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Abstract

Shocks to energy prices can have a direct impact on homeowners' disposable income, affecting their ability to pay their mortgage. Properties' energy efficiency can provide some protection against the transition risk of rising energy costs. Anecdotally, lenders appear to be increasingly differentiating mortgage interest rates based on energy efficiency. But did lenders account for it before relevant regulatory interventions came in? We estimate standard mortgage pricing models using a unique data set of 1.8 million mortgages originated in the United Kingdom pre-2018. We find no evidence of lenders charging higher rates on riskier mortgages against energy-inefficient properties. Overall, our findings do not provide conclusive evidence that lenders took energy efficiency into account when setting interest rates prior to regulatory interventions.

Key words: Mortgage pricing, energy efficiency, climate change, transition risk.

JEL classification: G21, Q40.

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1 Introduction

The current dramatic rises in energy prices can put pressure on homeowners' disposable incomes (House of Commons Library, 2022). It has spurred calls for more spending on home insulation and other energy efficiency improvements to protect homeowners from these costs (Harvey, 2022). Homeowners with energy-inefficient properties will see a greater impact on their disposable income, which could affect their ability to pay their mortgage – increasing risks to the lender. These risks are increasingly relevant to the financial sector, particularly as governments look to address climate change by transitioning the economy to net zero. This motivated the Bank of England to take regulatory action in 2018 based on concerns that banks' awareness and response to climate risks, whether through changes to pricing models or business strategy, are relatively immature (Bank of England, 2018).

In this paper, we examine whether banks accounted for energy- and climate-related financial risks in their mortgage pricing decisions prior to that regulatory response. Examining mortgages is important as they form the largest asset class for retail banks (Jordà et al., 2016; Arnould et al., 2020, Giasante et al., 2020). As their maturity can be up to 30 years, new mortgage lending can be exposed to transition risk from climate policy decades into the future. Such policies, for example, carbon taxes or higher energy standards of properties, can increase future costs for mortgage borrowers (Bank of England, 2019a). The degree to which this translates into higher credit risk in banks' mortgage books depends on the properties' energy efficiency, which serves as collateral, directly impacting disposable income. Higher energy efficiency means that mortgage borrowers are less exposed to shocks in energy prices because their energy consumption is lower, so they might experience relatively lower decreases in available income. In addition, such borrowers might face lower upfront costs of complying with future regulation should higher energy efficiency standards become mandatory, for example, investments in more efficient boilers or better-insulated windows (Burlinson et al., 2018a; Burlinson et al., 2018b).

These protections should result in lower credit risk as borrowers would less frequently fall into default. Future higher energy efficiency standards might also affect the property value. Due to higher costs of improvements, we can expect energy-inefficient properties to decrease in value relative to energy-efficient properties. This should further affect credit risk as, ceteris paribus, losses against mortgages on energy-efficient properties in a default event would be lower than losses against energy-inefficient properties if they had to be repossessed and sold by the bank.[1] Therefore, if mortgage lenders were forward-looking and profit-maximising, we can expect lower credit risk premiums on interest rates for mortgages against energy-efficient properties. That is because they would incur a lower probability of default due to a reduction in energy costs and potential upfront cost (disposable income effect); whilst reducing the loss given default via the

[1] In this section, we argue that higher energy efficiency can affect the two main dimensions of credit risk, probability of default (PD) via income and loss given default (LGD) via house prices.

higher value of the energy-efficient property (collateral asset effect). However, bank behaviour is not necessarily profit-maximising. Lenders might also be willing to support the greening of the economy as a strategic choice, either because of conduct greenwashing or for altruistic motivations (Wu and Shen, 2013; Shen et al., 2016). These motivations might also influence their lending decisions (Lentner, 2015). Hence, it seems possible that they offered favourable rates on mortgages against energy-efficient properties for such reasons. Yet, little is known about whether lenders considered such aspects when pricing mortgages against energy-efficient properties prior to climate-related financial regulation. This paper aims to fill this gap by exploring whether there is any evidence of a green premium applied by banks in response to the financial risk assessment from climate change on properties pre-2018.

To this purpose, we built a unique micro-level dataset containing information on more than 1.8 million outstanding mortgages on properties and their energy efficiency in England and Wales between 2008 and 2017. It is a relevant period as it allows us to examine lending behaviour before the PRA and UK Government intervened publicly on climate risks in the mortgage market. The two significant publications were the PRA's supervisory statement that required lenders to incorporate climate risk factors into risk management (PRA, 2018), and the Government's minimum EPC threshold for letting out Buy-to-Let properities (BEIS, 2018). Moreover, it is a relevant time period because a large share of the existing stock of mortgages was initially granted in this time period.

The financial data builds upon the information obtained from the Financial Conduct Authority's Product Sales Database, whose access is restricted to the FCA and the Bank of England. It contains information on the interest rate charged on domestic mortgages, as well as property, contract and borrower characteristics, e.g. property value, mortgage origination year, loan amount, lender name, income and age of the borrowers at the time of mortgage origination, loan-to-income ratios (LTI) [2], and loan-to-value ratios (LTV) (Page, 1964; Al-Bahrani and Su, 2015). The energy efficiency of each underlying property is sourced from the Energy Performance Certificates (EPC) logged on the Energy Performance of Buildings Registers since 2008 and available from the Ministry of Housing, Communities and Local Government. For all buildings constructed, sold, or let since 2008, the EPC provides information on several property characteristics such as the number of rooms, size and location, as well as the energy rating.

Jointly, the two datasets allow us to disentangle the *presence of a green discount on energy-efficient properties* from *standard* risk drivers that affect mortgage pricing, i.e. property, contract and borrower characteristics readily observable to lenders for traditional standard loans. It also allows us to assess whether the green discount is based on Corporate and Social Responsibility (CSR) values or *forward-looking profit maximising considerations based on the moderating*

[2] LTI is especially important as it proxies the borrowers' net disposable income, after accounting for maintenance and mortgage costs and hence the vulnerabilities to future energy cost increases as well as upfront costs that might be required to meet more stringent future energy efficient government standards

effect of energy efficiency on both the collateral value of properties and the potential risk of default caused by future energy costs and tighter energy standards.

