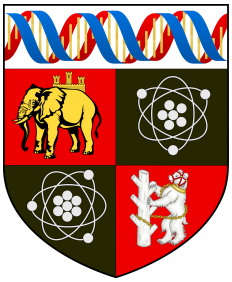

The Heterogeneous Impact of the Right to Buy Policy on Residential Gas Consumption: An Empirical Analysis of Hackney and Haringey.

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Abstract

This study investigates the heterogenous effect of the Right to Buy (RTB) policy on residential gas consumption across different housing types in Hackney and Haringey. Leveraging novel granular postcode-level data, a cross-sectional fixed-effect model is estimated and a bootstrapping analysis is undertaken, each resting on distinct set of assumptions. The results suggest that, in postcodes featuring a local-authority average proportion of flats in the residential property stock, a one standard deviation increase in the share of privatised housing through the RTB policy is associated with a 6.79% and 2.92% additional increase in average residential gas consumption in Hackney and Haringey, respectively. It is proposed that this effect is primarily ascribed to the fragmentation of ownership structures in multi-unit complexes, leading to inefficiencies in decisions pertaining to retrofit works. These findings contribute to the existing literature on energy efficiency and bear implications for policy dialogues aimed at curbing energy demand. Nonetheless, the potential measurement errors in the variables underscore the need for further examination, as they might introduce bias into the estimates.

*I am grateful to my supervisor, Professor Thiemo Fetzer, whose unwavering support and insightful guidance were pivotal throughout the course of this project. I am also indebted to the local authorities of Hackney and Haringey for their prompt and cooperative responses to my Freedom of Information requests, and for supplying data of commendable quality, which significantly bolstered the empirical underpinnings of this research.

Contents

1 Introduction

The United Kingdom (UK) has committed to a legally binding target of achieving net-zero emissions by 2050, necessitating significant reductions in greenhouse gas emissions. One major contributor to the country's emissions is the residential sector, which accounted for 23% of the UK's greenhouse gas emissions (90 MtCO2e) in 2020, primarily due to fuel combustion for heating and cooking, and electricity consumption (ONS, 2022).

At present, a significant portion of the UK's building stock does not meet the energy efficiency requirements necessary to achieve climate objectives, while 80% of the projected 2050 building stock already exists (IET, 2020). Research conducted in 2020 by the home climate management firm Tado° reveals that UK dwellings lose heat up to three times faster than their Western European counterparts. Furthermore, evidence suggests a potentially substantial energy efficiency gap in the UK's residential building sector, as approximately one third of energy consumption could be conserved if structures were retrofitted to the highest energy efficiency standards (Fetzer et al., 2023).

This energy-saving potential coupled with the significant carbon footprint of this sector makes it a policy priority to reach carbon neutrality. Besides, improved residential energy efficiency can also deliver economic and health benefits, especially in fuel poor populations, which represent a considerable share of the population in the UK (Charlier et al., 2019; Hinson & Bolton, 2023). However, previous initiatives such as the UK Green Deal have failed to meet targets aligned with the 2050 net-zero trajectory as highlighted by low levels of heat pumps installations and solid-wall insulations (CCC, 2019; Rosenow & Eyre, 2016). To design more effective policies, a better understanding of retrofitting needs and potential barriers to energy investments is required (Ahlrichs et al., 2022; Dowson et al., 2012; Rosenow & Eyre, 2016).

In this study, I exploit the Right-to-Buy (RTB) policy, a large-scale natural experiment, which generated significant variations in the residential ownership structure to investigate the differential effect of council housing privatisation on residential gas consumption across property building types in two local authorities of London, namely Hackney and Haringey. I hypothesise that a positive additional effect is present when sold properties are flats, driven primarily by the fragmentation of ownership structure below building-level, which generates collective decision frictions concerning retrofitting investments. Using new granular data at the postcode level from diverse sources, this project provides preliminary evidence for this mechanism by estimating a cross-sectional fixed-effect model of average postcode residential energy consumption comparing postcodes with different levels of council housing privatisation and flat prevalence controlling for property and

household characteristics. I find that, in postcodes featuring a local-authority average proportion of flats in the residential property stock, a one standard deviation increase in the share of privatised housing through the RTB policy is associated with an additional 6.79% increase in average residential gas consumption in Hackney and a 2.92% increase in Haringey. In contrast, the equivalent effects for other property building types are either negative or non-significant and these results are robust to a bootstrapping procedure relying on a different set of assumptions.

This research contributes to the economic literature in two key ways. First, it adds to the understanding of the energy efficiency gap by providing suggestive evidence of the role of collective decision frictions in energy investment inefficiencies. Second, it explores the impact of the RTB policy, which has received limited attention despite its substantial influence on the UK's housing ownership structure and housing economy on variable of most interest to policymakers today.

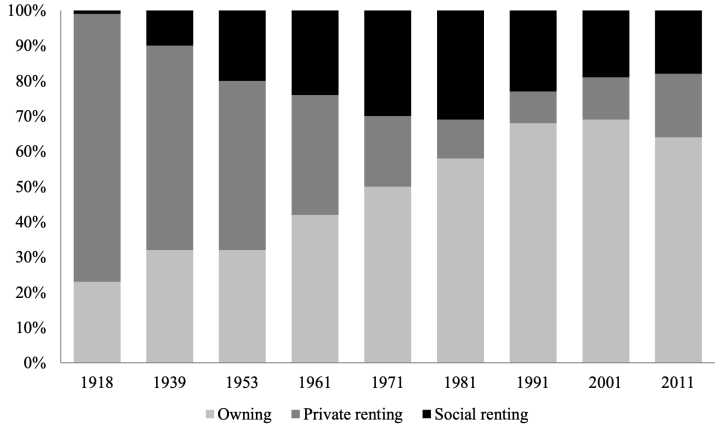
The remainder of this paper is structured as follows: Section 2 reviews the literature and provides an overview of the RTB policy and of its potential implications for residential energy efficiency. Section 3 details the data and methodology employed in this study. Section 4 presents empirical results and discusses their implications. Section 5 concludes.

