The Equilibrium Effects of Taxing Property Investors: A Welfare Analysis.

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Abstract

Housing prices have seen an unprecedented increase in developed countries, following an explosion of real-estate investment. This paper studies whether taxing property investors can increase welfare, by analyzing the equilibrium effects on the housing market. First, I estimate the impact of a 3% transfer-tax surcharge on 'buyers of additional properties' introduced in the UK in 2016, which targeted property investors but not owner-occupiers. Using an incremental diff-in-diff estimator, I document that the surcharge reduced pre-tax prices for investors by 2.7% and for owner-occupiers by 2.1%, but it decreased the volume of transactions by 10.4% and increased time-to-sell by 4%. A search model with ownership, rental and credit markets can rationalize these findings. The surcharge increases the probability to find a property to buy, which in turn decreases rental prices and construction costs leading to an equilibrium in which housing becomes more affordable for owner-occupiers. While unconditional transfer taxes lead to deadweight losses, my model shows that a transfer tax surcharge on investors generates a 2.3% increase in welfare by offsetting the crowding-out externality that investors impose on owner-occupiers while competing for the same properties.

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1 Introduction

Since the turn of the century housing prices have experienced a dramatic growth in almost all developed countries [Knoll et al., 2017]. In the UK, housing prices increased by 240% relative to retail prices and by 220% relative to average earnings (Figure 1). At the same time, a wave of property investors flooded housing markets all over the world [Martin et al., 2018]. In the UK, buy-to-let mortgages rose from virtually none to almost 2 millions, the share of privately rented properties doubled from 10 to 20%, while home-ownership dropped.

The simultaneous increase in investors' entry and prices might be a spurious correlation and the direction of causality is unclear without a more careful analysis. Policymakers are concerned that investors might increase property prices, exacerbate housing cycles and crowd-out owner-occupiers [HM Treasury, 2016; Bank of England, 2016; Reserve Bank of New Zealand, 2016; Reserve Bank of Australia, 2017; De Nederlandsche Bank, 2018]. Yet, investors may also have a beneficial impact on welfare by increasing real-estate liquidity, stimulating supply and reducing rental prices [Bayer et al., 2011; Gao et al., 2020].

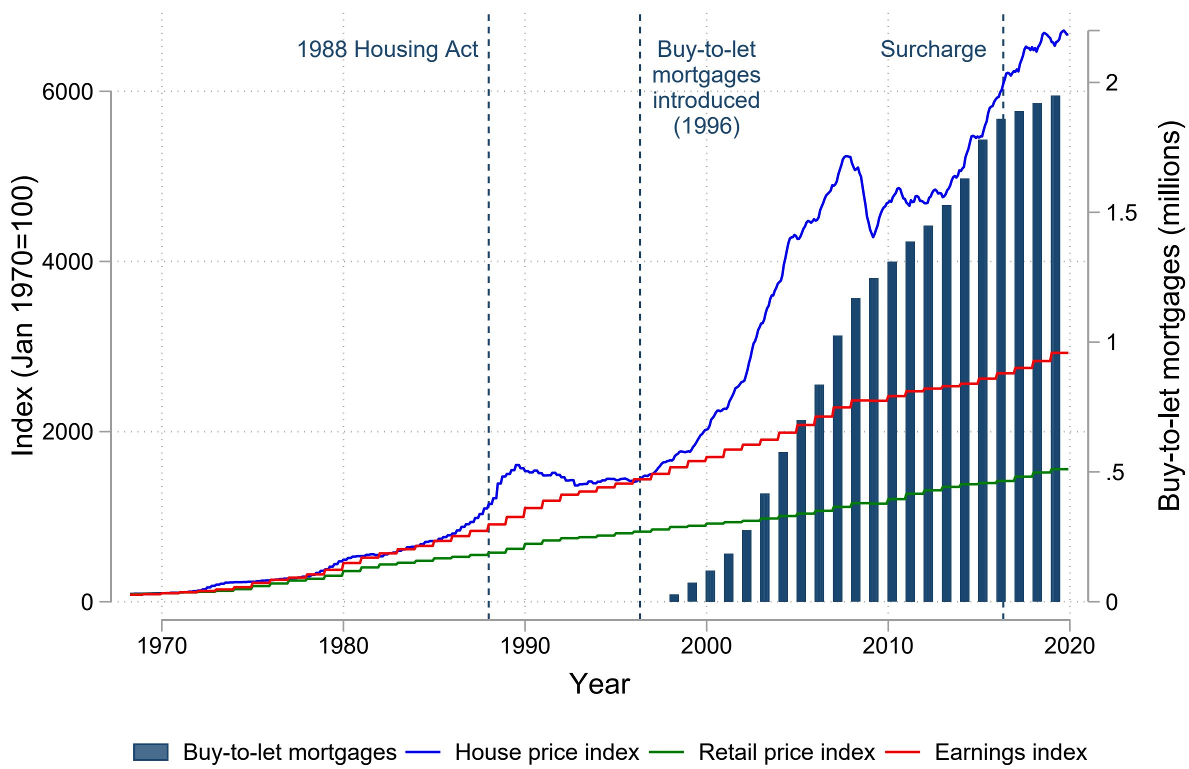
To shed light on the role of investors in the housing market, we need a large and exogenous demand shock, such as a tax, that directly affects property investors but not owner-occupiers. This paper asks whether a tax on property investors can increase total welfare by studying its spillover effects on owner-occupiers. I use an incremental diff-in-diff design and an equilibrium model with search frictions to evaluate a unique policy introduced in the UK in April 2016: a 3% transfer tax surcharge on 'buyers of additional properties'. Real-estate companies, investors that buy a property to let (buy-to-let) or to leave empty expecting its value will rise (buy-to-leave) are liable for this surcharge, whereas owner-occupiers (buy-to-live) are not.[1]

The surcharge was implemented nationally but there was large heterogeneity in the share of privately rented properties across local authorities. I exploit this pre-policy heterogeneity to identify the impact of the surcharge on housing market outcomes, using the incremental difference-in-differences estimator proposed by Card [1992]. I use the local authority share of rented properties in 2015 as a measure of the 'dose' of the treatment, since the surcharge was paid by owners of rented properties (buy-to-let investors) but not by owner-occupiers. To conduct the empirical analysis, I build a dataset that contains the universe of property transactions in England and Wales from 2013 to 2019 by matching Land Registry sale records with Energy Performance Certificates and confidential data on properties listed on Zoopla, the second most popular UK property platform. The combination of these datasets is crucial for a comprehensive understanding of how the housing market reacts to the surcharge: it allows me to identify buy-to-let from buy-to-live transactions and

[1] A property purchased by a future owner-occupier is not subject to the surcharge, unless the buyer owns a second property and does not sell it within 18 months from the transaction. Second homes were only 1.2% of total homes in England in 2015.

it includes rich information on paid and listing price, as well as property characteristics and time to sell.

Figure 1: The growth of housing prices and buy-to-let mortgages in the UK



Notes: The blue, red and green solid lines are the house price index, earnings index and retail price index from 1968 to 2019, normalized to 100 in year 1970. The histogram represents the number of outstanding buy-to-let mortgages (in millions) from 1998 to 2019.

I find that the tax surcharge had large and significant effects that can hardly be reconciled with a frictionless and perfectly competitive housing market. The surcharge reduced pre-tax property prices for buy-to-let investors by 2.7% and for future owner-occupiers by 2.1%, even though the latter were generally not liable for the surcharge. The differential impact on pre-tax prices is prima facie evidence that buyers had some degree of market power. Sellers would not have accepted a lower price from buy-to-let investors, unless the search for a future owner-occupier (willing to pay a higher price) was costly. Moreover, I find evidence of overshifting: had all buyers been liable for the surcharge, the impact on prices would have been higher than the tax itself, with a tax elasticity of prices of -3.4. Overshifting is not compatible with a perfectly competitive and frictionless market [Fullerton and Metcalf, 2002], but can be explained by imperfect competition and the amplification mechanisms that search frictions generate in a property market. In line with this interpretation, data from Zoopla reveal that it takes seven months to sell a property for a median seller in England and Wales, and that the surcharge significantly increased time-to-sell by 4%. Longer time-to-sell can push sellers to accept lower prices or to opt out and induce buyers to wait for even lower prices, amplifying the initial effect of the surcharge. Consistent with this mechanism, the volume of transactions fell by 10.2%, even though the surcharge did not reduce housing supply within four years from its introduction.

The magnitude of these results is large but comparable with previous estimates of transfer-tax elasticities on volumes and prices [Besley et al., 2014; Kopczuk and Munroe, 2015; Best and Kleven, 2018; Han et al., 2021]. Reassuringly, I do not find any evidence of significant effects in the eight quarters before the policy announcement which would invalidate the empirical strategy. Results are robust to the inclusion of a rich set of local authority controls and property characteristics and do not appear to be driven by other policies occurring in the same period (Section A), nor by the outcome of the Brexit referendum.

Guided by the empirical findings, I develop a search model of the housing market with buy-to-let investors, buy-to-live households and lenders to illustrate the mechanisms and quantify the impact of the surcharge on welfare. Households and investors compete in the same property market. Based on evidence of search frictions, the property market in the model is characterized by search costs and a matching function à la Pissarides [2000]. Households and investors are heterogeneous in wealth and a fraction of them search in credit markets for buy-to-live and buy-to-let mortgages, respectively. Since access to credit plays a central role in the housing market, I introduce credit rationing by assuming credit markets for households and investors are subject to search frictions in a symmetric way with respect to the property market. This is a common feature in search models that combine credit, labor and non-durable goods markets [Dell'Ariccia and Garibaldi, 2005; den Haan et al., 2003; Wasmer and Weil, 2004; Petrosky-Nadeau and Wasmer, 2013, 2015], but it is a modelling innovation for housing market models. It allows my framework to capture how credit market frictions contribute to the propagation of fiscal effects while maintaining model tractability. To replicate the UK standard practice of reaching a mortgage 'agreement in principle' before bargaining for a property [Lloyds Bank plc, 2022], loan amounts and property prices are negotiated in a sequential Nash bargaining process that maximizes the total surplus of borrowers-lenders and buyers-sellers, respectively. Given that the observed median time-to-let is less than one tenth of the median time-to-sell, I assume that the rental price instantaneously clears a frictionless rental market.