To distinguish between the *standard* risk observable to the lender versus the *green transition* risk, we estimate simple a mortgage pricing model that disentangles the energy efficiency premium from the well-known mortgage pricing factors (property, borrower and contract characteristics). Initial estimates of our mortgage pricing model provide evidence of a negative relationship between energy rating and interest rate on mortgages in that time period. However, as we control for the *standard* risk drivers such as property values, borrower income, and loan characteristics, which are observable to the lenders, the estimated negative relationship between energy efficiency and mortgage rates reverses, indicating a *green premium*. Mortgages against energy-efficient properties with EPC ratings of A, B or C were priced at 0.6 basis points higher than mortgages against energy-inefficient properties with EPC ratings of E, F or G.

Overall, we find no evidence that lenders priced the lower potential risks from future energy costs and higher collateral value of the energy-efficient assets pre-2018. If at all, our evidence suggests that banks charged a small premium to their customers to acquire energy-efficient assets, appropriating some of their net benefits rather than discounting and passing them on to their customers. We believe that this result supports the literature pointing to lenders' lack of awareness of the financial risks from climate change during that time period (Campiglio et al., 2018; Bank of England, 2018; Garbarino and Guin, 2021). We take our results as evidence that corporate social responsibility motivations, such as altruism and greenwashing (Wu and Shen, 2013; Shen et al., 2016), were not the drivers of the greening of the mortgage pricing decisions. By charging higher interest rates on energy efficiency properties, lenders could have appropriated some of the benefits generated by the greening of the property market, sharing with the borrowers some of the benefits derived from energy-efficient properties. However, given the size of the relationship, our findings do not provide conclusive evidence that lenders took energy efficiency into account when setting interest rates prior to regulatory interventions.

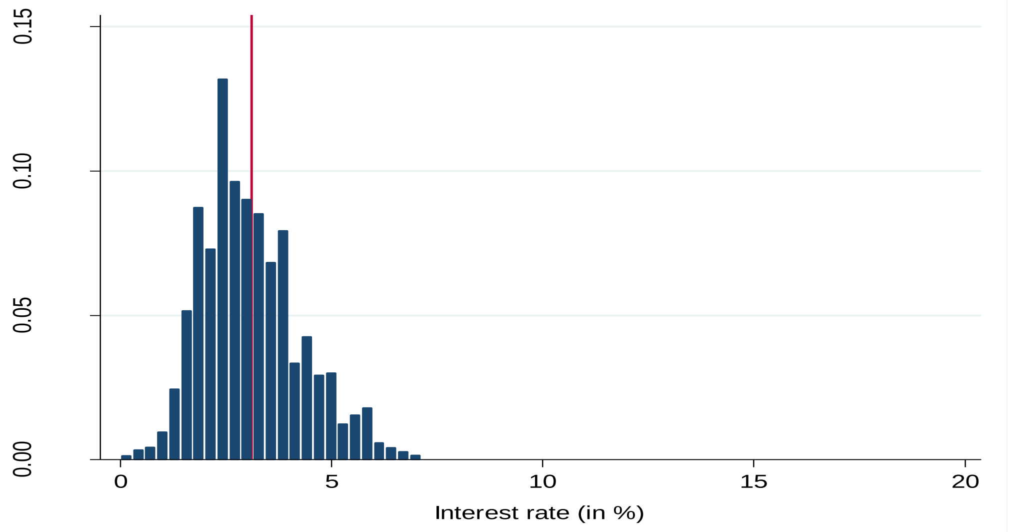
The paper is organised as follows. Before specifying the theoretical framework that outlines the expected relationship between mortgage pricing and energy efficiency, we first provide some background and context to the role of energy efficiency in the English residential market. We then describe the unique dataset, the statistical approaches to their analysis and discuss the results. A final section concludes.

2 Data

Our analysis takes advantage of a unique dataset. The energy efficiency dataset reports all the Energy Performance Certificates (EPCs) lodged on the Energy Performance of Buildings Registers since 2008 we obtained from the Ministry of Housing, Communities and Local Government. This dataset covers all domestic properties in England and Wales. It also includes useful control variables, such as EPC rating, inspection year and the number of heated rooms. We complement this dataset with information on owner-occupied mortgages (ie not buy-to-let) which we obtain from the Product Sales Database (PSD)[3] collected by the UK's Financial Conduct Authority (FCA) and available to restricted members of staff at the FCA and the Bank of England. PSD has information on all completed household mortgage product originations by all the lenders in the UK mortgage market from April 2005, and **borrower characteristics** (such as borrower income at the time of the mortgage origination and age), **loan characteristics** (such as loan amount and lender name), and **property characteristics** (such as property price and size). The resulting sample covers all owner-occupied mortgage originations by regulated entities in the UK from 2008 to end-2017.

Across these 1.8 million observations, the interest rate had a mean of 3.1%, with a range of 0-17.4%. It followed a normal distribution with some outliers (Figure 1), which is valuable to avoid biasing the model estimates.

Figure 1: Distribution of Interest Rates: England and Wales



Note: Distribution of interest rates charged on mortgages in the stock of mortgages year-end 2017.
Source: Ministry of Housing, Communities & Local Government (2018).

[3] This database has been well-established in the existing literature (Cloyne et al., 2019; Guin et al., 2022).

Looking at the loan characteristics, 85% of loans in the sample were provided against houses, 8% were flats, and 6% were bungalows. House prices ranged from GBP 14,700 to GBP 1.06 million, with a mean of GBP 254k (Table 1). In line with this, loan amounts ranged from GBP 0[4] to GBP 870k, with a mean of GBP 194k. On the risk indicators, the average LTV was 0.81 and the average LTI was 3.75. These are all typical and expected for the UK mortgage market and are in line with the existing literature (Arnould et al., 2020; Guin et al., 2022).