2 Context and Literature Review

2.1 The RTB Policy

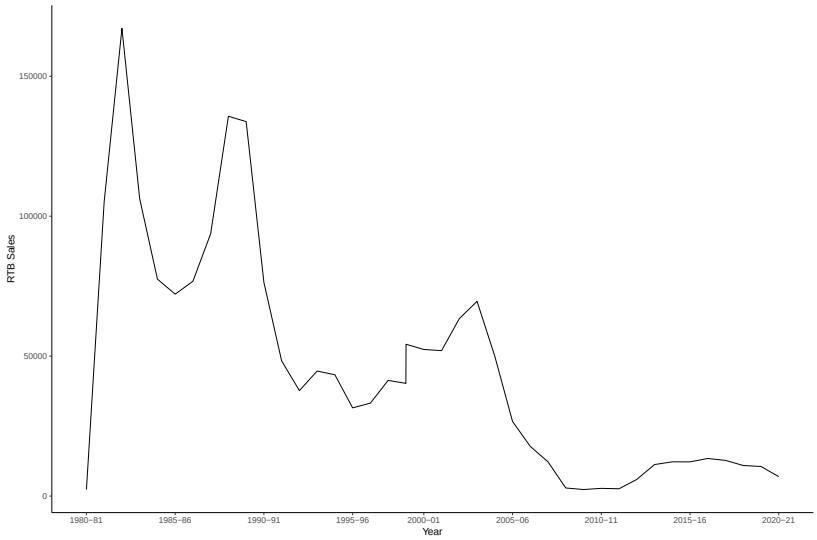
The RTB policy, introduced through the Housing Act 1980, enabled incumbent council housing tenants with a minimum of three years' tenure to purchase their residences at heavily discounted prices. The discount rate, contingent on years of residency, ranged from 33% to a maximum of 50%. Additionally, local councils were mandated to offer mortgages to potential purchasers, although this requirement became less relevant with the liberalisation of capital markets throughout the 1980s (Disney et al., 2021). The type of ownership rights varied depending on the context, but apartments tended to be sold through leasehold, with the local authority retaining freehold on the building (Bright & Weatherall, 2017). The policy has remained largely unchanged since its implementation and continues to operate today. RTB significantly influenced the housing sector's ownership structure, with homeownership among households increasing from 55% in 1979 to over 70% in the early 2000s (see Figure 1). By the mid-2000s, approximately half of the public housing stock, or 2.8 million properties, had been sold through RTB (Jones & Muriel, 2006) (see Figure 2).

Figure 1: Housing Tenure Shares by Tenure Type: England and Wales 1918-2011



Source: Disney and Luo (2017): Chart 1, calculated from Office for National Statistics (2013).

Figure 2: Right-to-Buy sales of Council Housing in England, 1980-81 to 2021-22



Source: DLUHC (2023b), Live Tables on Social Housing Sales: Table 691b annual.

Despite its far-reaching impact, the RTB policy has received limited attention from economists. Disney and Luo (2017) offer a theoretical analysis of the policy's social welfare implications and explore the effects of various policy adjustments. While Disney et al. (2021) provides the only empirical study of the policy and examine its long-run effects on crime rates through an instrumental variable long-differenced model, finding that RTB significantly reduced property and violent crimes.

In other countries, public housing privatisation policies have been studied to empirically assess the theorised effects of homeownership on various household- and community-level economic outcomes often cited by policymakers as justification for such policies (Haus-

man et al., 2022; Sodini et al., 2021).

This analysis contribute to this literature by estimating the effect of a public housing privatisation policy which led to massive variations in the UK on residential energy consumption and testing the hypothesis of a differential effect of across property building types on energy consumption. Understanding the multi-dimensional effects of policies in the residential sector is crucial to design effective policies. I show that the legacy of the RTB policy may have contributed to the energy efficiency gap and hindered the ability of the UK government to decarbonise its residential sector.

2.2 The Energy Efficiency Gap

The concept of the energy efficiency gap refers to the discrepancy between the economically optimal level of energy efficiency and the level actually achieved (Jaffe & Stavins, 1994). While energy consumption produces negative externalities, such as those from greenhouse gas emissions, leading to market failures, the energy efficiency gap literature indicates that investment inefficiencies also contribute to suboptimal energy consumption (Allcott & Greenstone, 2012). Addressing these inefficiencies could potentially yield significant welfare benefits.

Empirical evidence on the energy efficiency gap is inconsistent. Engineering model estimates report a substantial energy efficiency gap (McKinsey, 2009). However, an expanding body of research argues that these prediction models tend to overestimate the returns on energy investments due to unobserved factors and behavioural responses, including rebound effects (Allcott & Greenstone, 2012, 2017; Christensen et al., 2021; Coyne et al., 2018; Fowlie et al., 2018; Zivin & Novan, 2016). Nevertheless, some studies identify considerable potential for energy savings. Utilising the EPC database, Fetzer et al. (2023) estimate that upgrading the UK building stock to its highest energy efficiency standard could save 30% of the country's energy consumption. However, due to ill-calibrated subsidies and self-selection issues, current policies fail to harness this potential, leading to inefficient and regressive outcomes (Allcott & Greenstone, 2017; Fetzer et al., 2023). Consequently, it is crucial to understand the determinants of households' low energy investment rates for future policies targeting residential stock retrofitting.

Economists identify various factors that could potentially account for investment inefficiencies in energy-efficient products (Allcott & Greenstone, 2012; Gerarden et al., 2017; Jaffe & Stavins, 1994). Empirical evidence indicates that market failures can emerge from high non-monetary costs, such as imperfect information and inattention (Allcott & Taubinsky, 2015; Fowlie et al., 2015). Other explanations have been proposed, including

institutional costs. Fetzer (2023) shows that UK legislation on conservation areas presents significant barriers to retrofitting investments, resulting in 3.2 million tons of preventable CO2 emissions per year. Additionally, misaligned incentives in the rental sector, known as the principal-agent problem, may partly explain why rented properties are generally less efficient than owner-occupied ones (Druckman & Jackson, 2008; Krishnamurthy & Kriström, 2015; Lang et al., 2022).

This study adds to the residential energy efficiency gap literature by presenting suggestive evidence of the importance of collective decision inefficiencies in explaining low investments in energy-saving technologies.

2.3 Collective Decision and Retrofitting Decisions

This analysis examines the hypothesis that the RTB policy has differential effects on energy consumption across property building types, motivated by potential collective decision frictions arising from the fragmentation of ownership structures in multi-unit complexes.

Following WWII, local authorities prioritised constructing affordable apartment blocks to address the high demand for housing due to war destruction and a growing population, particularly in urban centres. In 1980, apartments constituted 37.8% of the UK council housing stock, while in Hackney, the figure was 79.9% (Disney & Luo, 2017), indicating a high likelihood of RTB sales in the local authority. Although open data for Haringey is unavailable, the council's location in inner London and border to Hackney suggest comparable characteristics.

