a phased approach.
2008	06 April: All new-built homes require EPC upon completion. 01 Oct: All home sales (including non-marketed), rentals, and non-domestic properties (built, rented or sold) require an EPC.
2009	10 August: Data quality improvement for register lodgement.
2010	21 May: Validity of EPC extended from 3 to 10 years.
2011	April: Change in EPC calculations where insufficient data is available for the building but not for the site.
2012	06 April: A copy of the first page of EPC has to be attached with all types of properties for marketing.
2013	09 Jan: Energy efficiency rating is mandatory at advertisement, first page need not be included. New provision for EPCs to include information about Green Deal plans, and that information also has to be stored on the EPB Register*.
2014	06 April: Allows data from the register to be disclosed to specific persons for particular purposes.
2015	April: Further changes to the disclosure requirements.
2016	June: Open access data from the register for greater transparency.
2017	April: Extending the list of data items that may be published online.
2018	01 April: Illegal to let (or renew lease) residential or commercial properties with EPC F or G. Domestic properties to reach EPC E by April 2020 and non-domestic by 2023. 06 April: Changes to the disclosure requirements for statistical and research purposes.
2020	28 Dec: Inspections to include consideration of the air conditioning system to optimise performance under typical conditions.

Notes: This table shows the regulations for domestic and commercial properties and not public buildings. Consolidated with the key points from the UK statutory instruments from the The National Archives (2021) and Department for Levelling Up, Housing and Communities and Ministry of Housing, Communities and Local Government (2021). *It also combined and therefore revoked earlier amendments of 2007 (other phased amendments, not included here), 2008 (Oct), 2009, and 2010 together.

The EPB regulations of 2007 have been amended multiple times. For example, from 6th of April, 2008 all domestic and non-domestic properties for sale or rent (including new builds) were required to have an EPC. In 2010, the validity of EPCs were extended from 3 years to 10 years. The table above details the different regulations that came into force regarding EPC disclosure requirements in England and Wales from 2007. In one of the recent changes in 2018, it became illegal to rent or lease properties with F or G EPC ratings and guidelines were set for all domestic and non-domestic properties to improve their ratings to at minimum to E. The EPBR 2011 regulation that we study in this paper warranted a front page of EPC to be attached with all marketing materials of properties for sale or rent.[24] Figure D1 is such an example front page of EPC.

D.2 Details on data and matching

In our approach, we follow an extremely conservative approach to link these two databases. Given that the EPC data began to be released in 2008, we restrict our attention to the time range of 2008–2021. The key challenge to this data merging is that addresses are recorded in a non-standardized way across and within the two datasets. But especially more so in the EPC data as the addresses are entered by the energy assessors. In order to carry out the address standardization, we use three sets of addresses available in the price paid data - 1) address, 2) address with locality, 3) Primary Addressable Object Name (PAON- this field often has the entire address listed). There is existing evidence that addresses in the EPC register often are recorded with a lot of manual errors (Hardy and Glew, 2019). Consequently, we perform a series of text manipulations on the address fields of EPC dataset to reduce possibilities of mis-recording of addresses. In order to treat the data correctly, we follow the address nomenclatures present in the price paid dataset. This included replacing all 'apartment' or 'maisonette' to 'flat' (inclusive of all cases), replacing for example, in both datasets uniformly 'FIRST AND SECOND FLOOR FLAT' to 'FIRST FLOOR FLAT', as well as some standard techniques of pre-processing text.

After this we parse and standardize addresses to create a fourth set of address fields for matching (Wasi and Flaaen, 2015). Moreover, we extract the numbers from the string addresses to make four sets of numbered addresses (addresses with one to four numbers) and isolate properties with house names as opposed to numbers. These processes give us address fields in the two datasets, which are similar (if not identical) and can be used for the matching techniques. After these text manipulations in both the raw files, we use the record linkage method (Wasi and Flaaen, 2015) to merge the two datasets.

We begin by separating houses with numbers from those with names and then conducting a merging process formed of four distinct blocks, the first three matching numbered properties and the find block matching named properties. The three numbered blocks differ according to the type of address variable we use, the degree of address standardization and the use of locality to aide differentiating between common addresses.

[24] It is important to note that homeowners also should have used all reasonable efforts to ensure the EPC is obtained within seven days of the marketing, in case a valid EPC for the property did not exist. Only in very limited cases a further 21 days are allowed to if despite all reasonable efforts EPC could not be obtained within seven days of marketing.

For the entire exercise, we use extremely conservative tolerance levels of 0.98 or more. We also give the highest weights to the address numbers (where present) and comparatively less weights to street names (due to high manual error possibilities). The entire matching process consists of 432 distinct stages and achieves a match rate of 86.8%.[25]

[25] Chi et al. (2021) take a slightly different approach to the matching of EPC to Land Registry data, first linking Land Registry data with Ordnance Survey data, and then linking the EPC database. The authors focus on the time period of 2011-2019, and achieve a match rate of a similar magnitude to ours – 79% of the full market sales.

Figure D1: An Example EPC Front Page

Energy Performance Certificate (EPC)

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17 Any Street, District, Any Town, B5 5XX

Dwelling type: Detached house
Date of assessment: 15 August 2011
Date of certificate: 13 March 2012

Reference number: 0919-9628-8430-2785-5996
Type of assessment: RdSAP, existing dwelling
Total floor area: 165 m²

Use this document to:

- Compare current ratings of properties to see which properties are more energy efficient
- Find out how you can save energy and money by installing improvement measures

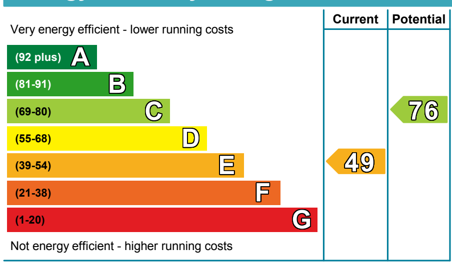
Estimated energy costs of dwelling for 3 years	**£5,367**
Over 3 years you could save	**£2,865**

Estimated energy costs of this home

	Current costs	Potential costs	Potential future savings
Lighting	£375 over 3 years	£207 over 3 years	You could save £2,865 over 3 years
Heating	£4,443 over 3 years	£2,073 over 3 years	
Hot water	£549 over 3 years	£222 over 3 years	
Totals:	**£5,367**	**£2,502**	

These figures show how much the average household would spend in this property for heating, lighting and hot water. This excludes energy use for running appliances like TVs, computers and cookers, and any electricity generated by microgeneration.

Energy Efficiency Rating



The graph shows the current energy efficiency of your home.

The higher the rating the lower your fuel bills are likely to be.

The potential rating shows the effect of undertaking the recommendations on page 3.

The average energy efficiency rating for a dwelling in England and Wales is band D (rating 60).

Top actions you can take to save money and make your home more efficient

Recommended measures	Indicative cost	Typical savings over 3 years	Available with Green Deal
1 Increase loft insulation to 270 mm	£100 - £350	£141	✓
2 Cavity wall insulation	£500 - £1,500	£537	✓
3 Draught proofing	£80 - £120	£78	✓

See page 3 for a full list of recommendations for this property.

To find out more about the recommended measures and other actions you could take today to save money, visit **www.direct.gov.uk/savingenergy** or call **0300 123 1234** (standard national rate). When the Green Deal launches, it may allow you to make your home warmer and cheaper to run at no up-front cost.

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