Table 1. Summary statistics

	Mean	St.Dev.	Min	Max	Observations
Mortgage rate					
Interest (%)	3.08	1.17	0.00	13.49	1,554,286
Energy efficiency					
High energy efficiency	0.23	0.42	0.00	1.00	1,826,399
Medium energy efficiency	0.49	0.50	0.00	1.00	1,826,399
Low energy efficiency	0.29	0.45	0.00	1.00	1,826,399
Borrower characteristics					
LTI	3.75	2.25	0.00	496.00	1,826,399
Gross income	54.80	36.81	1.00	231.13	1,826,399
Joint income	0.38	0.49	0.00	1.00	1,826,399
Age of borrower	36.62	9.37	17.00	92.00	1,826,399
Loan characteristics					
LTV	0.81	0.36	0.00	6.56	1,826,399
Loan value	194.34	148.20	0.00	870.00	1,826,399
Property characteristics					
House price	253.73	177.51	14.70	1,060.00	1,826,399
Floor area	98.98	69.45	0	605.06	1,826,399
New property	0.00	0.05	0	1	1,826,399

Note: This table shows summary statistics of the variables displayed in the regression tables. Definitions of the summary statistics can be found in Appendix 1. Summary statistics of property control variables, regional control variables, origination year and inspection year control variables are available upon request.
Source: HM Land Registry (2018), MCHLG (2018), and FCA PSD (2018) datasets with personal elaborations.

Improving energy efficiency is commonly viewed as the most cost-effective way to reduce CO_2 emissions (Burlinson et al., 2018a). In support of the Tokyo Agreement (and later the Paris Agreement) and to meet the requirements of the EU Directive on the energy performance of buildings, starting from 1 August 2007, the UK Government required Energy Performance Certificates (EPCs) for properties in the UK whenever they are built, sold, or rented (Ministry of Housing, Communities & Local Government, 2014). Such EPCs provide potential buyers and tenants with an indication of the energy efficiency of a property. EPCs contain information about

[4] Indicating a re-mortgage for no additional funds.

the property's typical energy costs for heating, lighting, and ventilation, less any energy generated from technology installed in the building, such as solar water heating (DCLG, 2017). The directive aimed to improve transparency in the market and allow buyers and renters to make informed decisions.

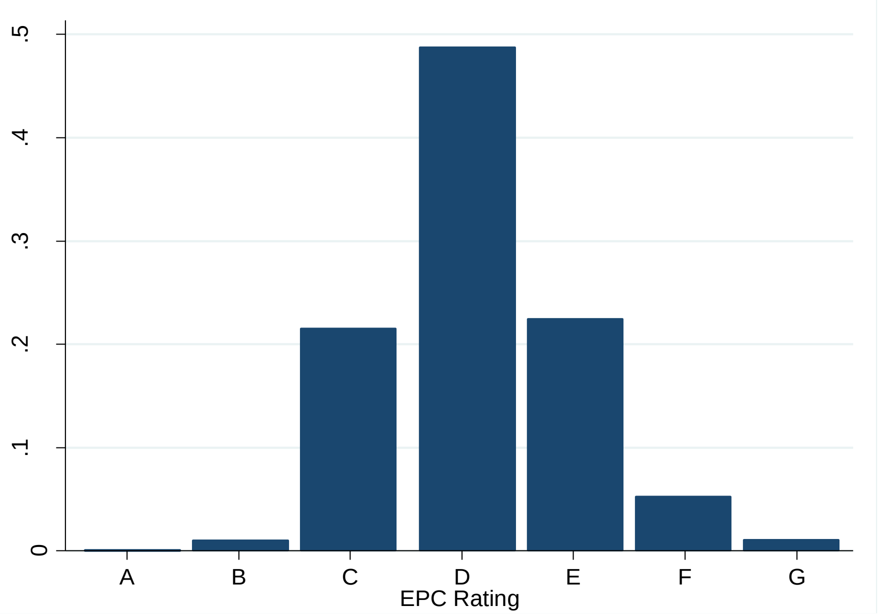
EPCs, similar to the mandatory energy labels used in many electrical goods, are designed to report the energy that a building uses on a rating scale A to G (A being the most efficient). EPCs are intended to inform potential buyers or occupiers about the energy performance and its associated services as built. In this way, potential buyers (or tenants) can easily assess how energy efficient the property is and the impact on their energy bills. EPCs also provide recommendations for improvements, encouraging to make ameliorations expected to increase the energy efficiency and hence the value of the property. The government changed the legal requirement of a HIP in May 2010, but the need to provide an EPC remained, and it is still an important aspect of selling or renting a building today[5]. The UK Government's Clean Growth Strategy aims for all homes to be EPC rating C or above by 2030 (HM Government, 2017). Policy is already tightening to achieve this (see Approved document L - Designing Buildings Wiki). Since April 2018, private rental properties in England and Wales are required to be EPC E or higher before landlords can grant a new tenancy (BEIS, 2018[6]).

To obtain an EPC, the property must be surveyed by an accredited energy assessor, who visits the property to collect the necessary information. A typical EPC survey costs between GBP 60 and GBP 120. The EPC then remains valid for 10 years. The rating incorporates energy costs for space and water heating, lighting, and ventilation, net of energy generation savings, adjusted for floor area. The final rating is between 0-100, with 100 being the most efficient (Ministry of Housing, Communities & Local Government, 2018). This rating is translated into a band: A (92-100), B (81-91), C (69-80), D (55-68), E (39-54), F (21-38), and G (1-20). Figure 2 shows the ratings of the domestic properties with an EPC in England and Wales in 2018, published by the Ministry of Housing, Communities & Local Government. About 23% of all properties were rated as having high energy efficiency (EPC ratings of A, B or C), 49% were medium energy efficiency (EPC rating of D) and about 29% were low energy efficiency (EPC ratings of D, E or F).

[5] The UK government introduced a number of energy-saving schemes such as the energy company obligation, that obliged energy suppliers to subsidise home insulation for low-income households; or Building regulations energy standards for existing and new buildings (see Building regulations, document L https://www.gov.uk/government/publications/conservation-of-fuel-and-power-approved-document). Of all the tools, EPC is our preferred one as it measures the output of the various government interventions designed to achieve energy efficiency targets.

[6] This was broadened to apply to all private domestic rental properties in April 2020, regardless of whether the tenancy changed. However, the rental market is not the focus here.