The tractability of the model allows me to analytically identify three equilibrium effects through which the surcharge on investors can make housing more affordable for owner-occupiers, despite not being directly affected by the tax change. First, the surcharge reduces the number of buy-to-let investors and it makes it easier to find a property to buy. This favors buyers over sellers and reduces prices. Second, since households and investors find properties to buy more easily, rental demand decreases relative to supply. The resulting fall in rental prices generates further downward pressure on property prices. Third, in the long run construction cost decreases to adjust to a less tight housing market with lower prices and this has a negative feedback effect on prices themselves. Interestingly, if the tax on investors becomes too high, the effects are reversed. Not enough buy-to-let investors enter the market, rental prices increase and this induces too many households to search for a property to buy. Finding a property to buy becomes more difficult and property prices for owner-occupiers rise.

I estimate model parameters using pre-surcharge data and the 4% increase in days-to-sell after the surcharge. Qualitatively, the model is able to replicate all the empirical effects. Quantitatively, it captures the magnitude of the effects on transactions, housing supply and rental prices reasonably well. It overestimates the effect on prices in order to match the observed change in housing market tightness, in a similar manner labor search models require large changes in wages to generate the magnitude of observed fluctuations in employment [Shimer, 2005].[2] As prices are transfers between equally weighted risk-neutral individuals, price effects do not directly affect the welfare analysis. Using a utilitarian welfare function that weighs the utility of households, investors and lenders equally, the model shows that the transfer-tax surcharge on investors increased overall welfare by 2.3%. Investors do not internalize the negative externality they impose on households: their competition in the property market makes it longer and more expensive to find a property to buy, reducing the home-ownership rate. As I estimate that households have higher intrinsic home-owning utility than investors, the surcharge on investors increases welfare because it partially offsets this negative 'crowding-out' externality. Households are the beneficiaries of the welfare increase, as they are exempt from the tax surcharge, they pay lower rental prices and find more easily a property to own which gives them positive utility.

My paper contributes to the literature in several ways. While previous papers have analyzed the impact of transfer taxes that target all buyers unconditionally, little is known about the housing market response when the tax targets those who do not purchase properties for consumption, but only for investment.[3] Whereas previous papers find that unconditional transfer taxes lead to welfare losses due to lock-in effects and destruction of matches with positive surplus [Best and Kleven, 2018; Dachis et al., 2012; Eerola et al., 2021; Fritzsche and Vandrei, 2019; Han et al., 2021; Hilber

[2]Different papers have advanced different solutions to this 'unemployment volatility puzzle'. Ljungqvist and Sargent [2017] show that all these ultimately diminish the fundamental surplus fraction, an upper bound on the fraction of a job's output allocated to the vacancy creation (e.g. the difference between productivity and worker's value of leisure).

[3]An exception is the empirical analysis by Fu et al. [2016] on the withdrawal of a stamp duty deferral in the presale market in Singapore, which reduced speculative trading but raised price volatility. While they study short-term investment in a presale market, my paper analyzes the impact of taxing long- and short-term investors on the spot market.

and Lyytikäinen, 2017; Kopczuk and Munroe, 2015; Määttänen and Terviö, 2021], my paper shows that a moderate transfer tax can increase social welfare if it is imposed on property investors only.

Following the seminal work by Wheaton [1990], several papers have used search models to study frictions and amplification effects in the housing market (see Han and Strange [2015] for a review).[4] Few papers focused on the role of investors. Halket and Pignatti Morano di Custoza [2015], Ioannides and Zabel [2019] and Bø [2021] build search models with property and rental markets, but to study different questions (e.g. the relationship between home-ownership and rent-to-price ratio). Lundborg and Skedinger [1999] analyze the effect of transfer taxes on search effort but they abstract from the rental market. Closer in spirit to my paper, Han et al. [2021] find that a land transfer tax in Toronto induced a rise in buy-to-let transactions but a fall in owner-occupiers transactions, despite the tax applying to both. Contrary to my analysis in which owner-occupiers are exempt from the surcharge, this unconditional transfer tax increased the share of investors in the housing market, reduced home-ownership and caused large deadweight losses. My empirical and normative results have first-order relevance for policymakers because increasing home-ownership and decreasing property prices without discouraging housing supply is among the main objectives of current housing policies around the world.

The paper is organized as follows. Section 2 presents the policy background of the surcharge and describes the data used to analyze its impact. Section 3 explains the empirical strategy and Section 4 discusses the empirical results. Section 5 illustrates the search model and analyzes the comparative statics of introducing a surcharge on investors. Section 6 describes the identification and estimation of model parameters. Section 7 validates the model and analyses the impact of the surcharge on social welfare. Section 8 concludes.

2 Policy background and data

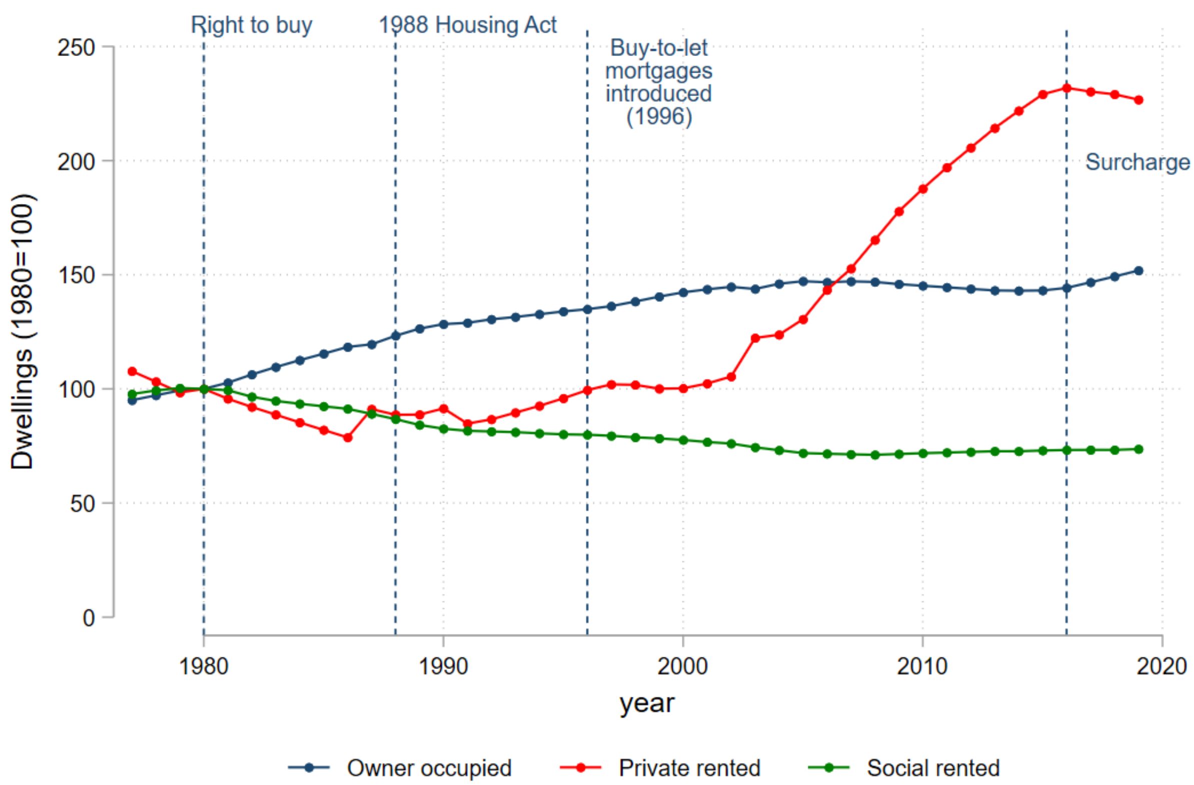
A series of changes in the rental and credit markets triggered the explosion of buy-to-let investment in the UK. Until 1988, tenants could appeal to rent officers to obtain a 'fair rent' and the 1977 Rent Act ensured a long-term security of tenure and restricted landlords' powers of eviction [Kemp, 2015]. The Housing Act 1988 liberalized the heavily regulated private rental sector. It allowed landlords to let properties at market rents, it reduced to 2 months the minimum notice to evict and to 6 months the minimum tenancy tenure [Housing Act, 1988].

Another push to the buy-to-let sector came from the credit market. Before 1996, loans for properties bought to let were mortgages based on the mortgagor's income with an additional risk

[4] Recent examples are Albrecht et al. [2016], Anenberg and Bayer [2020], Díaz and Jerez [2013], Gabrovski and Ortego-Marti [2019], Genesove and Han [2012], Head et al. [2014], Moen et al. [2021], Ngai and Tenreyro [2014], Ngai and Sheedy [2020], Piazzesi et al. [2020].

premium of around 2% with respect to standard mortgage interest rates. As a consequence, buy-to-let mortgages were rather uncommon. In 1996, a panel of mortgage lenders in concert with the Association of Residential Letting Agents devised the 'buy-to-let mortgage': a new mortgage product based on expected rent with an interest rate close to the standard one for residential mortgages [Leyshon and French, 2009]. As a result, the number of outstanding buy-to-let mortgages raised from virtually none to almost 2 millions (Figure 1) and the share of privately rented properties doubled from 10 to 20% in two decades (Figure 2).