Prior to the implementation of the RTB policy, a majority of council apartments were situated in wholly council-owned multi-unit complexes. However, the introduction of the RTB policy resulted in a fragmentation of the ownership structures within these buildings. In most cases, local authorities retained freehold on buildings comprising a mix of council housing tenants and RTB leaseholders (Bright & Weatherall, 2017). Consequently, collective decisions became necessary regarding communal aspects of the buildings, such as the roof, facade, entrance hall, lifts, staircases, and exterior surfaces like windows (Economidou, 2017). When a freeholder local authority intends to upgrade its housing stock for its tenants, it must collaborate with RTB leaseholders. Given that most retrofitting efforts in multi-unit complexes, such as upgrading the building envelope, insulating communal walls, floors, and roof spaces, or changing heating systems, must occur at the building level, these collective decision-making settings may generate frictions that result in underinvestment in energy efficiency upgrades (Bright & Weatherall, 2017; Economidou, 2017).

These frictions can emerge in public good provision settings due to the classical free-rider problem, which may vary in magnitude depending on group-size effects (Hardin, 1968; Olson, 1971). Experimental evidence broadly supports the free-rider effect hypothesis, though the magnitude of the effect varies, and evidence for the hypothesis that a group's ability to provide the optimal level of a pure public good is inversely related to group size remains inconclusive (Isaac & Walker, 1988; Marwell & Ames, 1979). Collective decisions also involve non-monetary costs associated with time commitment, coordination effort, conflict resolution, cognitive load, and administrative burden. Additional obstacles faced by residents of multi-unit complexes include legal barriers specific to the leaseholder-freeholder system, which, for example, preclude freeholders from reclaiming the costs of energy efficiency improvements (Bright & Weatherall, 2017).

Drawing upon the existing literature, an additional positive effect of the RTB policy on residential energy consumption in flats should be observed and is to be tested in this analysis.

3 Data and Methodology

3.1 Data

Residential Energy Consumption

The Department for Business, Energy & Industrial Strategy supplies domestic energy consumption data at the postcode level. For this study, the analysis relies on the 2019 mean domestic gas consumption in kWh data. The focus on gas as a measure of residential energy consumption is justified by its predominant role in the UK's residential energy mix, accounting for 64.4% in 2019. Moreover, gas is primarily consumed for purposes sensitive to building-level retrofitting efforts, such as space heating (DBEIS, 2020). The utilisation of 2019 data aims to mitigate potential confounding effects arising from the Covid-19 pandemic and subsequent energy crisis.

RTB Sales and Current Council Housing Stock

Under the Freedom of Information Act 2000, public authorities are required to disclose information to citizens upon request. Utilising the "WhatDoTheyKnow" online platform, freedom of information requests were submitted to all local authorities in England and Wales concerning their existing council housing stock and the properties sold under the

RTB policy since its introduction in 1980[1]. Only Hackney and Haringey councils provided comprehensive postcode-level datasets in time for this project, covering the period from 1980 to 2022 as both responses were received in late December.

In Hackney, according to the provided data, 1,215 postcodes experienced at least one property sale under the RTB scheme (approximately 26.7% of active postcodes in the local authority), amounting to 9,364 properties sold. This represents 80.6% of the aggregated official figure reported by the Department for Levelling Up, Housing & Communities (DLUHC, 2023b). For Haringey, 1,593 postcodes had at least one RTB property sale (approximately 36.2% of active postcodes in the local authority), totalling 10,245 properties sold, which accounts for 96% of the official figure. This discrepancy is likely attributable to human error, as councils were not digitised for a significant portion of the policy's duration. The current council stock in Hackney and Haringey stands at 21,770 and 14,850 properties, respectively, representing 100% and 99.1% of the aggregate official figures for 2021-2022 (DLUHC, 2022).

Unfortunately, the provided data does not include individual sale dates or use start dates of council properties, thus incorporating observations that occurred after 2019. In both Hackney and Haringey, 110 council properties were sold through the RTB post-2019. While these sales were likely not homogeneously distributed across postcodes, it is assumed that the number of RTB sales includes random measurement errors. Likewise, it is assumed that there were no changes in the current council stock between 2019 and 2022. The implications and limitations of assumptions are dicussed in Section 4.

Dwelling Stock

The 2011 Census Postcode Headcounts and Household Estimates offer information on the number of occupied households per postcode. In the absence of publicly available data on the current dwelling stock per postcode, the occupied household estimates are utilised as a proxy. Additionally, this dataset supplies the total headcount per gender, enabling the derivation of the average household size and proportion of females in each postcode.

Building Type Composition

The Energy Performance Certificate (EPC) database contains 24 million certificates that classify property building types as flat, house, maisonette, or bungalow. This database encompasses 79,744 unique properties in Hackney and 76,570 in Haringey, accounting for 70.5% and 68.6% of the 2021 official total dwelling stock, including vacant properties,

[1]Requests are available here:
https://www.whatdotheyknow.com/request/social_housing_and_right_to_buy_20#describe_state_form_1
https://www.whatdotheyknow.com/request/social_housing_and_right_to_buy_22#describe_state_form_1

respectively (DLUHC, 2023a). EPC legal requirements were introduced in 2007, mandating that all residential properties have an EPC upon construction, sale, or lease. Consequently, some properties currently lack an EPC and are not included in the database. This database is utilised to derive a proxy for the contemporary distribution of property building types across postcodes.

Council Tax

Finally, the Valuation Office Agency (VOA), a government body responsible for valuing properties for Council tax purposes, supplies data on the council tax band assigned to each registered domestic property. These bands range from A to H and are used to derive the average council tax band and standard deviation per postcode.

3.2 Estimation Strategy

Following Fetzer et al. (2023), the residential energy consumption of postcode i is a function of at least three factors:

$$E_i = f(What_i, Who_i, How_i) \tag{1}$$

The *What* factor represents the composition of the dwelling stock in postcode i, including variables such as the distribution of property types and the predominant materials used in construction. Domestic energy consumption primarily arises from space heating, hot water generation, room lighting, and appliance usage. Certain properties inherently consume more energy due to their physical attributes; for instance, poorly insulated and draughty buildings lose heat more rapidly.

The *Who* factor encompasses the characteristics of the residents, including household size and composition. For example, households with different socio-economic backgrounds may exhibit varying levels of energy demand.

The *How* factor pertains to individual preferences, such as perceptions of comfortable indoor temperatures or the choice to use dishwashers instead of washing dishes by hand, both of which influence energy consumption levels. Additionally, these factors can interact nonlinearly, with energy demand potentially being higher in a poorly insulated property and further exacerbated if occupants prefer warmer indoor temperatures.

In this study, I investigate the possibility of a heterogeneous impact of RTB sales across property building types, which may arise due to the altered decision-making processes caused by ownership fragmentation following council apartment sales in multi-unit com-

plexes. This potential effect can be attributed to the legal framework governing energy-related decisions, such as the implementation of insulation work. Consequently, the *What* category of factors can be expanded to encompass specific decision-making systems that influence energy use faced by residents.