Figure 2: Distribution of EPC Ratings: England and Wales



Note: This figure shows the distribution of EPC ratings for domestic properties with an EPC in England and Wales in 2018.

Source: Ministry of Housing, Communities & Local Government (2018).

3 Hypotheses and empirical model

An increasing literature has looked at the impact of EPC on the value of residential and commercial properties and the purchase versus rental property price. The evidence confirms that there is a price premium associated with a higher energy rating (Hyland et al., 2013; Brounen and Kok, 2011; Fruest et al. 2011) and that energy efficiency matters to home-buyers and is reflected in relatively higher property values (Eichholtz et al., 2010, 2013; Fuerst et al., 2015). Contrary to the impact of energy efficiency on the demand and quality of properties, however, very little is known about the credit risk premiums on interest rates for mortgages against energy-efficient properties.

There are several reasons why one might expect banks to have priced mortgages against energy-efficient properties at lower interest rates, what we refer to as *green discount*. The literature on corporate social responsibility (CSR) argues that bank behaviour was not always profit-maximising and driven by financial motives. Instead, banks might be willing to support the greening of the economy to improve their appearance to the public because of capital market shareholders' green tastes and preferences (Kleimeier and Viehs, 2018) or because of genuinely altruistic motivations and beliefs (Wu and Shen, 2013; Shen et al., 2016). These motivations could have reasonably influenced their lending decisions (Lentner, 2015). Indeed, there is evidence that lower lending spreads were associated with borrowers' (companies in this case) lower carbon emissions (Kleimeier and Vieh, 2018), more ethical behaviour (Kim et al., 2014) and higher social responsibility (Goss and Roberts, 2011). Based on the previous evidence, it is reasonable to assume that bank lenders applied their CSR policy to the property market by offering favourable rates on mortgages against the properties' environmental performance.

In addition to the CSR drive, it could be argued that financial markets and, in particular, lenders aimed to mitigate transition risk by taking extra-financial information on properties environmental performance when assessing the creditworthiness of borrowers. They were aware of the risks that can arise due to poor environmental performance. Higher energy efficiency means that mortgage borrowers need to consume less energy, so they are less exposed to shocks in energy prices that might impact their disposable income. In addition, such borrowers might face lower upfront costs of complying with future tighter regulation on energy standards and efficiency. For example, they might not need to invest in more efficient boilers or better-insulated windows (Burlinson et al., 2018a; Burlinson et al., 2018b). Energy prices and upfront installation costs represent variable and fixed energy costs, respectively, that can impact available income and the loan to income ratio (LTI), increasing the probability of default. Hence, banks might have expected mortgages against energy-efficient properties to be less likely to default in the future than mortgages against energy-inefficient properties. In addition, compliance with energy standards could have significantly affected the property value. Due to the lower costs of improvements in the prospect of tighter regulations alongside the impact of energy savings on household bills, we could expect energy-efficient properties to decrease less in value relative to energy-inefficient properties. This should further affect the overall credit risk as, ceteris paribus, losses against energy-efficient properties in a default event would be lower than losses against energy-inefficient properties if they had to be repossessed and sold by the bank. Hence, it is reasonable to posit that lenders discounted mortgages against energy-efficient properties by applying lower interest rates. This will be our working hypothesis.

It is increasingly argued that banks' CSR activities are positively related to their financial performance (Wu and Shen, 2013; Shen et al., 2016; Simpson and Kohler, 2002). By some, this should be interpreted as evidence that banks' CSRs are motivated out of self-interest rather than altruism. Banks are unlikely to lead to changes in mortgage pricing decisions and are instead "greenwashing" showing the lenders' lack of awareness of the financial risks from climate change (Campiglio et al., 2018; Bank of England, 2018; Garbarino and Guin, 2021). If that was true, we would expect that banks not to adjust mortgage interest rates based on the state of energy efficiency of properties, but only on the *standard* risk measures based on borrower's characteristics, contract/loan size and the property value.

Empirical model

In the baseline analyses of this paper, we estimate a simple mortgage pricing model to assess the relationship between the energy efficiency and the interest rate charged on a mortgage against it. Using OLS, we assume a linear relationship between interest rate and Energy Efficiency and an uncorrelated normally distributed error term ε_i.

$$Interest_{\,i} = \alpha + \beta_1 Energy\, efficiency_i + \varepsilon_{\,i} \qquad (1)$$

However, even if there were evidence of a negative relationship, ex-ante it wouldn't be clear which of the two motivations, profit-maximising or non-profit maximising, drove that relationship. In the absence of additional data on bank motivation, to disentangle the two CSR versus the risk minimising/profit maximising motivation, we reduce the unobservable and confounders by explicitly modelling the traditional factors affecting the lenders' decision: borrower, the property and the loan characteristics.

$$Interest_{\,i} = \alpha + \beta_1 Energy\, efficiency_i + \gamma_1 Borrower_i + \gamma_2 Loan + \gamma_3 Property_i + \gamma_4 X_i + \varepsilon_i \quad (2)$$

The dependent variable ($Interest_i$) is a continuous variable representing the initial gross nominal rate charged on the loan at origination, measured in percentage terms. Energy efficiency is measured by EPC. Previous findings confirm that the impact of energy efficiency level might be non-linear and decreasing for high rate where the effect is cofounded with other high property standards and benefits. Hence, we experiment with various classifications of energy ratings. The best specification that also ensures enough observations in each category to produce robust results is obtained when we cluster our ratings into $High\ energy\ efficiency$ (EPC A, B, C), $Medium\ energy\ efficiency$ (EPC D), and $Low\ energy\ efficiency$ (EPC E, F, G). This is the classification we use in the paper.[7]

Borrower is a vector of variables containing gross income at origination, LTI, age of the borrower and whether there is a joint income from different sources. *Loan* contains information on the contract, loan amount and LTV. The vector *Property* contains the property price, its size in terms of floor area, and a dummy variable indicating whether it is a new property.