Figure 2: Number of dwellings by type of tenure



Notes: This Figure shows the number of dwellings that were owner-occupied, private rented and social rented in the UK from 1977 to 2019. Their number is normalized to 100 in 1980.

To contrast the fall in home-ownership, on 25 November 2015 Chancellor George Osborne announced a 3% surcharge for 'buyers of additional properties' on top of the standard Stamp-Duty Land Tax (SDLT), which is a transfer tax paid by every residential property buyer in England, Northern Ireland and Wales [Ministry of Housing, 2022a].[5] The surcharge was part of a Five-

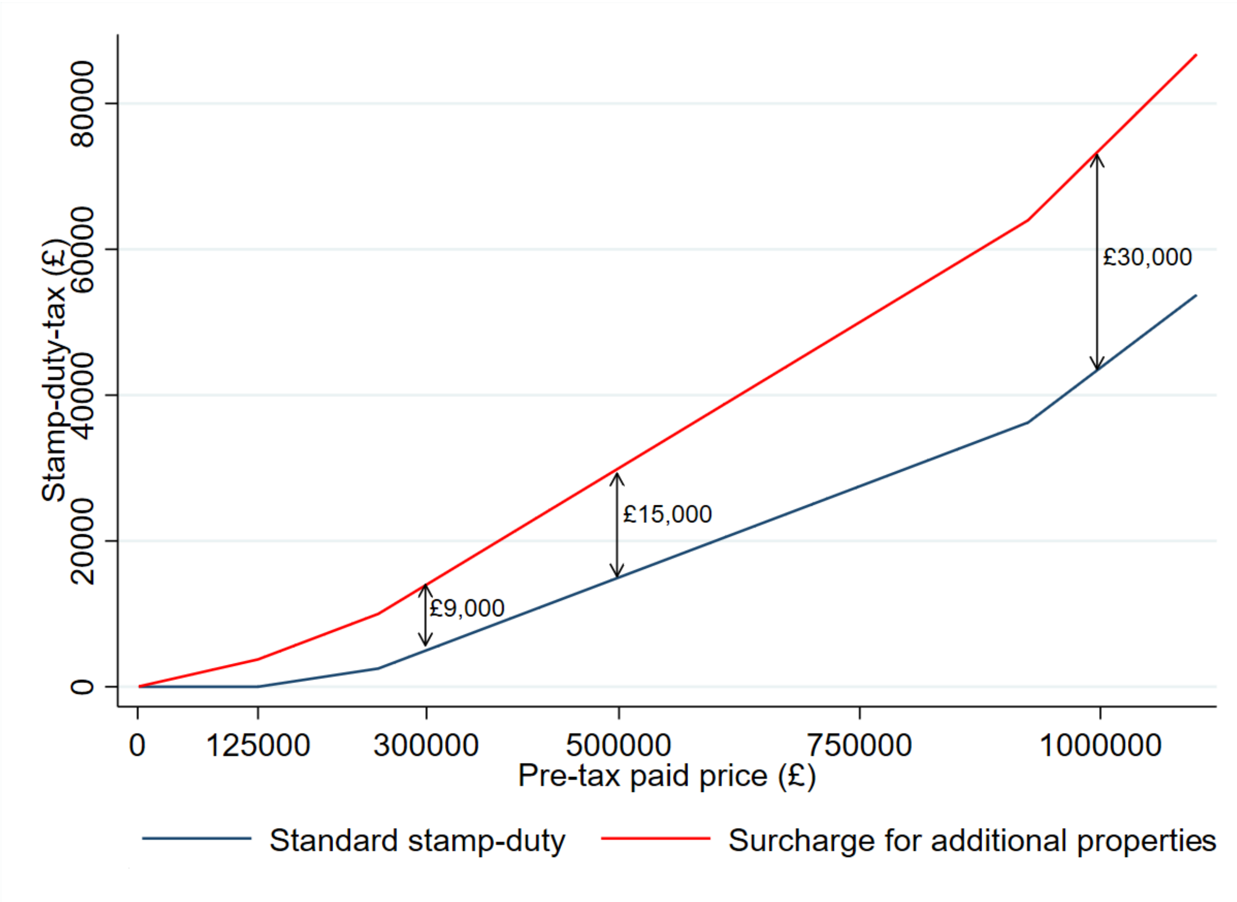
[5]The STDLT became the 'Land and Buildings Transaction Tax' in Scotland from 1 April 2015 and the 'Land Transaction Tax' in Wales from 1 April 2018. In Wales, the tax schedule remained unchanged until December 2020.

Point-Plan whose other points were: to deliver 400,000 affordable housing starts by 2020-21; to accelerate housing supply and get more homes built (e.g. by releasing public sector land); to prolong the already existing 'Help to Buy' Equity Loan scheme until 2021 and to create a London 'Help to Buy' scheme; to extend the 'Right to Buy' scheme to Housing Association tenants [HM Treasury, 2015, 2016].[6] In Section A, I explain how I can isolate the effect of the surcharge from the other policies of the Five-Point-Plan and show that the main results stand when performing several robustness checks.

As we can see in Figure 3, the SDLT schedule presents several kinks as the marginal rate increases in the transaction price, starting from 0% of the portion of the transaction price below $\pounds 125,000$ up to 12% of the portion of the transaction price above $\pounds 1.5m$ in 2016. The SDLT surcharge consists of an increase of 3 percentage points on the standard SDLT rates independently of the transaction price, but it applies only to buyers of additional properties. If the buyer owns more than one property after 18 months from the transaction, the surcharge applies. Accordingly, the SDLT surcharge applies to buy-to-let investors, buy-to-leave investors, real estate companies and second-home buyers, but does not apply to owner-occupiers. The diagram in Figure D2 specifies the liability of the SDLT surcharge in more detail.

[6] The 'Help to Buy' Equity Loan is a government equity loan that covered from 5% to 20% of the property purchase price of a newly built home. The London 'Help to Buy' scheme covered up to 40% of the price if the property was in London. The 'Right to Buy' scheme allows tenants of public housing to buy their homes at a discount.

Figure 3: Stamp-duty schedule



Notes: This Figure shows the SDLT tax schedule in 2015 ('Standard stamp-duty') and how it increased for buyers of additional properties in 2016 ('Surcharge for additional properties').

The SDLT surcharge was announced on November 25, 2015 and came into effect on April 1, 2016. As we can see in Figure D3, the period between the announcement and the implementation of the reform saw an increase in the volume of property transactions. Some buyers of additional properties appear to have anticipated their planned property transactions in order to avoid the transfer tax increase. Section 4 explains how I account for these anticipation effects in the analysis of the housing market impact of the SDLT surcharge.

2.1 Data

To analyze the impact of the surcharge on the housing market, I have geocoded and merged three datasets: the HM Land Registry Price Paid data, the Energy Performance Certificates dataset and WhenFresh/Zoopla data provided by the Consumer Data Research Centre. The linking variable is the property address, which consists in the Primary Addressable Object Name (typically the house number or name), the Secondary Addressable Object Name (e.g. flat number), the street and the full postcode.

The Land Registry dataset contains the universe of residential property transactions occurred in the UK from 1995 to 2021. Each observation includes the property address, its coordinates, the transaction date, the price paid, and several property characteristics (e.g. whether the property is new/old, whether the property is a leasehold/freehold) [HM Land Registry, 2022a].

The Energy Performance Certificates dataset contains every energy performance certificate produced on sale or rent of a building in England and Wales from October 2008 to December 2021. Each certificate reports the property address, the certificate date, a richer set of property characteristics (e.g. floor area size, energy efficiency rate) and the type of tenure (private rented, public rented or owner-occupied) [Department for Levelling Up, Housing and Communities, 2022a].[7] To merge this dataset with the Land Registry dataset, I use the certificate that has the closest date *after* the property transaction date.[8] I identify transactions in which buyers are buy-to-let investors as properties that have an Energy Performance Certificate after the transaction that classifies them as privately rented. I identify transactions in which buyers are future owner-occupiers as properties that have the an Energy Performance Certificate after the transaction that classifies them as owner-occupied.[9]

The WhenFresh/Zoopla data includes information on all properties in England and Wales to sell and to rent listed on Zoopla in the period 2012-2019 and sold in the period 2014-2019. For each property, we can observe the listing dates for sales and lets, the listing price, the listing rental price, the transaction date, the starting tenancy date and additional property characteristics (e.g. listed number of bedrooms/batrooms)[Consumer Data Research Centre, 2020a,b].

I use several other datasets for the regression covariates at local authority levels. For population and GDP per capita in each local authority, I use annual estimates provided by the ONS [2021a,b,c]. To account for the outcome of the Brexit referendum, I also control for the interaction between an indicator for the post-policy period and the population share with EU nationality in each local authority in 2015, which is obtained from the Annual Population Survey [ONS, 2015], and the share of properties owned by EU companies in each local authority in October 2015 [HM Land

[7] The EPC register does not hold data for every residential building, but only for those buildings for which an energy performance certificate was required in the period 2008-2021. After September 2008, lodging the data became a mandatory requirement and a building must have a valid EPC when constructed, sold or let. An EPC is valid for 10 years.

[8] The algorithm for merging the Land Registry and EPC dataset was kindly shared by Hans Koster and Edward Pinchbeck. For details on this algorithm, I refer to their paper [Koster and Pinchbeck, 2022].

[9] This approach is different from Bracke [2021] who identifies buy-to-let purchases as transactions where a Zoopla rental advertisement follows a sale on the same property during the following six months. Bracke [2021] cannot identify properties purchased by future owner-occupiers: a transaction that is not followed by a Zoopla rental advertisement might still be a buy-to-let transaction (e.g. if the property is not advertised, or it is advertised in other platforms).