Including the proportion of flats in a postcode, however, would not exclusively measure the effect of collective decision-making, as it may be confounded by other factors, such as inherent characteristics of flats that generally render them more energy-efficient. To address this issue exploit variations from the RTB policy. I construct a variable called PRIVATISED, which represents the extent of a postcode's exposure to this situation and is defined as the proportion of RTB sales out of the current dwelling stock in a postcode. Additionally, I introduce the variable FLAT, which captures the contemporaneous share of flats in a postcode, serving as a proxy for the likelihood that an RTB sale involved a flat.

Based on available data, I estimate the following cross-sectional fixed-effect model of 2019 average residential gas consumption in postcode i :

$$log(\text{GAS}_{ij}) = \delta_j + \beta_1 \text{PRIVATISED}_i + \beta_2 \text{FLAT}_i + \beta_3 \text{PRIVATISED}_i \times \text{FLAT}_i + \boldsymbol{\gamma} X_i' + \varepsilon_i \quad (2)$$

where GAS_{ij} is the natural logarithm of average residential gas consumption in 2019 in postcode i and Lower Layer Super Output Area (LSOA) j, PRIVATISED_i is the share of properties sold under the RTB policy out of the current dwelling stock, FLAT_i is the contemporaneous share of flats, and X_i' is a vector of postcode-level covariates.

In Equation (2), the interaction term represents the likelihood that a property in postcode i has undergone an RTB sale and is a flat. Consequently, β_3 captures the additional impact of RTB sales on the average residential gas consumption for flats in postcode i compared to non-flats.

LSOAs are geographical areas used by the ONS for the Census and comprise an average of 20.72 properties in Hackney and 22.79 in Haringey within the analysis dataset. Incorporating LSOA fixed-effects controls for unobserved heterogeneity specific to each LSOA, thereby mitigating the influence of omitted variable bias from the *What*, *Who*, and *How* categories. For instance, average temperature and building age may vary across LSOA influencing energy demand.

To enhance identification and reduce omitted variable bias, I add postcode-level covariates. These include the mean council tax band, which is a function of the average property

value in a postcode, and the current share of social housing, capturing factors from both the *What* and *Who* categories. For example, a property with a relatively high value is likely to be larger and inhabited by households with higher incomes, potentially increasing gas consumption. Additionally, I include the average household size and the share of females to account for factors from the *Who* category. For instance, larger households typically consume more energy than smaller ones.

Summary statistics for the analysis dataset from each council are presented in Appendix A. In Hackney, 65.5% of the active postcodes have complete observations, while 75.1% in Haringey.

4 Estimation Results and Limitations

4.1 Estimation Results

Table 1 presents the estimation results of regression testing the differential impact of the RTB policy across flat and non-flat properties within the boroughs of Hackney and Haringey (see Appendix B for the comprehensive regression tables). For each local authority, four separate models are estimated, each employing LSOA clustered standard errors. The baseline model (1) includes controls for the share of properties privatised as a result of the RTB policy since its initiation, the share of flats, and an interaction term combining these two variables. The second model extends the baseline by adding LSOA fixed-effects. The third model features only covariates, while the fourth model, the preferred specification, incorporates both LSOA fixed-effects and covariates, thus estimating equation (2). The same suite of models is estimated on a combined sample of both Hackney and Haringey. The outcomes are reported in Table 2, along with the coefficients associated with the full list of covariates.

The baseline model (1) accounts for approximately 24% to 27% of the variability observed in residential gas consumption at the postcode level across the three samples. However, the preferred model (4) substantially enhances this explanatory power, capturing approximately 48% to 61% of the variance in the data, suggesting a decent explanatory power.

The coefficients associated with the share of privatised properties are consistently negative and statistically significant at least at the 5% level across all model specifications, except in the case of Haringey. However, as I incrementally introduce additional parameters to the model, these coefficient estimates tend to decrease, which could signal the presence of a considerable omitted variable bias.

Table 1: The Differiential Effect of the RTB policy across flats and non-flats in Hackney

Dependent Variable:	log(GAS)			
Model:	(1)	(2)	(3)	(4)
Covariates	No	No	Yes	Yes
Fixed-effects	No	Yes	No	Yes
Hackney				
Privatised	-0.008391***	-0.006181***	-0.003414***	-0.002371***
	(0.000869)	(0.000718)	(0.000805)	(0.000701)
Flat	-0.006897***	-0.006463***	-0.003707***	-0.003692***
	(0.000350)	(0.000351)	(0.000394)	(0.000369)
Privatised × Flat	0.000064***	0.000053***	0.000071***	0.000059***
	(0.000017)	(0.000012)	(0.000016)	(0.000012)
Fit statistics				
Observations	2,984	2,984	2,984	2,984
R^2	0.23879	0.38366	0.39386	0.48215
Within R^2		0.19681		0.32515
Haringey				
Privatised	-0.008421***	-0.004356***	-0.001721**	-0.001070
	(0.000931)	(0.000862)	(0.000662)	(0.000797)
Flat	-0.006691***	-0.006473***	-0.002947***	-0.002836***
	(0.000581)	(0.000445)	(0.000440)	(0.000295)
Privatised × Flat	0.000072***	0.000059***	0.000038***	0.000032***
	(0.000015)	(0.000012)	(0.000011)	(0.000008)
Fit statistics				
Observations	3,304	3,304	3,304	3,304
R^2	0.25345	0.45532	0.52236	0.60616
Within R^2		0.22986		0.44313

Fixed-effects (LSOA) for models (2) and (4)
Clustered (LSOA) standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

Table 2: The Differiential Effect of the RTB policy across flats and non-flats in the combined sample of Haringey and Hackney

Dependent Variable:	log(GAS)			
Model:	(1)	(2)	(3)	(4)
Variables				
Constant	9.83639***		8.63056***	
	(0.026602)		(0.065555)	
Privatised	-0.008611***	-0.005205***	-0.001998***	-0.001329**
	(0.000704)	(0.000603)	(0.000528)	(0.000537)
Flat	-0.007170***	-0.006436***	-0.003339***	-0.003305***
	(0.000351)	(0.000294)	(0.000299)	(0.000238)
Privatised × Flat	0.000070***	0.000055***	0.000053***	0.000045***
	(0.000011)	(0.000008)	(0.000009)	(0.000007)
Mean Council Tax Band			0.142196***	0.121777***
			(0.009115)	(0.011333)
S.D. Council Tax Band			0.158350***	0.152006***
			(0.014521)	(0.013595)
Council Housing			-0.001346***	-0.001120***
			(0.000405)	(0.000421)
Average Household Size			0.159311***	0.147553***
			(0.013519)	(0.013116)
(Average Household Size)^2			-0.004164***	-0.003767***
			(0.000429)	(0.000403)
Female			-0.000682	-0.000946
			(0.000738)	(0.000673)
Fixed-effects				
LSOA	No	Yes	No	Yes
Fit statistics				
Observations	6,288	6,288	6,288	6,288
R^2	0.27096	0.45254	0.47560	0.56585
Within R^2		0.21220		0.37525

Clustered (LSOA) standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

Despite this, the observed negative effect is in line with established findings from the economic literature that suggest homeowners tend to exhibit higher energy efficiency when compared to renters (Druckman & Jackson, 2008; Krishnamurthy & Kriström, 2015; Lang et al., 2022).