Finally, X_i is a vector of further control variables such as regional controls. 3-digit postcode fixed effects remove the effect of omitted time-invariant variations which vary across regions, such as infrastructure, religion, gender, and race, which influence mortgage interest rates (Haughwout et al., 2009; Boehm et al., 2010; Cheng and Lin, 2011; Cheng and Lin, 2015) and are correlated within regions but vary significantly between regions (Degryse, 2005)[8]. It also accounts for the fact that similar absolute values of energy savings and other benefits associated with good

[7] The results with alternative specifications are available upon request.
[8] The pattern of price effects is broadly as expected. The largest premiums and discounts related to dwellings rated D are in the region with the lowest house prices – the North East. In regions with the highest house prices (London, South East, South West and East Anglia), there are either lower or no statistically significant price premiums/discounts. Thus, the findings from a regional disaggregation are consistent with the expectation that similar absolute values of energy savings and other benefits associated with good energy ratings will have different relative effects on house prices (Fuerst et al., 2015).

energy ratings will have different relative effects on house prices depending on the neighbourhood and geographical location (Fuerst et al., 2015). Moreover, it includes time control variables representing when the mortgage was taken out (which we call the origination year) and when the EPC inspection was performed, which we call the inspection year.[9]

To avoid outliers biasing the results, we winsorise income, house price, and loan size by reassigning extreme values to the 99th percentile. Furthermore, to test the validity of the result, the model will also be run with the continuous measure of energy efficiency (the numerical 0-100 rating) instead of the discrete measure. Interest rates on mortgages are never negative, i.e. there is left-censoring of the dependent variable in the linear regression model. In this case, OLS can provide inconsistent estimates of the parameters, meaning that the coefficients from the analysis will not necessarily approach the "true" population parameters as the sample size increases (Long, 1997). To account for it, we estimate Tobit models, which are designed to estimate linear relationships between variables when there is left-censoring in the dependent variable (Long, 1997).

4 Results

Simple univariate comparisons show that, pre-2018, the average interest rate charged on a mortgage against an energy-efficient property was 1.3 basis points lower than against an energy-inefficient property, significant at the 1-percent level (Table 2). This represents savings of about GBP 635 over the lifetime of a typical GBP 250,000 30-year term mortgage, assuming zero discounting.[10] This suggests there was a negative relationship between the energy efficiency of a property and the interest rate charged for a mortgage on that property pre-2018.

Table 2. Average interest rate (in %) by energy efficiency of the property

	High energy efficiency	Medium energy efficiency	Low energy efficiency	Difference	Difference
	(1)	(2)	(3)	(1)-(3)	(2)-(3)
Interest (%)	3.0813	3.0802	3.0945	-0.0132***	-0.0144***
	(N=350,477)	(N=757,773)	(N=441,255)	(N= 791,732)	(N=1,199,028)

Note: This table shows the mean average interest rate charged on a mortgage, *Interest (%),* by energy efficiency rating (EPC) of the underlying property (in columns (1)-(3)). Columns (4)-(5) test the mean differences. N indicates the number of mortgages. ***, **, * denote statistical significance at the 0.01, 0.05 and 0.10-level respectively. *Source: MCHLG (2018) and FCA PSD (2018) datasets with personal elaborations.*

There is evidence that borrowers with higher income were more likely to take out mortgages against energy-efficient properties (Griffiths et al., 2015, Burlinson et al. 2018b), and higher current income can explain lower default risk among borrowers (Elul et al., 2010). Hence, first, we control for the Borrower's characteristics via income and LTI to account for the possibility

[9] We define relevant variables in Appendix 1.
[10] Assuming zero percent discounting and a baseline interest rate of 3.08% (the average interest rate for the sample). For a simple calculation of interest payments of standard Uk mortgages, e.g. https://www.calculator.net/.

that higher-income households might have self-selected themselves into energy-efficient houses. We then include the property price to account for the possibility that energy efficiency was reflected in higher property values. Last, we control for other property, borrower and regional characteristics.

The regression results presented in Table 3 confirm this univariate finding (column 1). In column 2, we then add borrower characteristics (LTI, gross income, joint income dummy, age of borrower) as well as further control variables for **property characteristics** (property price, floor area, new build dummy, property type, number of rooms) and **contract characteristics** (loan amount, LTV and loan maturity). These variables are important risk indicators, and research has shown lenders factor them into mortgage pricing (Page, 1964; Al-Bahrani and Su, 2015). In particular, the property price and LTV might have been affected by differences in energy efficiency. These additional controls further strengthened the estimated relationship between energy efficiency and mortgage rates. In this specification, the interest rate charged for a mortgage on an energy-inefficient property was 7.1 basis points higher than an energy-efficient property pre-2018, significant at the 1-percent level. This represents an additional interest cost of about GBP 3,474 over the lifetime of a GBP 250,000 30-year mortgage.[11]

[11] Again assuming zero percent discounting and a baseline interest rate of 3.08%.

Table 3. Multivariate analyses: mortgage interest rate and energy efficiency of the property

	Interest (%) (1)	Interest (%) (2)	Interest (%) (3)
Energy efficiency			
High energy efficiency	-0.0132***	-0.0717***	0.0060**
	(0.0046)	(0.0030)	(0.0023)
Medium energy efficiency	-0.0144***	-0.0650***	0.0099***
	(0.0032)	(0.0024)	(0.0018)
Borrower characteristics			
LTI		-0.0557***	-0.0528***
		(0.0079)	(0.0071)
Gross income		0.0031***	0.0021***
		(0.0003)	(0.0003)
Joint income		0.4109***	0.1158***
		(0.0034)	(0.0026)
Age of borrower		-0.0071***	-0.0035***
		(0.0003)	(0.0005)
Loan characteristics			
LTV		0.6081***	0.9158***
		(0.0226)	(0.0202)
Loan value		-0.0017***	-0.0016***
		(0.0001)	(0.0000)
Property characteristics			
House price		-0.0020***	-0.0002***
		(0.0001)	(0.0000)
Floor area		0.2077***	-0.0573***
		(0.0335)	(0.0184)
New property		-0.0020***	-0.0002***
		(0.0001)	(0.0000)
Property control variables	No	Yes	Yes
Contract control variables	No	Yes	Yes
Regional control variables	No	Yes	Yes
Origination year control variable	No	No	Yes
Inspection year control variable	No	No	Yes
Observations	1,549,505	1,549,505	1,549,505
Pseudo R2	0.0000	0.1654	0.4015
Mean of dep. variable	3.0845	3.0845	3.0845

Note: This table shows the results of ordinary least squares analyses with the mortgage interest rate, Interest (%), as the dependent variable. Explanatory variables are indicators of the energy efficiency of the properties, as well as borrower, property and contract-specific characteristics. Observations are at the mortgage level. Standard errors are clustered on the 3-digit postcode. ***, **, * denote statistical significance at the 0.01, 0.05 and 0.10-level respectively.
Source: HM Land Registry (2018), MCHLG (2018), and FCA PSD (2018) datasets with personal elaborations.