Registry, 2022b]. For council total and housing expenditures, I use data from the Department for Levelling Up, Housing and Communities [2022b] and the Welsh Government [2021a,b].

Finally, for model calibration I also use aggregate UK annual data in 2015, the year before the surcharge was introduced. This includes administrative data on the housing stock, the housing flows, the vacant stock, the number of outstanding residential and buy-to-let mortgages provided by the Ministry of Housing [2014, 2022b] and the Council of Mortgage Lenders [2022].

3 Empirical strategy

The surcharge amounted to 3% of the price paid by property investors and was introduced in the whole UK simultaneously. Yet, local authorities in England and Wales presented a high and longstanding geographic variation in buy-to-let investment. As we can see in Figure 4, the share of properties that were privately rented in 2008-2015 ranged from 9.5% in the Welsh county borough of Torfaen to 50.4% in the City of London district. This variation implies that the surcharge affected local authorities to different intensities. The larger the private rental sector in a local authority, the stronger the 'dose' of the treatment in that local housing market because buy-to-let investors had to pay the surcharge, whereas owner-occupiers did not.

My empirical analysis is based on the incremental difference-in-differences estimator introduced by Card [1992] and exploits the heterogeneous degree to which local housing markets are affected by the surcharge.[10] I use the share of private residential properties that were privately rented according to Energy Performance Certificate data from 2008 to 2015 in local authority j as a measure of the dose of the treatment. Then, I apply the incremental diff-in-diff estimator to analyse the impact of the surcharge on a range of housing market outcomes within four years from its introduction (2016-2019).

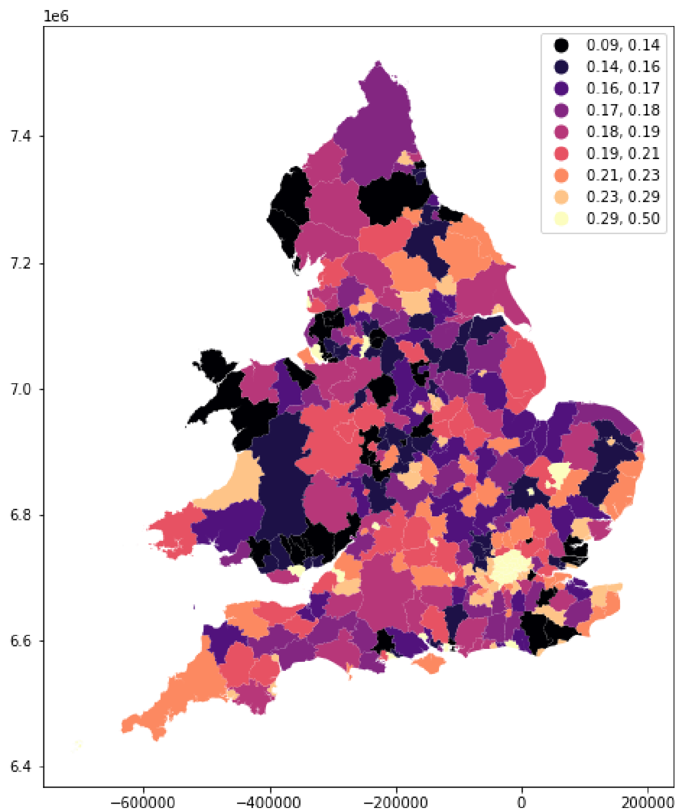
The choice of what constitutes a local housing market is open to discussion. Since local housing policies (e.g. council taxes) are determined at local authority level, the natural choice is to have local authorities as the geographical units. In 2011, there were 348 local authorities in England and Wales: 36 Metropolitan Districts, 201 Non-Metropolitan Districts, 31 London Boroughs and 54 Unitary Authorities in England, as well as 22 Unitary Authorities in Wales.[11]

I restrict the regression sample to properties *sold* in the period October 2013-December 2019, except when the dependent variable is the listing price, in which case I restrict the sample to all the properties *listed* on Zoopla in the same period. This is because the Land Registry includes

[10] Callaway et al. [2021] call this estimator the 'dose-response' difference-in-differences estimator. See Dolton et al. [2010] and Caliendo et al. [2018] for more recent applications.

[11] In 2019 some local authorities changed and new local authorities were created. Address geocoding allows to maintain the boundaries of the local authorities fixed at the 2011 boundaries throughout the entire sample period and to assign each property to a fixed spatial unit.

Figure 4: Share of private rented properties by local authorities in 2008-2015



Notes: This heat map of England and Wales shows the share of private rented properties by local authorities using Energy Performance Certificate data from 2008 to 2015. The legend reports the range of the share of private rented properties corresponding to each color.

buy-to-let mortgage transactions only from October 2013 and because stopping the analysis at the end of 2019 avoids potential confounding factors such as the withdrawal agreement from the EU formalized in January 2020 and the insurgence of the COVID-19 pandemic in February 2020. Since the Energy Performance Certificates and Zoopla datasets do not contain information on properties in Scotland and Northern Ireland, I also restrict the regression sample to England and Wales. I use standard errors clustered at local authority levels in all regressions. For regressions at property-level, which may be heavily affected by spatial correlation, I also allow for spatial correlation within $100km$ from the local authority using Conley [1999]'s heteroskedasticity and autocorrelation-consistent standard errors.

For each property i, local authority j and quarter t, I estimate the following regression equation:

$$\begin{aligned} y_{ijt} = & \alpha_j + \eta_t + Post_t \cdot (\gamma Rented_{j,2015} + \xi Second_{j,2015} + \lambda London_j \\ & + \iota EUcom_{j,2015} + \kappa EUpop_{j,2015}) + \omega X_{ijt} + \zeta Z_{jt-4} + \upsilon_{ijt} \end{aligned} \tag{1}$$

Equation (1) is estimated for housing market outcomes y_{ijt} at property transaction level. I use the same regression specification dropping the subscript i and property-level controls when the housing market outcome is at local authority level y_{jt}. In this regression, α_j are local authority fixed effects and η_t are quarter fixed effects. $Post_t$ is a binary variable equal to 1 for each quarter since the introduction of the surcharge and 0 otherwise, whereas $Rented_{j,2015}$ is the share of properties that were rented in local authority j in 2015. Note that the non-interacted variable $Post_t$ is captured by the quarter fixed effects η_t. γ is the parameter of interest that captures the outcome change for a local authority in which all properties were bought to let ($Rented_{j,2015} = 1$) with respect to a local authority in which all properties were owner-occupied ($Rented_{j,2015} = 0$). It can be interpreted as the change in housing market outcome y_{ijt} for a 3% surcharge on property investors if all properties in the local authority were bought to let.

To account for housing quality heterogeneity, I control for a rich set of property-level characteristics X_{ijt} which includes quadratics in latitude and longitude, type of property (detached, semi-detached, terraced or flat), an indicator for whether the property is new, leasehold/freehold, property size, number of rooms, energy performance, type of wall, the presence of a fireplace and property extensions. Z_{jt-4} is a vector of local-authority covariates lagged by one year, which includes population, GDP per capita, housing stock, council total expenditures, council housing expenditures and the (band-D) council tax amount. $Post_t \cdot London_j$ controls for the impact of the surcharge on London with respect to the rest of the country to account for the introduction of the London 'Help to Buy' scheme. $Second_{j,2015}$ is the share of second homes in local authority j in 2015 and $Post_t \cdot Second_{j,2015}$ controls for the impact of the surcharge on second-home buyers.[12] $EUpop_{j,2015}$ is the share of residents with a EU nationality and $EUcom_{j,2015}$ is the share of properties owned by EU companies in local authority j in 2015. $Post_t \cdot EUpop_{j,2015}$ and $Post_t \cdot EUcom_{j,2015}$ control for the potential impact that the result of the Brexit referendum on 23 June 2016 may have had on housing demand by EU citizens and companies. v_{ijt} is an error term.

Recent papers have pointed out that two-way fixed effect specifications other than the canonical two-groups diff-in-diff, such as fuzzy or staggered designs, estimate a weighted sum of the average treatment effects in each unit and period, with weights that may be negative [Borusyak et al., 2021; de Chaisemartin and D'Haultfœuille, 2018, 2020; Goodman-Bacon, 2021; Sun and Abraham, 2021]. In my setting, the treatment is not staggered over time but it varies in intensity ('dose') across local authorities. Callaway et al. [2021] study this case. They show that, under a parallel trends assumption, the incremental diff-in-diff coefficient γ is equal to a weighted average of the average causal responses for different doses, where all the weights are guaranteed to be non-negative.[13] The parallel trend assumption is that for all doses d, the average change in outcomes over time across all units had they been assigned dose d is the same as the average change in outcomes over time for all units that actually experienced dose d.[14]

In the context of the UK surcharge, the required parallel trend assumption is that, for each share of rented properties, the average change in housing market outcomes over time across all local authorities had they been assigned that share is the same as the average change in housing market outcomes over time for all local authorities that actually had that share of rented properties. This would be violated if certain local housing markets would have reacted differently to the surcharge even if they had the same share of rented properties. I account for differences across local authorities that might induce heterogeneous treatment effects by including the controls Z_{jt-4} and the interactions between $Post_t$ and , $Second_{j,2015}$, $London_j$, $EUcom_{j,2015}$, $EUpop_{j,2015}$. Moreover, to indirectly assess the validity of the 'parallel trends assumption', I also check for the presence of pre-policy trends using the following regression equation:

[12] For Wales, data on second homes is absent. In its place, I use the local-authority share on homes without a usual resident from the 2011 census [Office for National Statistics, 2011]

[13] The average causal response at dose d_j is $ACR(d_j) = E[Y_t(d_j) - Y_t(d_{j-1})]$ where $Y_t(d_j)$ is the potential outcome at time t that the local authority would have in the case it had a d_j share of rented properties. Under a parallel trend assumption, Callaway et al. [2021] show that $\gamma = \sum_{d_j} \omega(d_j) \frac{E[Y_t(d_j) - Y_t(d_{j-1})]}{d_j - d_{j-1}}$ with $\omega(d_j) \geq 0$ and $\sum_{d_j} \omega(d_j) = 1$. If average causal responses are constant over d (the treatment effect function is linear), γ is equal to the average treatment effect of the surcharge applied to all properties in the local authority: $\gamma = E[Y_t(1) - Y_t(0)]$.