Similarly, the coefficient estimates corresponding to the share of flats indicate a diminished energy demand for apartments relative to other types of residential buildings. This observation aligns with empirical findings in the literature (Kavousian et al., 2013).

Conversely, the point estimates for the coefficient of interest - the interaction term - exhibit relative stability, particularly within the Hackney sample, thereby alleviating concerns regarding selection on unobservables (Altonji et al., 2005). Furthermore, despite recent empirical investigations that underscore the role of energy efficiency in homebuyers' decisions (Fuerst et al., 2015), it is crucial to remember that the majority of RTB sales occurred during a time when energy considerations were not as paramount as they are in the contemporary context (see Figure 2). In this earlier period, domestic energy prices were relatively low and exhibited less volatility than the post-2008 era (see Appendix C). Furthermore, information regarding residential energy efficiency was not as readily accessible to potential homebuyers as it is today. It should be noted that EPCs, which rate the energy efficiency of a building and offer suggestions for improvement, were introduced in England and Wales only in 2007 in accordance with the European Union's Energy Performance of Buildings Directive. In fact, a significant majority of the RTB sales - 90.1% in Hackney and 88.8% in Haringey - occurred before the introduction of EPCs. This lends further weight to the argument that endogeneity concerns are likely to be minimal in this analysis.

I find that, in postcodes featuring a local-authority average proportion of flats in the residential property stock, a one standard deviation increase in the share of privatised housing through the RTB policy out of the current dwelling stock is associated with an additional 6.79% increase in average residential gas consumption in Hackney and a 2.92% increase in Haringey. The equivalent effect in the combined sample is estimated to be 4.62%.

In order to check the robustness of these findings, I replaced the proportion of flats variable in Model (4) with alternative residential building types. This equates to separately assessing the differential impact of the RTB policy across three distinct types of residential buildings. If the primary channel of this additional positive effect of the RTB policy on gas consumption is indeed collective decision-making frictions, then a parallel examination for other property building types should yield no effects or perhaps even

negative effects attributable to the alignment of ownership levels and the one of retrofit works. The results of this analysis for each sample are detailed in Appendix D, with all coefficient estimates being either statistically insignificant from zero or negative and statistically significant, thereby supporting the hypothesis of this study.

4.2 Model Validity and Bootstrapping Analysis

The interpretation of these estimates warrants a degree of caution. Diagnostic examinations of Model (4) for each subset are documented in Appendix E, suggesting an absence of functional form misspecification. Nevertheless, the analysis of residuals strongly indicates the presence of heteroskedasticity and non-normality. To accommodate heteroskedastic errors, standard errors are clustered at the LSOA level, and as demonstrated in Tables 1 and 2, coefficients of significance persistently retain statistical significance at the 1% level. However, the residuals also exhibit high kurtosis, which has the potential to bias standard errors and compromise the validity of the hypothesis testing procedure.

To address the issue of non-normality, a bootstrapping analysis is undertaken to estimate the parameters of model (4) without relying on the normality assumption. The bootstrapping procedure is founded on the assumptions that the sample is a unbiased representation of the population and that the model is correctly specified. The sample encompasses all postcodes with complete observations for the variables included in the model. Despite the removal of some observations due to missing values, this represents a substantial fraction of the population of interest to this analysis. In addition, the functional form test coupled with the high explanatory power of the model suggests a correct model specification.

A bootstrapping of Model (4) is executed with 10,000 replicates. The Bias-Corrected and Accelerated confidence intervals of the coefficient of interest for each sample are displayed in Table 3, and distribution statistics of the coefficients are provided in the Appendix F. Confidence intervals are unambiguously positive for all samples at the 99% level, thereby supporting the hypothesis of a positive additional effect of the RTB policy on gas consumption for flats relative to non-flats.

Table 3: Confidence Intervals of the Bootstrapped Coefficient of Interest

Dependent Variable:		log(GAS)	
Sample:	Hackney	Haringey	Whole Sample
95%			
Privatised × Flat	(0.000037, 0.000078)	(0.000017, 0.000046)	(0.000033, 0.000058)
99%			
Privatised × Flat	(0.000030, 0.000084)	(0.000013, 0.000051)	(0.000029, 0.000061)

Displayed are Bias-Corrected and Accelerated bootstrap confidence intervals.

4.3 Assumptions and Potential Bias

This analysis hinges on a set of assumptions, the validity of which may be subject to scrutiny. The foremost among these is the supposition that estimates of total occupied households and average household size from 2011 serve as an apt stand-in for the 2019 dwelling stock at the postcode level. The total occupied household variable underpins the construction of all variables in relative terms. Naturally, both the dwelling stock and the number of occupied households evolved between 2011 and 2019. For the proxy to retain validity and for the estimates to remain consistent, these shifts must have been randomly distributed across postcodes, a scenario that would only augment the magnitude of the standard errors. However, the dwelling stock and the count of occupied households in a postcode react to distinct factors, such as demographic factors or housing market conditions, that could themselves exert an effect on residential gas consumption, thereby inducing bias.

The next assumption is that the proportion of flats in a postcode, as documented in the EPC database, is indicative of the likelihood that a council property sold via the RTB scheme was a flat. This assumption becomes necessary due to the unavailability of the precise variable of interest: the proportion of RTB sales that were flats in a given postcode. The EPC database, however, considers the entirety of the dwelling stock in a postcode, inclusive of private dwellings. Given that the council housing stock in Hackney and Haringey likely comprises a higher proportion of flats relative to its total stock than the private sector, this approach may underestimate the actual figure and bias the estimates outward. This assumption is further complicated by the fact that the database does not accommodate the time varying prevalence of flats in the council stock since the advent of the RTB policy.

Another critical assumption is that the contemporaneous council tax and EPC data represent a fair approximation of the 2019 scenario. Nevertheless, these figures have most likely undergone changes since 2019, in correlation with variables influencing residential gas consumption, once again raising concern of bias in the estimates.

To address these issues, future research endeavours could aim to collect data on RTB sales by residential building type. However, given that the policy was enacted before the importance of systematic data collection was widely recognised and the advent of enabling technology., most local authorities did not document such data. Moreover, assembling panel data on RTB sales, council housing stock, and dwelling stock at the postcode level could help enhance the identification of the heterogeneous impact of the policy on gas consumption by accounting for the dynamics of these variables over time.