The final model specification includes time control variables representing when the mortgage was taken out, the origination year, and when the EPC inspection was performed, the inspection year. This yields interesting results. In this model specification, the relationship between energy efficiency and mortgage interest rate turns positive, significant at the 5-percent level. This suggests that a mortgage on an energy-inefficient property had an interest rate that was very slightly lower, 0.6 basis points, than the interest rate on an energy efficient property pre-2018. This represents an interest saving of GBP 293 over the lifetime of a GBP 250,000 30-year mortgage.[12] This appears to be driven by the mortgage origination year variable, suggesting that an omitted variable changes over time and is the dominant influence on mortgage interest rates. We attribute this to the Bank of England Base Rate, which fell from 5.5% in 2008 to 0.5% by 2017 (Bank of England, 2019b). This suggests energy efficiency had very limited influence in comparison. Once we take EPC out of specification shown in column 3, the R2 does not change. This is supportive evidence that energy efficiency cannot explain a large variation in banks' mortgage pricing decisions pre-2018.

Based on this analysis, it can be concluded that the energy efficiency of a property was a limited predictor of interest rate pre-2018, and an energy-inefficient property was associated with a very slightly higher interest rate. On this basis, we find evidence in support of our main hypothesis. However, as the size of the relationship between energy efficiency and interest rate is so small, the findings do not provide conclusive evidence that energy efficiency had a strong influence over interest rates. Overall, the analysis suggests that lenders did not take energy efficiency into account when setting interest rates prior to the introduction of climate regulation in 2018.

Distributional consequences

It is possible that borrower and property characteristics differ across different energy efficiency classes. For example, the existing literature found evidence that high-income individuals are more likely to buy energy-efficient properties (Adalilar et al., 2014). In this section, we compare key characteristics across each energy efficiency bucket. Table 4 suggests that borrowers are heterogeneously distributed across these energy efficiency categories. For example, high-income borrowers did appear to be buying energy-inefficient properties . The average income in the low energy efficiency bucket was GBP 59k which is relatively higher than the average income in the high energy efficiency bucket, which was GBP 52k.[13] Moreover, energy-inefficient properties were larger, 107 square meters, relative to energy-efficient properties, 94 square meters on average. This resulted in a higher average property value of GBP 277k, relative to the value of energy-inefficient properties, which is GBP 236k.

Table 4 suggests that lower pricing of mortgages against energy-inefficient properties had consequences for the income distribution. It shows that borrowers of mortgages against energy-inefficient properties had relatively higher income than borrowers of mortgages against energy-efficient properties. A lower pricing of their mortgages suggests that these borrowers would have even more available income relative to borrowers against energy-efficient properties.

However, the magnitude of this distributional consequence is small. In our preferred specification in Table 3, we found that a mortgage on an energy-inefficient property had an interest rate that is very slightly lower, 0.6 basis points, than the interest rate on an energy-

[12] Assuming zero percent discounting and a baseline interest rate of 3.08% (the average in interest rate for the sample).
[13] However, it goes against previous research that high-income borrowers value energy efficient properties (Adalilar at el., 2014).

efficient property pre-2018. This represents an interest saving of GBP 293 over the lifetime of a GBP 250,000 30-year mortgage, which is about GBP 10 per year.

Table 4. Distribution of borrowers and properties by energy efficiency

	High energy efficiency		**Medium energy efficiency**		**Low energy efficiency**	
	Mean	St.Dev.	Mean	St.Dev.	Mean	St.Dev.
Borrower characteristics						
LTI	3.79	2.11	3.75	2.19	3.70	2.45
Gross income	52.21	34.46	53.67	34.78	58.74	41.35
Joint income	0.35	0.48	0.39	0.49	0.40	0.49
Age of borrower	35.92	9.39	36.49	9.33	37.37	9.36
Loan characteristics						
LTV	0.83	0.37	0.82	0.37	0.79	0.36
Loan value	186.78	138.89	191.75	144.04	204.65	161.12
Property characteristics						
House price	235.90	157.56	248.35	167.93	276.82	203.79
Floor area	94.32	51.22	96.62	40.22	106.64	109.09
New property	0.01	0.07	0.00	0.03	0.00	0.03

Note: This table shows the mean and standard deviation of a selection of control variables displayed in the regression tables. *Source: HM Land Registry (2018), MCHLG (2018), and FCA PSD (2018) datasets with personal elaborations.*

Robustness

To improve the validity of these findings, we run a battery of robustness tests. To remove the impact of the Base Rate, the sample was restricted to 2011-2017 when the rate was largely constant (Bank of England, 2019b). Under these conditions, the relationship between energy efficiency and interest rate strengthened slightly but remained largely similar. We also winsorise the upper end of our interest rate variable at the 99th percentile to account for outliers in the interest rate charged on mortgages. The results remained very similar. In addition, we run the regressions with the continuous measure of energy efficiency (EPC score 0-100) instead of discrete variables. All regressions produced similar findings (Appendix 2), which confirms the validity of our main analyses. However, the linear relationship imposed by this regression may not be a true representation. It is more likely that increases in EPC score had a diminishing marginal impact on the interest rate. To check this, the square of energy efficiency was included. This yielded the same results, which are available upon request.