[14] The parellel trend assumption in Callaway et al. [2021] is: $E[Y_t(d) - Y_{t-1}(0)] = E[Y_t(d) - Y_{t-1}(0)|D = d]$ where t is the post-surcharge period, $t-1$ the pre-surcharge period. This is likely to be stronger than the standard parallel trend assumption $E[Y_t(0) - Y_{t-1}(0)|D = d] = E[Y_t(0) - Y_{t-1}(0)|D = 0]$.

$$y_{ijt} = \alpha_j + \eta_t + \gamma_t Rented_{j,2015} + \xi_t Second_{j,2015} + \lambda_t London_j + \iota_t EUcom_{j,2015} + \kappa_t EUpop_{j,2015} + \omega X_{ijt} + \zeta Z_{jt-4} + \upsilon_{ijt} \quad (2)$$

The vector of coefficients γ_t are the coefficients of interest, which capture the effect of the surcharge on buy-to-let investors in each quarter relative to the default period of the sample (the quarter before the surcharge announcement). Since these coefficients are quarter-specific, we can check for pre-trends by testing the significance of coefficients γ_t in the quarters t before the surcharge announcement.

4 Reduced-form results

In this Section, I analyze how the surcharge affected multiple aspects of the housing market in England and Wales. As shown in Appendix Section A, the results do not appear to be driven by other housing policy changes in the same period, nor by the outcome of the Brexit referendum.

Table 1 reports the estimates of the impact of the surcharge on the log number of quarterly property transactions at local authority level. In column (1), I estimate the coefficient γ in (1) without local authority controls (Z_{jt-4}), which are added in column (2). In column (3), I control for anticipation effects by adding the interaction $Ant_t * Rented_{j,2015}$ in which Ant_t is a binary variable equal to 1 in the quarter between the announcement and the introduction of the surcharge and 0 otherwise. In order to account for the anticipation effects described in Section 2, in column (4) I estimate the coefficient γ in (1) using a donut hole approach: I test whether dropping all property transactions within 6 months before and after the introduction of the surcharge significantly changes the estimates. In column (5) I add the interactions $Post_t * EUcom_{j,2015}$ and $Post_t * EUpop_{j,2015}$ to account for potential effects of the outcome of the Brexit referendum.

Table 1: Effect of stamp-duty surcharge on log number of quarterly property transactions

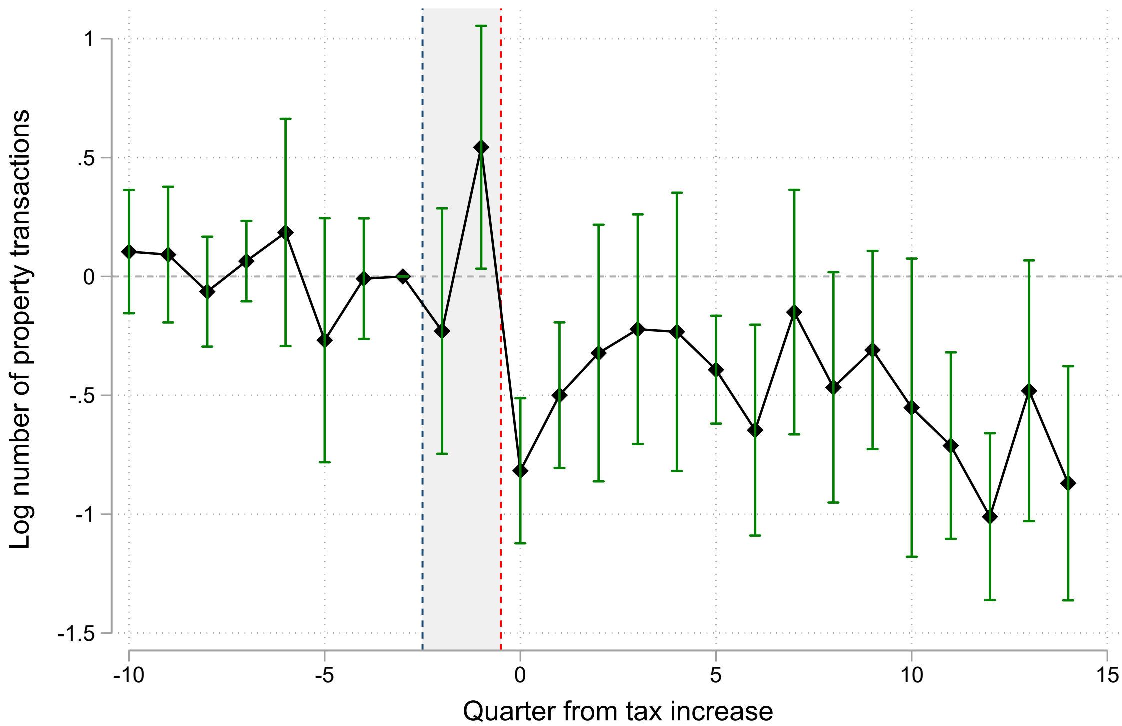
	(1)	(2)	(3)	(4)	(5)
Post*Share Rented	-0.597***	-0.655***	-0.489***	-0.591***	-0.502**
	(0.146)	(0.145)	(0.188)	(0.196)	(0.242)
Ant.*Share Rented			0.600***		
			(0.189)		
N	8,700	8,700	8,700	7,308	7,308
LA controls	NO	YES	YES	YES	YES
Donut hole	NO	NO	NO	YES	YES
Post*London	YES	YES	YES	YES	YES
Post*Second shares	YES	YES	YES	YES	YES
Post*EU shares	NO	NO	NO	NO	YES
S.E.	Clustered at LA	Clustered at LA	Clustered at LA	Clustered at LA	Clustered at LA

Notes: This table reports results from OLS regressions of Equation (1) using the log of the number of days between the transaction date and the listing date as the dependent variable. Controls (LA level): lagged population, GDP per capita, housing stock, council total expenditures, council housing expenditures, council tax. ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

The estimates for γ range from -0.489 to -0.655 and are robust to every specification: the surcharge significantly reduces the volume of transactions in local authorities in which the buy-to-let market is larger (p-value< 0.05). The significantly positive coefficient of $Ant_t * Rented_{j,2015}$ represents evidence that some buyers anticipated a property purchase to avoid the surcharge payment. However, the estimates for γ in columns (3), (4) and (5) are only slightly lower than the estimates in columns (1)-(2), showing that neither anticipation effects nor the Brexit referendum are the main drivers of the policy impact on transactions.

These estimates can be interpreted as the percentage change in transactions for a 3% stamp-duty surcharge increase if all properties were buy-to-let properties. Using column (5), the estimated elasticity of the number of transactions with respect to the tax is $-0.502/0.03 = -16.7$, which is large but in the ballpark of previous estimates. Best and Kleven [2018] analyze the impact of a UK stamp-duty holiday in 2008-9 on the number of transactions and estimate a short-run elasticity of -20.62 and a long-run elasticity of -14.3. To obtain the average impact on the housing market outcome, we need to multiply each coefficient by the average share of rented properties (assuming the surcharge effect is linear in the rented share). Considering that only 20.35% of the properties were rented, the average impact of the 3% surcharge on the English and Welsh housing market was a $-0.502 \cdot 0.2035 = 10.2\%$ decrease in the volume of property transactions over 2016-2019.

Figure 5: Quarterly effect on log-number of transactions



Notes: This figure reports point-estimates and 90% confidence intervals for γ_t from the OLS regression of Equation (2) using the log number of transactions as the dependent variable. The horizontal axis shows the number of quarters from the introduction of the 3% surcharge. The shaded area represents the period between the surcharge announcement and its introduction.

Figure 5 shows estimates of γ_t from regression (2) using the log number of transactions as dependent variable and can be regarded as a test for the parallel trend assumption. Reassuringly, there is no clear trend before the introduction of the surcharge: pre-policy effects are never significant except for the significantly positive one in the anticipation period. On the other hand, the quarterly estimates are negative in all quarters after the introduction of the surcharge and significantly negative in half of them.

The extensive margin response on transactions might cause a selection bias in the estimation of the impact of the surcharge on prices. The surcharge might have disproportionately changed transactions of properties of higher (lower) quality than average.[15] To account for this, I control for the rich set of property characteristics described in Section 3 with the addition of the *listing* price on Zoopla, which can be regarded as a measure of housing quality provided by the seller. Importantly, in Table C1, we see that sellers did not significantly change the property prices listed on Zoopla in response to the surcharge. Therefore, the listing price can be used as a control for

[15]For instance, in Tables C13 and C14 we see that the surcharge significantly increased the average size of transacted properties, but not the energy performance.

housing quality in the regressions on paid prices.[16]

The results are shown in Table 2, separately for buy-to-let investors and buyers that will be owner-occupiers. Even though the surcharge had a stronger impact on the price of buy-to-let transactions, the effect on prices for owner-occupiers is significant and economically meaningful. Housing has become more affordable for owner-occupiers, even if they were generally not liable for the surcharge. On average, the surcharge reduced property prices for future owner-occupiers by 0.9-2.1% and property prices for buy-to-let investors by 1.7-2.7%.[17] The difference in the price effects between buy-to-let and future owner-occupiers is significant (Table C2) and it is prima facie evidence that the housing market is not perfectly competitive. Sellers were willing to accept a lower price from investors liable for the surcharge, because the search for another (owner-occupier) buyer was costly. As shown in Section 5, search frictions and price bargaining can intuitively explain why prices for all agents decrease but prices for investors decrease more. Only investors' transaction surplus is directly cut by the surcharge and this results in a lower price at the end of the price negotiation.