Despite these limitations, this study provides valuable insights into the heterogeneous impact of the RTB policy on residential gas consumption across flats. However, the findings should be interpreted with caution, and further research is needed to fully understand the complexities of this policy's long-lasting effects.

5 Conclusion

This research presents a pioneering exploration of the heterogeneous impact of the RTB policy on residential gas consumption across flats and non-flats. Utilising granular, postcode-level data, the study employs cross-sectional fixed-effects regression analysis and estimates that, in postcodes with an local-authority average proportion of flats, a one standard deviation increase in the share of RTB privatised properties is associated with an additional 6.79% and 2.92% rise in average residential gas consumption in Hackney and Haringey, respectively.

Whilst the validity of the model may be subject to discussion, the results indicative of a significant additional positive effect for flats, as opposed to non-flats, are corroborated by a bootstrapping analysis predicated on a separate set of assumptions. The study advances the hypothesis that the primary causal pathway is through the collective decision-making frictions associated with the provision of public goods relating to energy-efficient upgrades. This friction is generated by the fragmentation of ownership within multi-unit complexes.

However, the analysis is not impervious to potential measurement errors in the variables, which may introduce bias. Future research endeavours should concentrate on the collection of more precise data to mitigate this issue. Despite this, the findings of this

research make a valuable contribution to the literature on factors that contribute to the energy efficiency gap, and indeed, stimulate further investigation.

Given the substantial influence of the RTB policy within the housing sector, it would be beneficial for future research to extend its scope to other local authorities to enhance external validity. Currently, further postcode-level data is being examined following responses from councils to Freedom of Information requests. In addition, a study at the local authority level across England and Wales is underway, employing a long-differenced model. This ongoing research aims to provide a more comprehensive understanding of the policy's effects on residential energy consumption.

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Appendix

Appendix A: Summary Statistics

Table 4: Hackney Summary Statistics

Statistic	N	Mean	St. Dev.	Min	Max
RTB sales	2,984	3.013	5.458	0	39
Current Council Stock	2,984	6.665	11.663	0	83
Headcount	2,984	74.762	50.287	1	437
Occupied Households	2,984	30.416	20.045	1	165
log(GAS)	2,984	9.248	0.448	6.047	10.591
GAS	2,984	11,317.080	4,619.044	422.684	39,791.300
Privatised	2,984	10.186	17.154	0.000	87.500
Mean Council Tax Band	2,984	3.245	1.069	1.000	7.000
S.D. Council Tax Band	2,984	0.580	0.458	0.000	3.464
Flat	2,984	67.101	34.076	0.000	100.000
House	2,984	22.552	32.308	0.000	100.000
Bungalow	2,984	0.413	4.731	0.000	100.000
Maisonette	2,984	9.934	17.250	0.000	100.000
Female	2,984	50.158	8.546	0.000	100.000
Council Housing	2,984	21.054	31.209	0.000	150.000
Average Household Size	2,984	2.503	0.948	1.000	36.417

Table 5: Haringey Summary Statistics

Statistic	N	Mean	St. Dev.	Min	Max
RTB sales	3,304	2.943	5.566	0	39
Current Council Stock	3,304	4.186	9.035	0	77
Headcount	3,304	73.242	46.365	3	315
Occupied Households	3,304	29.065	18.417	1	170
log(GAS)	3,304	9.466	0.456	5.368	10.925
GAS	3,304	14,129.610	6,083.848	214.474	55,564.540
Privatised	3,304	10.329	17.703	0.000	100.000
Mean Council Tax Band	3,304	3.835	1.264	1.000	8.000
S.D. Council Tax Band	3,304	0.662	0.527	0.000	3.536
Bungalow	3,304	0.590	5.564	0.000	100.000
Flat	3,304	51.523	36.919	0.000	100.000
House	3,304	42.649	38.796	0.000	100.000
Maisonette	3,304	5.238	11.772	0.000	100.000
Female	3,304	50.667	7.885	0.000	100.000
Council Housing	3,304	13.647	23.757	0.000	116.667
Average Household Size	3,304	2.568	0.656	1.000	9.556

Table 6: Whole Sample Summary Statistics

Statistic	N	Mean	St. Dev.	Min	Max
RTB sales	6,288	2.976	5.515	0	39
Current Council Stock	6,288	5.362	10.438	0	83
Headcount	6,288	73.964	48.268	1	437
Occupied Households	6,288	29.706	19.217	1	170
log(GAS)	6,288	9.363	0.465	5.368	10.925
GAS	6,288	12,794.910	5,616.182	214.474	55,564.540
Privatised	6,288	10.261	17.443	0.000	100.000
Mean Council Tax Band	6,288	3.555	1.212	1.000	8.000
S.D. Council Tax Band	6,288	0.623	0.497	0.000	3.536
Bungalow	6,288	0.506	5.186	0.000	100.000
Flat	6,288	58.915	36.436	0.000	100.000
House	6,288	33.112	37.239	0.000	100.000
Maisonette	6,288	7.467	14.815	0.000	100.000
Female	6,288	50.425	8.209	0.000	100.000
Council Housing	6,288	17.162	27.791	0.000	150.000
Average Household Size	6,288	2.537	0.808	1.000	36.417

Appendix B: Comprehensive Regression Tables

Table 7: The Differiential Effect of the RTB policy across flats and non-flats in Hackney

Dependent Variable:	log(GAS)			
Model:	(1)	(2)	(3)	(4)
Variables				
Constant	9.75771***		8.76518***	
	(0.029658)		(0.101332)	
Privatised	-0.008391***	-0.006181***	-0.003414***	-0.002371***
	(0.000869)	(0.000718)	(0.000805)	(0.000701)
Flat	-0.006897***	-0.006463***	-0.003707***	-0.003692***
	(0.000350)	(0.000351)	(0.000394)	(0.000369)
Privatised × Flat	0.000064***	0.000053***	0.000071***	0.000059***
	(0.000017)	(0.000012)	(0.000016)	(0.000012)
Mean Council Tax Band			0.081167***	0.083921***
			(0.011028)	(0.012359)
Council Housing			-0.001880***	-0.001497***
			(0.000472)	(0.000478)
Average Household Size			0.179704***	0.145835***
			(0.019595)	(0.018842)
Average Household Size^2			-0.004528***	-0.003602***
			(0.000513)	(0.000493)
S.D. Council Tax Band			0.168803***	0.156609***
			(0.018723)	(0.019217)
Female			-0.000307	-0.000058
			(0.001064)	(0.000991)
Fixed-effects				
LSOA	No	Yes	No	Yes
Fit statistics				
Observations	2,984	2,984	2,984	2,984
R^2	0.23879	0.38366	0.39386	0.48215
Within R^2		0.19681		0.32515