Moreover, to check the robustness of OLS, other models were used. In particular, we estimate a Tobit regression to account for the truncation of the interest rate variable at zero. Interest rates can never be negative, causing censored data that could bias the point estimate and underestimate the relationship between energy efficiency and the interest rate. The Tobit results verified a small positive relationship between energy efficiency and interest rate, significant at the 1-percent level (Appendix 3). This is consistent with OLS and in line with previous well-published papers that show OLS is a reliable approach under these conditions (Jiménez, et al., 2012; Degryse, 2005). Last, we check whether the results stay similar once we exclude income and loan value from our regressions. This addresses the concern that including both variables could be highly correlated with LTI. Our coefficients of interest remain statistically significant and qualitatively similar (Appendix 4).

5 Conclusion

The financial risks from climate change, and society's response to it, are becoming increasingly prevalent across the financial system (Campiglio et al., 2018). This includes the risks from lending against energy-inefficient properties in the face of both carbon price increases that impact affordability, and regulation that can affect house values and future costs of improving the property. The current energy crisis is bringing these issues into present day – demonstrating the protective quality that energy efficient homes can provide when homeowners are faced with rising energy prices. This is motivating increasing action by financial regulators and governments to require banks to incorporate these factors into risk management and pricing decisions.

In this paper, we examine to which extent these risks were reflected in lenders' pricing decisions in the UK residential mortgage market in a relevant time period until 2017 before relevant regulatory interventions on climate risks came in.

We make use of a rich dataset of over 1.8 million observations with numerous control variables, including mortgage, property, and borrower characteristics. Once we control for relevant risk drivers, there is evidence of a small *positive* relationship between the energy efficiency of a property and the interest rate. The interest rate for a mortgage against an energy-efficient property compared to an energy-efficient property was 0.6 basis points higher on average in the time period before 2018, significant to the 5-percent level. However, as the size of the relationship between energy efficiency and interest rate was so small, the findings do not provide conclusive evidence that energy efficiency had a strong influence over interest rates, and is supportive of evidence that energy efficiency did not explain a large variation in lenders' mortgage pricing decisions.

We interpret this result as evidence of a lack of awareness of lenders' response to the financial risks from climate change at that time (Campiglio et al., 2018; Bank of England, 2018; Garbarino and Guin, 2021). This result is consistent with anecdotal evidence that lenders have *only recently* started to price in energy efficiency either in pilot phases or restricted to a sub-set of lenders' portfolios (Barclays, 2019; EeMAP, 2019). The results also do not align with Eichholtz et al.'s findings (2018), which demonstrate that the corporate bond market was more advanced in its incorporation of energy efficiency into pricing. This may reflect a greater awareness of the financial risks from climate change in the US corporate bond market and more advanced integration of energy efficiency into pricing models.

This analysis and related literature also demonstrates the clear benefit, in terms of house price and ability to sell a property, from owning an energy efficient property (Hyland et al., 2013; Brounen and Kok, 2011; Fruest et al. 2011; Eichholtz et al., 2010, 2013; Fuerst et al., 2015). This suggests that lenders that factor incentives for energy efficiency improvements into lending could see preferable results in terms of reduced credit risk, whilst also helping to drive the transition to net zero. This provides further support for the regulatory interventions that occurred from 2018.

This is a novel piece of analysis and the first to consider the relationship between energy efficiency and interest rate on residential mortgages. There are many areas where further research would be valuable. Primarily, a follow-up piece of research that assesses the relationship between energy efficiency and mortgage pricing for the period post-regulation (2018 onwards) would provide a useful comparison. As more government policies are put in place to address climate change through energy efficiency standards, and more regulatory interventions that require lenders to consider environmental factors, this should increase the likelihood that banks differentiate lending based on energy efficiency. We would expect to see a strong, negative relationship between energy efficiency and mortgage pricing as banks become more sophisticated in factoring climate risk metrics into their risk management and pricing decisions. To test this hypothesis, follow-up research could replicate our analyses but using a more recent sample period from 2018 onwards. It can compare the sign and magnitude of estimated coefficients over time to see if the relationship between energy efficiency and mortgage rate has changed.

Other useful further analysis includes analysing the relationship in different asset classes, such as buy-to-let mortgages. Theoretically, the relationship should be stronger in this asset class, as government policy has already tightened on the buy-to-let sector, restricting landlords from letting out energy-inefficient properties (BEIS, 2018). This should signal to lenders that buy-to-let mortgages on those properties are more risky, therefore, a higher interest rate is justified. Moreover, additional research into the link between EPC, energy use, and borrower affordability would be valuable. Further research could also look into other mortgage markets, for example, in other jurisdictions, to explore the dynamics and pricing of loans on energy-efficient properties when institutional settings differ.

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Appendices

Appendix 1. Definitions of variables

Variable name	Definition	Source
Mortgage characteristics		
Interest (%)	Interest rate charged to a borrower at mortgage origination (in percent).	PSD
Energy efficiency		
High energy efficiency	Indicator of whether the property has an energy efficiency rating of A, B or C.	EPC
Medium energy efficiency	Indicator of whether the property has an energy efficiency rating of D.	EPC
Low energy efficiency	Indicator of whether the property has an energy efficiency rating of E, F or G.	EPC
Energy efficiency (cont.)	Continuous EPC measure.	EPC
Borrower characteristics		
LTI	Loan-to-income ratio of the home buyer.	PSD
Gross income	Gross income of all home buyers (in GBP).	PSD
Joint income	Indicator of whether the lender's income assessment has been made on a single or joint basis.	PSD
Age of borrower	Age of the mortgage borrower (in years).	PSD
Loan characteristics		
LTV	Ratio of loan amount to value of the property.	PSD
Loan value	Loan amount in 1,000 GBP.	PSD
Property characteristics		
House price	House price in 1,000 GBP.	PSD
Floor area	The total useful floor area (in m^2).	EPC
New property	Indicator of whether the property is a new build.	PSD

Note: This table shows the definition of variables displayed in the regression tables. The definition of Property control variables, Contract control variables, Regional control variables, Origination year control variable and Inspection year control variable are available upon request.
Source: HM Land Registry (2018), MCHLG (2018), and FCA PSD (2018).