The estimates for γ are significantly negative in every specification. In column (6), the standard errors adjusted for spatial correlation are lower than the clustered ones originally calculated, which is common in longitudinal studies with fixed effects [Kelly, 2020].[18] The estimate becomes larger in magnitude when we control for local authority characteristics that are likely to affect house prices (e.g. the council tax) and they remain stable after accounting for anticipation effects and the shares of EU residents and companies (p-value< 0.01).

Reassuringly, as we can see in Figures 6 and 7, the quarterly effects on paid prices are around 0 until the introduction of the surcharge, and they become gradually more negative and significant over time. The fact that the impact on prices accrues over time cannot easily be explained by a tax incidence effect in a perfectly competitive market. Instead, they are consistent with the presence of amplifying equilibrium effects that take some time to develop.

[16] Estimates are qualitatively unchanged and of a similar magnitude if I do not include the listing price as a control.

[17] Given the large degree of heterogeneity in the share of rented properties, the impact of the surcharge vary substantially across local authorities. Figure D4 shows that in areas as London, where the buy-to-let market is stronger, the surcharge reduces the number of transactions by as much as 22% and prices by as much as 4%.

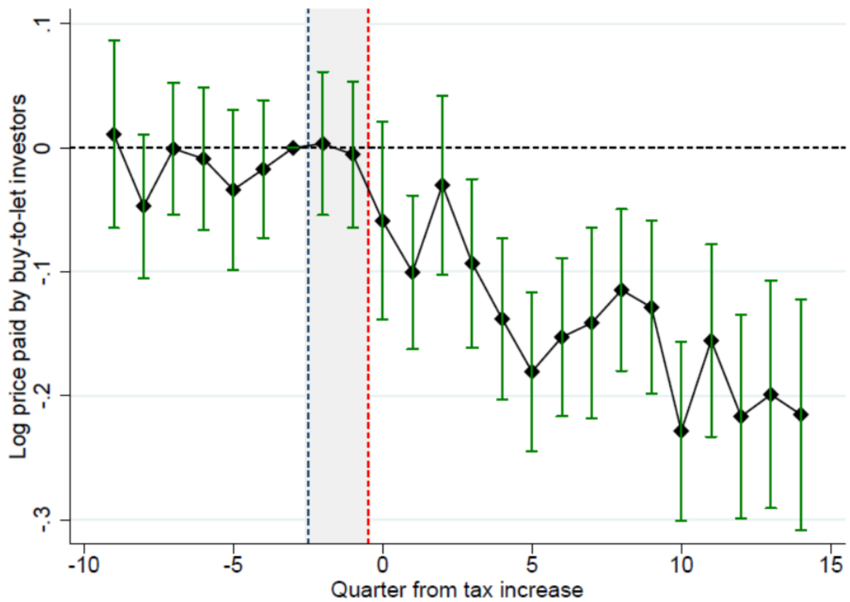
[18] Kelly [2020] argues that fixed effects already absorb a large degree of the spatio-temporal structure of the residuals and 'clustering is an aggressive solution to a problem that has substantially dissipated'.

Table 2: Effect of stamp-duty surcharge on log paid price

	(1)	(2)	(3)	(4)	(5)	(6)
Dependent variable:	**Log price paid by buy-to-let investors**					
Post*Share Rented	-0.085***	-0.121***	-0.117***	-0.122***	-0.135***	-0.135***
	(0.024)	(0.018)	(0.019)	(0.021)	(0.025)	(0.023)
Ant.*Share Rented			0.031**			
			(0.015)			
N	342,803	342,803	342,803	283,801	283,801	283,801
Dependent variable:	**Log price paid by future owner-occupiers**					
Post*Share Rented	-0.045**	-0.078***	-0.076***	-0.085***	-0.102***	-0.102***
	(0.021)	(0.016)	(0.016)	(0.019)	(0.022)	(0.019)
Ant.*Share Rented			0.022**			
			(0.010)			
N	1,226,749	1,226,749	1,226,749	978,144	978,144	978,144
LA controls	NO	YES	YES	YES	YES	YES
Donut hole	NO	NO	NO	YES	YES	YES
Post*London	YES	YES	YES	YES	YES	YES
Post*Second shares	YES	YES	YES	YES	YES	YES
Post*EU shares	NO	NO	NO	NO	YES	YES
S.E.	Clustered at LA	Clustered at LA	Clustered at LA	Clustered at LA	Clustered at LA	Spatial HAC (100km)

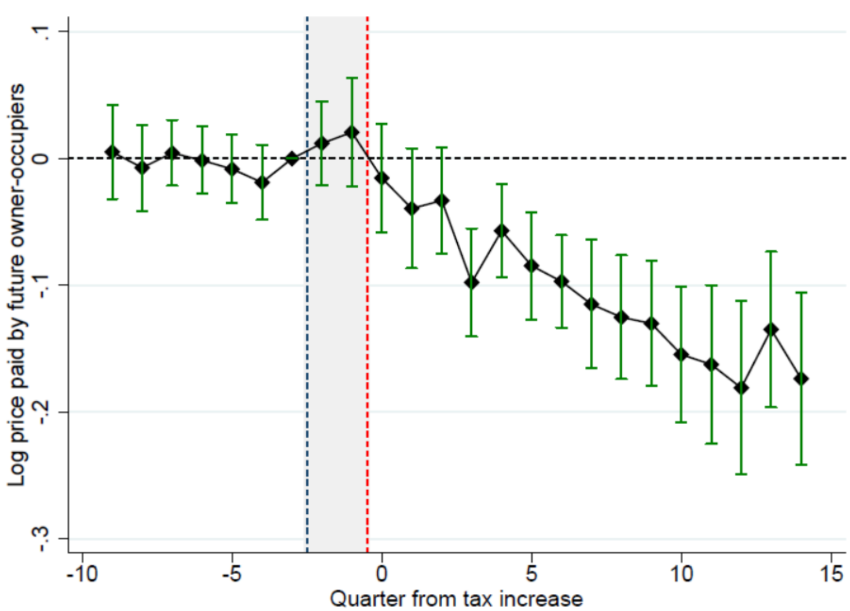
Notes: This table reports results from OLS regressions of Equation (1) using the log price paid buy buy-to-let investors (top panel) and the log price paid by future owner-occupiers (bottom panel) as dependent variables. Controls (property level): log listing price, quadratics in latitude and longitude, size, number of rooms, energy performance, type of property, new, leasehold, fireplace, type of wall, extensions. Controls (LA level): lagged population, GDP per capita, housing stock, council total expenditures, council housing expenditures, council tax. In columns (1)-(5), s.e. are clustered at local authority level. In column (6), I allow spatial HAC s.e. to be serially correlated over the entire period. Spatial weighting kernels are assumed to decay linearly. Zero spatial correlation is assumed beyond 100km. ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

Figure 6: Quarterly effect on prices paid by buy-to-let investors



Notes: This figure reports point-estimates and 90% confidence intervals for γ_t from the OLS regression of Equation (2) using the log price paid by buy-to-let investors as the dependent variable. The horizontal axis shows the number of quarters from the introduction of the 3% surcharge. The shaded area represents the period between the surcharge announcement and its introduction.

Figure 7: Quarterly effect on prices paid by future owner-occupiers



Notes: This figure reports point-estimates and 90% confidence intervals for γ_t from the OLS regression of Equation (2) using the log price paid by future owner-occupiers as the dependent variable. The horizontal axis shows the number of quarters from the introduction of the 3% surcharge. The shaded area represents the period between the surcharge announcement and its introduction.

If we pool together all transactions and assume all buyers are tax liable for comparability with previous estimates, the estimated elasticity of prices with respect to the tax is $-0.112/0.03 = -3.7$ (Column (5) in Table C5). This large value is not far from estimates in previous studies that study similar tax variations. Kopczuk and Munroe [2015] analyze the impact of transfer taxes on property prices in New York and New Jersey and estimate a range of tax elasticities of prices between -2 and -3. Transfer taxes appear to be overshifted on property prices. Overshifting (a tax elasticity of prices larger than one in absolute value) is not possible in a perfectly competitive and frictionless market [Fullerton and Metcalf, 2002]. A potential explanation for this puzzling result is proposed by Kopczuk and Munroe [2015]. They argue that overshifting and excessive market unravelling are consequences of search frictions in the housing market that amplify the initial price decrease: sellers may opt out or continue waiting for better offers, and buyers may continue searching in order to benefit from locally depressed prices.

However, the fall in transaction volumes and prices did not discourage housing supply in the medium term. I do not find any significant response in the construction of new private residential buildings or in the number of demolitions within four years from the introduction of the surcharge (Tables C3-C4 and Figure D5). These insignificant results are consistent with previous estimates in the UK of a low (between 0 and 1) long-run price elasticity of supply of new residential constructions [Malpezzi and Maclennan, 2001].