Clustered (LSOA) standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

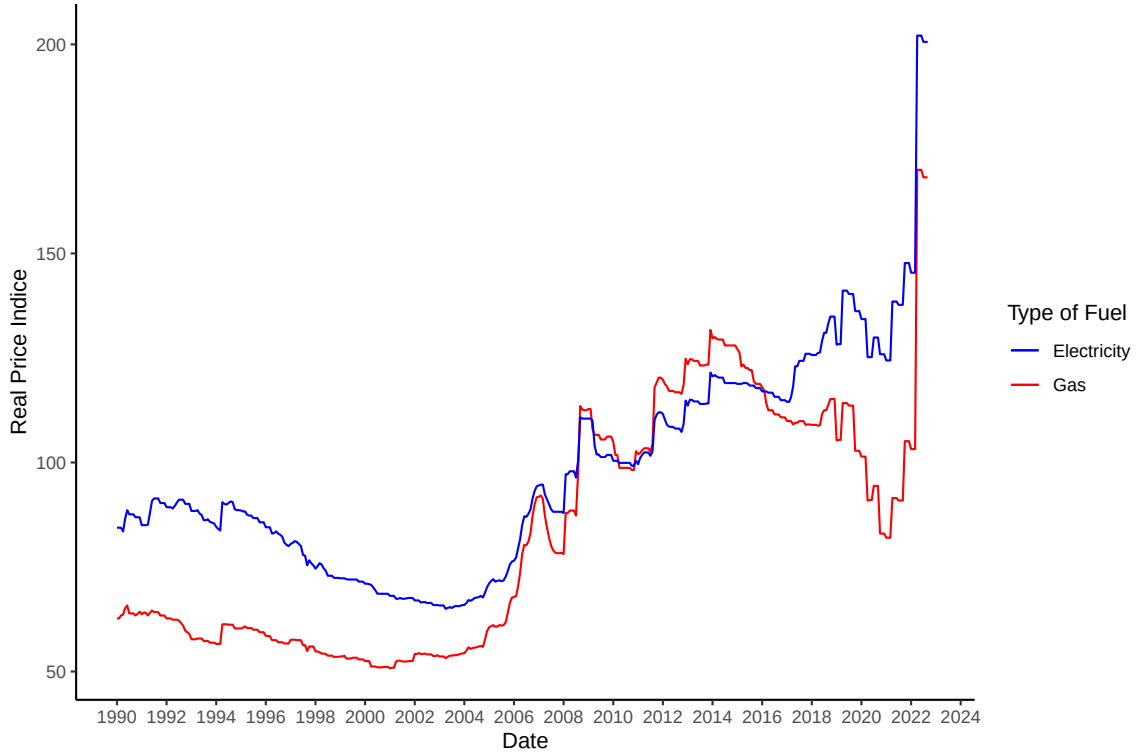
Table 8: The Differiential Effect of the RTB policy across flats and non-flats in Haringey

Dependent Variable:	log(GAS)			
Model:	(1)	(2)	(3)	(4)
Variables				
Constant	9.86516***		8.30541***	
	(0.037474)		(0.111223)	
Privatised	-0.008421***	-0.004356***	-0.001721**	-0.001070
	(0.000931)	(0.000862)	(0.000662)	(0.000797)
Flat	-0.006691***	-0.006473***	-0.002947***	-0.002836***
	(0.000581)	(0.000445)	(0.000440)	(0.000295)
Privatised × Flat	0.000072***	0.000059***	0.000038***	0.000032***
	(0.000015)	(0.000012)	(0.000011)	(0.000008)
Mean Council Tax Band			0.164254***	0.144038***
			(0.009648)	(0.016682)
Council Housing			-0.000723	-0.000718
			(0.000681)	(0.000695)
Average Household Size			0.389933***	0.388329***
			(0.060383)	(0.054309)
Average Household Size^2			-0.042863***	-0.042285***
			(0.009327)	(0.008692)
S.D. Council Tax Band			0.147165***	0.145685***
			(0.022683)	(0.018645)
Female			-0.002072**	-0.002101**
			(0.001027)	(0.000877)
Fixed-effects				
LSOA	No	Yes	No	Yes
Fit statistics				
Observations	3,304	3,304	3,304	3,304
R^2	0.25345	0.45532	0.52236	0.60616
Within R^2		0.22986		0.44313

Clustered (LSOA) standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

Appendix C: Domestic Energy Prices

Figure 3: Real Monthly Domestic Energy Price Indices in England, January 1990-December 2022, Base 100 in 2010



Source: DESNZ (2023), Consumer Prices index UK fuel components in the UK.

Appendix D: The Heterogeneous Effect of the RTB policy across other Building Types

Table 9: The Differiential Effect of the RTB policy across other residential building types

Dependent Variable:	log(GAS)		
Z:	Bungalow	Maisonette	House
Hackney			
Privatised × Z	-0.000004	-0.000052**	-0.000047***
	(0.000052)	(0.000023)	(0.000011)
Haringey			
Privatised × Z	0.000094	0.000007	-0.000035***
	(0.000147)	(0.000026)	(0.000009)
Whole Sample			
Privatised × Z	0.000082	-0.000020	-0.000043***
	(0.000061)	(0.000016)	(0.000007)

Fixed-effects (LSOA) and covariates included.
Clustered (LSOA) standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