Appendix 2. Multivariate analyses: mortgage interest rate and energy efficiency of the property (continuous measurement)

	Interest (%) (1)	Interest (%) (2)	Interest (%) (3)
Energy efficiency			
Energy efficiency (cont.)	-0.0005***	-0.0023***	0.0003***
	(0.0001)	(0.0001)	(0.0001)
Borrower characteristics			
LTI		-0.0557***	-0.0528***
		(0.0079)	(0.0071)
Gross income		0.0031***	0.0021***
		(0.0003)	(0.0003)
Joint income		0.4110***	0.1158***
		(0.0034)	(0.0026)
Age of borrower		-0.0071***	-0.0035***
		(0.0003)	(0.0005)
Loan characteristics			
LTV		0.6077***	0.9158***
		(0.0226)	(0.0202)
Loan value		-0.0017***	-0.0016***
		(0.0001)	(0.0000)
Property characteristics			
House price		-0.0020***	-0.0002***
		(0.0001)	(0.0000)
Floor area		0.0005*	-0.0000
		(0.0003)	(0.0000)
New property		0.2152***	-0.0594***
		(0.0337)	(0.0184)
Property control variables	No	Yes	Yes
Contract control variables	No	Yes	Yes
Regional control variables	No	Yes	Yes
Origination year control variable	No	No	No
Inspection year control variable	No	No	No
Observations	1,549,505	1,549,505	1,549,505
Pseudo R2	0.0000	0.1654	0.4015
Mean of dep. variable	3.0845	3.0845	3.0845

Note: This table shows the results of ordinary least squares analyses with the mortgage interest rate, *Interest (%),* as the dependent variable. Explanatory variables are the continuous measurement of the energy efficiency of the properties, *Energy Efficiency,* as well as borrower, property and contract-specific characteristics. Observations are at the mortgage level. Standard errors are clustered on the 3-digit postcode. ***, **, * denote statistical significance at the 0.01, 0.05 and 0.10-level respectively.
Source: HM Land Registry (2018), MCHLG (2018), and FCA PSD (2018) datasets with personal elaborations.

Appendix 3. Tobit analyses: mortgage interest rate and energy efficiency of the property

	Interest (%) (1)	Interest (%) (2)	Interest (%) (3)
Energy efficiency			
High energy efficiency	-0.0132***	-0.0668***	0.0150***
	(0.0046)	(0.0032)	(0.0026)
Medium energy efficiency	-0.0144***	-0.0538***	0.0118***
	(0.0032)	(0.0025)	(0.0019)
Borrower characteristics			
LTI		-0.0551***	-0.0575***
		(0.0078)	(0.0076)
Gross income		0.0029***	0.0021***
		(0.0003)	(0.0003)
Joint income		0.4341***	0.1084***
		(0.0030)	(0.0026)
Age of borrower		-0.0081***	-0.0037***
		(0.0003)	(0.0005)
Loan characteristics			
LTV		0.5674***	1.0015***
		(0.0203)	(0.0202)
Loan value		-0.0016***	-0.0018***
		(0.0001)	(0.0001)
Property characteristics			
House price		-0.0012***	-0.0004***
		(0.0000)	(0.0000)
Floor area		0.0003*	0.0001**
		(0.0002)	(0.0000)
New property		0.1885***	-0.0519***
		(0.0333)	(0.0182)
Property control variables	No	Yes	Yes
Contract control variables	No	Yes	Yes
Regional control variables	No	No	No
Origination year control variable	No	No	Yes
Inspection year control variable	No	No	Yes
Observations	1,549,505	1,549,505	1,549,505
Pseudo R2	0.0000	0.0381	0.0653
Mean of dep. variable	3.0885	3.0845	3.0845

Note: This table shows the results of tobit regression analyses with the mortgage interest rate, *Interest (%),* as the dependent variable. Explanatory variables are indicators of the energy efficiency of the properties, High energy efficiency and Medium energy efficiency, as well as borrower, property and contract-specific characteristics. Observations are at the mortgage level. Standard errors are clustered on the 3-digit postcode. ***, **, * denote statistical significance at the 0.01, 0.05 and 0.10-level respectively.
Source: HM Land Registry (2018), MCHLG (2018), and FCA PSD (2018) datasets with personal elaborations.

Appendix 4. Multivariate analyses: mortgage interest rate and energy efficiency of the property (no income, loan value)

	Interest (%) (1)	Interest (%) (2)	Interest (%) (3)
Energy efficiency			
High energy efficiency	-0.0132***	-0.0740***	0.0037
	(0.0046)	(0.0030)	(0.0024)
Medium energy efficiency	-0.0144***	-0.0676***	0.0078***
	(0.0032)	(0.0025)	(0.0018)
Borrower characteristics			
LTI		-0.0802***	-0.0698***
		(0.0078)	(0.0065)
Joint income		0.4242***	0.1239***
		(0.0052)	(0.0039)
Age of borrower		-0.0078***	-0.0041***
		(0.0003)	(0.0005)
Loan characteristics			
LTV		0.3353***	0.6360***
		(0.0262)	(0.0219)
Property characteristics			
House price		-0.0026***	-0.0008***
		(0.0001)	(0.0000)
Floor area		0.0005*	0.0000
		(0.0003)	(0.0000)
New property		0.2108***	-0.0570***
		(0.0336)	(0.0184)
Property control variables	No	Yes	Yes
Contract control variables	No	Yes	Yes
Regional control variables	No	Yes	Yes
Origination year control variable	No	No	Yes
Inspection year control variable	No	No	Yes
Observations	1,549,505	1,549,505	1,549,505
Pseudo R2	0.0000	0.1592	0.3968
Mean of dep. variable	3.0845	3.0845	3.0845

Note: This table shows the results of ordinary least squares analyses with the mortgage interest rate, *Interest (%),* as the dependent variable. Explanatory variables are indicators of the energy efficiency of the properties, *High energy efficiency* and *Medium energy efficiency,* as well as borrower, property and contract-specific characteristics. Observations are at the mortgage level. Standard errors are clustered on the 3-digit postcode. ***, **, * denote statistical significance at the 0.01, 0.05 and 0.10-level respectively.
Source: HM Land Registry (2018), MCHLG (2018), and FCA PSD (2018) datasets with personal elaborations.