4.1 Evidence of search frictions

The mere coexistence of an inventory of homes for sale and a stock of potential buyers indicates the presence of search frictions in the property market. These appear to be substantial in England and Wales. Figure 8a shows that it takes almost seven months to sell a property for a median seller and more than a year for the average seller, in the sample of properties listed on Zoopla in 2012-2019. Time-to-sell is calculated by subtracting the transaction date recorded in the Land Registry and the date the property was listed on Zoopla. These estimates are a lower bound of the actual median and average time-to-sell considering that: 1) some properties may have been for sale before being listed on Zoopla; 2) some properties listed on Zoopla were not sold.[19]

To test whether the surcharge affected the search process as suggested by Kopczuk and Munroe [2015], we can estimate whether it had a significant impact on this measure of time-to-sell. Table C6 show estimates of γ in regression (1) using the log number of days between the listing date on Zoopla and the transaction date recorded in the Land Registry (henceforth *days to sell*). The surcharge increases days to sell in all specifications and is statistically significant after adding controls at local authority level. Considering that only 20.35% of the properties were rented, the

[19] The Zoopla dataset contains only properties that are listed *and* sold, so the variable time-to-sell is truncated.

average impact of the 3% surcharge on English and Welsh local housing markets was a 3.4-5.7% increase in days-to-sell. This result is confirmed by the analysis of quarterly effects in Figure D6: time-to-sell gradually increases and becomes significantly higher one year after the introduction of the surcharge.

Search frictions can amplify the volatility of housing prices as the evidence of tax overshifting suggests, but can also generate equilibrium effects on the price paid by owner-occupiers who are not liable for the surcharge. In a perfectly competitive and frictionless market, pre-tax prices should not be lower for investors than for owner-occupiers as sellers can always find a owner-occupier that buys the property without having to pay the surcharge. All the evidence gathered in this section highlights the importance of the interaction between investors and search frictions in the determination of prices in the housing market.

5 The model

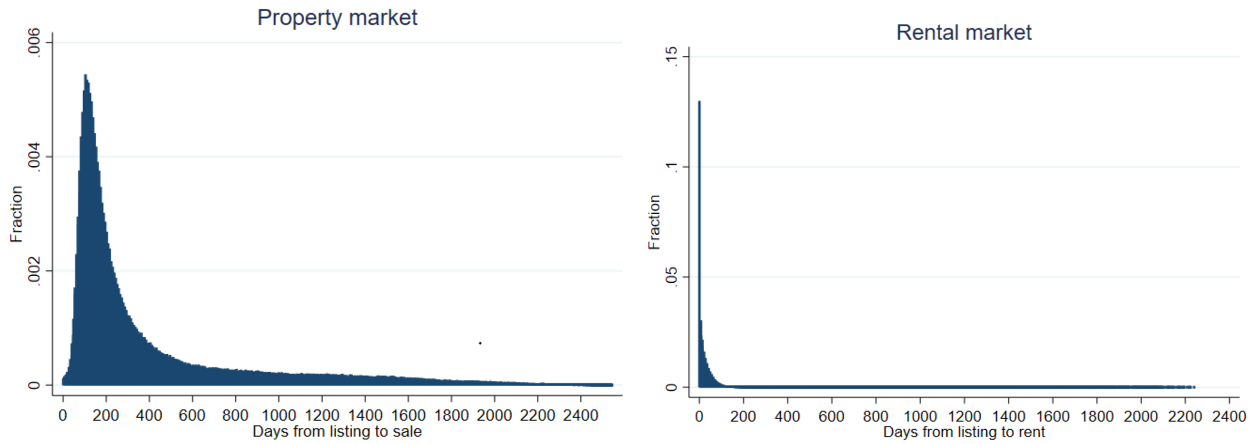
This section presents a search model with property, rental and credit markets to illustrate the mechanisms behind the effects discussed in Section 4 and perform a welfare analysis of the surcharge on property investors. The property market is characterized by search frictions: it is costly and time-consuming to search for a house to buy and it is costly and time-consuming to sell a house. For simplicity, the rental market is assumed to be frictionless. This simplification is based on the empirical evidence that it takes a substantially lower amount of time to let than to sell a property. As we can see in Figure 8, for the sample of properties listed on Zoopla, the median number of days to sell a property is 208, whereas the median number of days to let a property is 20.[20]

The introduction of buy-to-let mortgages has had a relevant impact in the British housing market (Figure 1) and can be interpreted as a reduction in credit market frictions for investors. To account for the role of credit rationing in the housing market, credit markets for households and investors are also subject to frictions. I model credit rationing by introducing a credit search cost and a credit matching function symmetrically with respect to the property market.[21] This modelling choice is not new to models that combine credit, labor and non-durable goods markets [Dell'Ariccia and Garibaldi, 2005; den Haan et al., 2003; Wasmer and Weil, 2004; Petrosky-Nadeau and Wasmer, 2013, 2015] but it is surprisingly novel for models of the housing market, in

[20]Time-to-sell is measured as the number of days between the listing date on Zoopla as a property for sale and the transfer date on the Land Registry. Time-to-let is measured as the number of days between the listing date on Zoopla as a property to let and the starting date of the tenancy period recorded on Zoopla.

[21]The presence of credit rationing can be micro-founded in a model of asymmetric information between lenders and borrowers, as in [Stiglitz and Weiss, 1981]. The reason of excess demand equilibria in credit markets is that the higher the interest rate set by the bank, the riskier the borrowers that are willing to get a loan (adverse selection) and/or the riskier the projects they will engage in (moral hazard). Non-monotonicity of profits in the interest rate can result in a profit-maximizing equilibrium interest rate that is lower than the market-clearing interest rate.

Figure 8: Evidence of search frictions in property and rental markets.



(a) Days to sell: median=208; mean=420

(b) Days to let: median=20; mean=55

which access to credit plays a central role.

Characterizing the credit market via an aggregate matching function maintains the model tractable and is in line with several empirical findings. Dell'Ariccia and Garibaldi [2005] document that credit contractions are more volatile than credit expansions and that gross flows are much larger than net flows in the credit market. This evidence is consistent with a matching model in which banks need time to identify new profitable clients after a positive aggregate shock, but can recall credit without time delay after a negative aggregate shock. An efficiency increase of the credit market matching function can also explain the observed increase in average geographical distance between lenders and borrowers that occurred during the IT revolution [Petersen and Rajan, 2002].

Agents in the economy are risk-neutral and of four different types: households (h), investors (i) and their respective lenders (l_h and l_i).[22] Time is continuous with an infinite horizon. All agents discount the future with factor $r > 0$. The population of households is exogenously given and denoted by $\mathcal{H}$. Investors can enter freely the housing market and lenders can enter freely in the credit market. Their respective total number in equilibrium is endogenously determined by the model.

Developers can build new houses if existing properties are not sufficient to satisfy households and investors' demand. Vacant homes depreciate at rate δ, whereas new homes are supplied at construction cost K. As in Gabrovski and Ortego-Marti [2019], I assume that new sellers can enter the housing market at this cost.[23] Given that all houses are identical, the value of a house

[22]The model focuses on long-term buy-to-let investors rather than on short-term speculators (flippers). Empirically, buy-to-let investors appear to engage in long-term operations: using data on repeated sales in the Land Registry from 1995 to 2019, I calculate an implied average duration of ownership of 22.2 years for buy-to-let investors.

[23]The only role developers play in the model is to supply new homes when the existing stock of properties for sale

for sale is determined by the entry condition, regardless of whether it is a newly built or an old house. Construction cost is an increasing function of new residential constructions e due to capacity constraints: $K = K(e)$ and $K'(e) \geq 0$. This corresponds to assuming a positive cost elasticity of supply and is a generalization of Gabrovski and Ortego-Marti [2019] that assume an infinite elasticity of supply with constant K.

Houses are homogeneous, but buyers are heterogeneous in terms of wealth. A fraction σ_h (σ_i) of households (investors) who search for a property do not need a mortgage to purchase it. Households own at most one property so they pay a standard ad-valorem transfer tax τ_h, whereas investors are buyers of multiple properties, so they pay a higher ad-valorem transfer tax which includes the surcharge $\tau_i > \tau_h$. Households earn income y. When they rent a house, they pay rental price R to investor-owners which is endogenously determined by the model. When they become owners, they stop paying the rent and receive homogeneous home-owning utility ε_h. On the other hand, investors earn R when they own a house and receive homogeneous home-owning utility ε_i (e.g. maintenance costs). Rental price R instantaneously clears the rental market.

5.1 Timing and meeting probabilities

Buyers of type $j \in \{h, i\}$ can either buy a house outright or use a mortgage. In the latter case, loan amounts are negotiated before prices. This replicates the common practice of mortgage 'agreements in principle' in the UK. Buyers obtain information on the loan amount they can obtain from a bank before searching for a house, and sellers generally ask to see a mortgage agreement in principle before agreeing to a sale [Lloyds Bank plc, 2022]. Agents face three stages:

- Stage 0: buyers and lenders randomly search for each other. When they meet, they negotiate over the loan amount a_j in exchange for a flow mortgage repayment ρ_j for any given price p_j^L.
- Stage 1: buyers and sellers randomly search for each other. When they meet, they negotiate the price p_j^L and buyers pay $p_j^L(1 + \tau_j) - a_j$,
- Stage 2: owners receive home-owning utility ε_j and pay lenders ρ_j until a moving shock, which occurs at rate π_j.[24]

is insufficient to meet demand. Free entry of both buyers and sellers is a departure from standard search models of the labour market, in which the measure of sellers (the labor force) is exogenously given. This is necessary to obtain an *upward* sloping Beveridge curve consistent with the signs of empirically estimated elasticities in housing markets [Díaz and Jerez, 2013; Gabrovski and Ortego-Marti, 2019].