Appendix E: Model Validity Tests

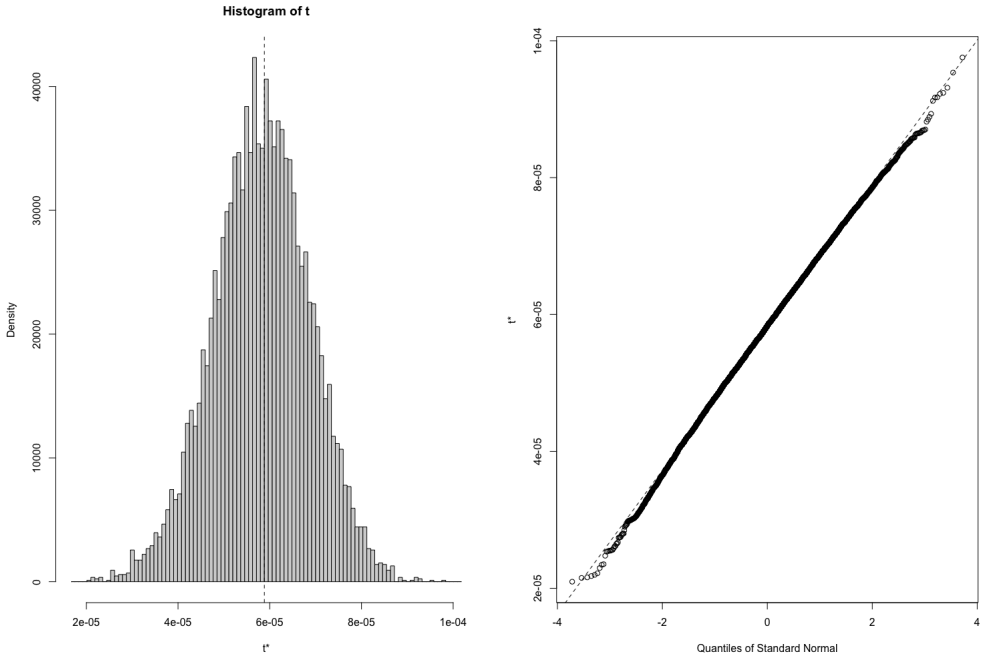
Table 10: Test of Model (4) Validity

Dependent Variable:	log(GAS)		
Sample:	Hackney	Haringey	Whole Sample
Functional Form: RESET(2)			
$\Pr(>\chi^2)$	0.5278	0.5258	0.3757
H0 Rejection	Fail at 10%	Fail at 10%	Fail at 10%
Heteroskedasticity: Breush-Pagan			
$\Pr(>\|t\|)$	$2.2e^{-16}$	$2.2e^{-16}$	$2.2e^{-16}$
H0 Rejection	Reject at 1%	Reject at 1%	Reject at 1%
Normality: Jarque-Bera			
P-value	$2.2e^{-16}$	$2.2e^{-16}$	$2.2e^{-16}$
H0 Rejection	Reject at 1%	Reject at 1%	Reject at 1%

All tests are conducted on model (4) from Table 1 and 2.

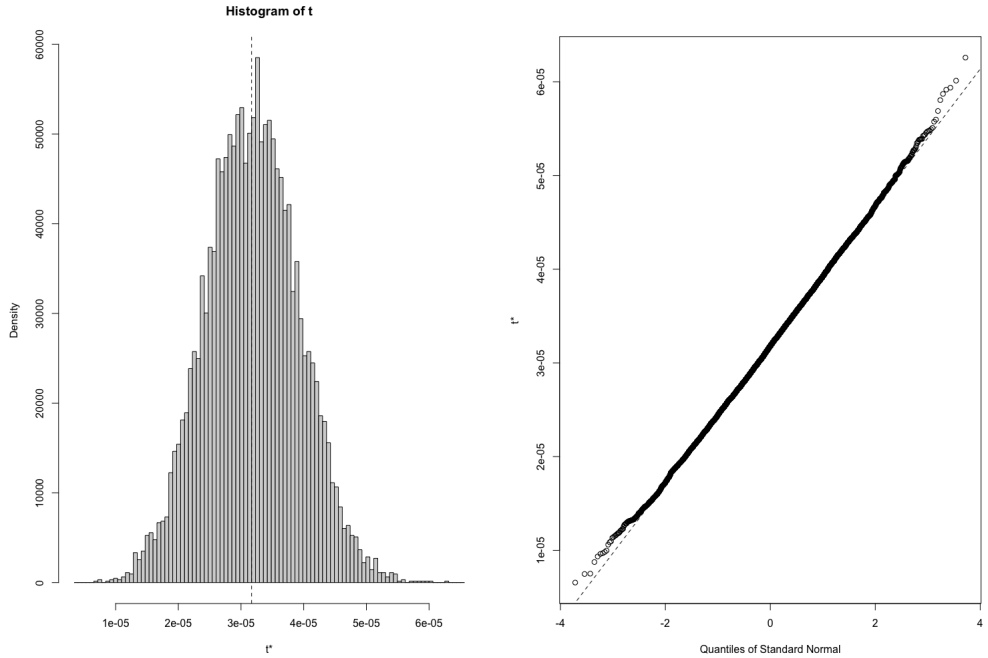
Appendix F: Bootstrapped Coefficient Distributions

Figure 4: Distribution of the Bootstrapped Privatised × Flat coefficient for Hackney.



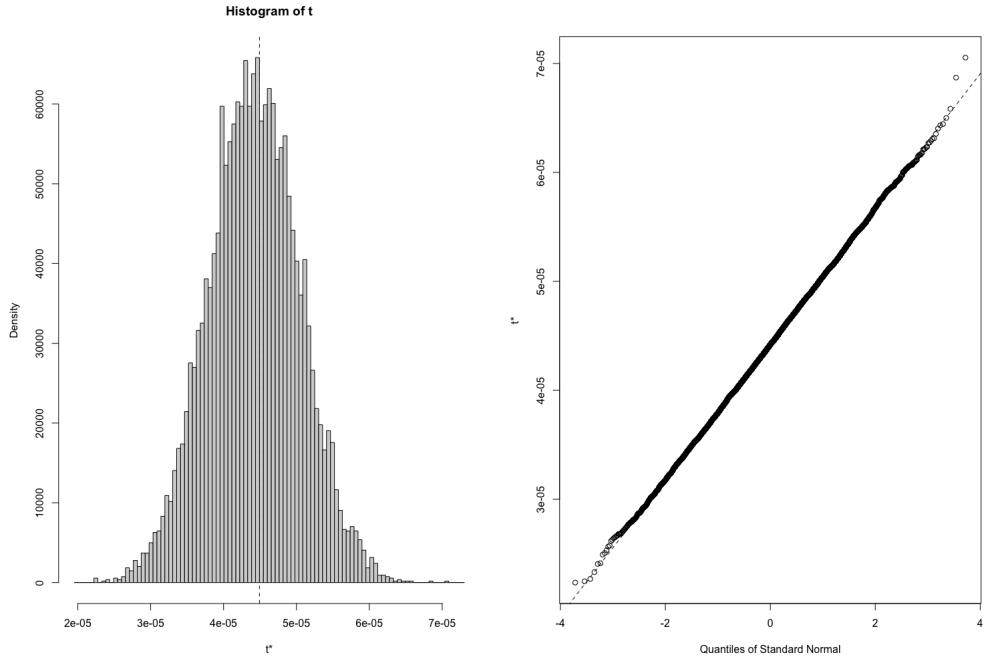
Notes: *Bootstrapped coefficient with 10,000 replicates.*

Figure 5: Distribution of the Bootstrapped Privatised × Flat coefficient for Haringey.



Notes: *Bootstrapped coefficient with 10,000 replicates.*

Figure 6: Distribution of the Bootstrapped Privatised × Flat coefficient for the whole sample.



Notes: *Bootstrapped coefficient with 10,000 replicates.*