[24]Using Land Registry data, I calculate an average home-ownership duration of 22.2 years for investors and 25.6 years for households (Section 6). This is quite similar to the median mortgage duration, which was 25 years in 2006 [FCA, 2019]. Since agents have linear utility of income and they discount utility at the same rate of lenders, mortgage duration is not relevant for their decisions.

If they choose to buy a house outright, they face two stages:

- Stage 1: buyers and sellers randomly search. When they meet, they negotiate the price p_j and buyers pay $p_j(1+\tau_j)$.
- Stage 2: owners receive home-owning utility ε_j until a moving shock, which occurs at rate π_j.

To find a seller, household-buyers and investor-buyers compete in the same property market with tightness $\theta = \frac{h_1+h_1^L+i_1+i_1^L}{s_1}$, where h_1, i_1, h_1^L, i_1^L and s_1 are the measures of sellers, household-buyers and investor-buyers with and without a mortgage agreement in stage 1, respectively. Meeting probabilities are determined by a standard constant returns to scale matching function $M(h_1+h_1^L+i_1+i_1^L, s_1)$ which is increasing and concave in its arguments [Pissarides, 2000]. Accordingly, buyers find sellers with probability

$$\frac{M(h_1+h_1^L+i_1+i_1^L, s_1)}{h_1+h_1^L+i_1+i_1^L} = M(1,\theta^{-1}) \equiv m(\theta) \tag{3}$$

Since search is random, sellers find a type-j buyer with probability $\tilde{j}\theta m(\theta)$ where $\tilde{j} = \frac{j}{h_1+h_1^L+i_1+i_1^L}$ for $j \in \{h_1, h_1^L, i_1, i_1^L\}$. By properties of the matching function $m(\theta)$ and $\theta m(\theta)$ are respectively decreasing and increasing in θ.

If they choose to buy using a mortgage, household- and investor-buyers randomly search for a lender in different credit markets with tightness $\phi_h = \frac{h_0^L}{l_{h0}}$ and $\phi_i = \frac{i_0^L}{l_{i0}}$, where h_0^L, i_0^L, l_{h0} and l_{i0} are the measures of household-buyers, investor-buyers and their respective lenders in stage 0. Meeting probabilities are determined by standard matching functions à la Pissarides [2000] $M_h(h_0^L, l_{h^L0})$ and $M_i(i_0^L, l_{i0})$. Accordingly, buyers find a lender with probabilities

$$\frac{M_j(j_0^L, l_{j0})}{j_0} = M(1,\phi_j^{-1}) \equiv q_j(\phi_j), \quad j \in \{h, i\} \tag{4}$$

Lenders find a type-j buyer with probability $\phi_j q_j(\phi_j)$. By properties of the matching function $q_j(\phi_j)$ and $\phi_j q_j(\phi_j)$ are respectively decreasing and increasing in ϕ_j.

5.2 Agent values

Household-renters who are not sufficiently wealthy to buy a property outright choose whether to search for a lender. If they do, they pay search cost χ_h and find a lender at rate $q_h(\phi_h)$. They have value:

$$rH_0^L = y - R + \max\{-\chi_h + q_h(\phi_h)\max\{H_1^L - H_0^L, 0\}, 0\} \tag{5}$$

Once they have a mortgage agreement in principle, household-renters decide whether to search for a seller at cost c_h and they find one at rate $m(\theta)$. They have value:

$$rH_1^L = y - R + \max\{-c_h + m(\theta)\max\{H_2^L - [p_h^L(1+\tau_h) - a_h] - H_1^L, 0\}, 0\} \tag{6}$$

If they purchase a house they pay the after-tax price $p_h^L(1+\tau_h)$ net of the loan amount a_h. Once they own a house, households with a mortgage receive additional utility ε_h, pay mortgage repayment ρ_h until a moving shock which occurs at rate π_h. In that case they become renter-buyers and sellers at the same time with value $H_0^L + S_1$:

$$rH_2^L = y + \varepsilon_h - \rho_h + \pi_h[H_0^L + S_1 - H_2^L] \tag{7}$$

In equilibrium, households are indifferent between searching for a mortgage or not: $-\chi_h + q_h(\phi_h)\max\{H_1^L - H_0^L, 0\} = 0$

The values for investors who need a mortgage to buy a house are symmetric to the households, except for the fact that investors do not pay rent while searching for a house and they receive rental payment R when they own a property. They are:

$$rI_0^L = \max\{-\chi_i + q_i(\phi_i)\max\{I_1^L - I_0^L, 0\}, 0\} \tag{8}$$

$$rI_1^L = \max\{-c_i + m(\theta)\max\{I_2^L - [p_i^L(1+\tau_i) - a_i] - I_1^L, 0\}, 0\} \tag{9}$$

$$rI_2^L = R + \varepsilon_i - \rho_i + \pi_i[\max\{I_0^L, 0\} + S_1 - I_2^L] \tag{10}$$

In equilibrium, investors are indifferent between searching for a mortgage or not: $-\chi_i + q_i(\phi_i)\max\{I_1^L - I_0^L, 0\} = 0$

For household-renters that are sufficiently wealthy to buy a house outright, the choice is between searching for a seller, searching for a lender or not searching. Their value is:

$$rH_1 = y - R + \max\{-c_h + m(\theta)\max\{H_2 - p_h(1+\tau_h) - H_1, 0\}, -\chi_h + q_h(\phi_h)\max\{H_1^L - H_1, 0\}, 0\} \tag{11}$$

The value for a household-owner without a mortgage is simply:

$$rH_2 = y + \varepsilon_h + \pi_h[\max\{H_1, H_0^L\} + S_1 - H_2] \tag{12}$$

For investors that are sufficiently wealthy to buy a house outright, the values are symmetric:

$$rI_1 = \max\{-c_i + m(\theta)\max\{I_2 - p_i(1+\tau_i) - I_1, 0\}, -\chi_i + q_i(\phi_i)\max\{I_1^L - I_1, 0\}, 0\} \quad (13)$$

$$rI_2 = R + \varepsilon_i + \pi_h[\max\{I_1, 0\} + S_1 - I_2] \quad (14)$$

Notice that households and investors that are sufficiently wealthy to buy a house outright will always choose to do so in equilibrium (see Appendix Section C.4).

Lenders pay a screening cost χ_{Lj} until they find a type-*j* buyer, which occurs at rate $\phi_j q_j(\phi_j)$. Their value is:

$$rL_{j0} = -\chi_{Lj} + \phi_j q_j(\phi_j)\max\{L_{j1} - L_{j0}, 0\}, \quad j \in \{h, i\} \quad (15)$$

The value of a lender waiting for the type-*j* buyer to find a seller is:

$$rL_{j1} = m(\theta)[L_{j2} - a_j - L_{j1}], \quad j \in \{h, i\} \quad (16)$$

When the type-j buyer find a property to buy, the lender pays the loan amount a_j. A lender under a mortgage contract with a type-*j* buyer receive flow payments ρ_j until the moving shock:

$$rL_{j2} = +\rho_j + \pi_j[\max\{L_{j0}, 0\} - L_{j2}], \quad j \in \{h, i\} \quad (17)$$

Finally, household- and investor-sellers have an identical value. They pay search cost c_s, face depreciation δ and find a buyer with probability $\theta m(\theta)$. Since search is random, the probability to find a buyer of a particular type conditional on finding a buyer is equal to the type-share of buyers. Denote these type-share as $\tilde{j} = \frac{j}{h_1 + h_1^L + i_1 + i_1^L}$ for $j \in \{h_1, h_1^L, i_1, i_1^L\}$. They are derived in section C.3 as functions of housing market tightness θ and new constructions e. Then, the value of sellers is:

$$\begin{aligned} rS_1 = -c_s - \delta S_1 + \theta m(\theta)\Big[&\tilde{h}_1^L(e,\theta)\max\{p_h^L - S_1, 0\} + \tilde{h}_1(e,\theta)\max\{p_h - S_1, 0\} \\ &+ \tilde{i}_1^L(e,\theta)\max\{p_i^L - S_1, 0\} + \tilde{i}_1(e,\theta)\max\{p_i - S_1, 0\}\Big] \end{aligned} \quad (18)$$

In equilibrium, there is free entry of lenders ($L_{h1} = L_{i1} = 0$) and sellers enter at construction cost $K(e)$: $S_1 = K(e)$. To summarize, the entry conditions in the steady state equilibrium are:

$$\begin{aligned} S_1 = K(e), \quad H_1^L - H_0^L = \frac{\chi_h}{q_h(\phi_h)}, \quad I_1^L - I_0^L = \frac{\chi_i}{q_i(\phi_i)}, \\ L_{h1} - L_{h0} = \frac{\chi_{lh}}{\phi_i q_h(\phi_h)}, \quad L_{i1} - L_{i0} = \frac{\chi_{li}}{\phi_i q_i(\phi_i)} \end{aligned} \tag{19}$$

5.3 Prices and mortgage negotiations

There are two types of negotiations in the economy: the loan amount negotiated between buyers and lenders and the property transaction price bargained between buyers and sellers. For buyer-borrowers, these contracts are negotiated sequentially. Buyers and sellers take as given the loan amount which was agreed before they met. Accordingly, lenders and buyers know that the result of their negotiation will affect the bargaining over the property price.

To solve this sequential problem, we proceed by backwards induction. In stage 1, buyers and sellers bargain the price, given the loan amount negotiated in stage 0. They maximize the surplus of the property transaction according to the following Nash bargaining rules:[25]

$$\begin{aligned} &\max_{p_h^L} [p_h^L - S_1]^{\beta_h} [H_2 - p_h^L(1+\tau_h) + a_h - H_1]^{1-\beta_h}, \\ &\max_{p_i^L} [p_i^L - S_1]^{\beta_i} [I_2 - p_i^L(1+\tau_i) + a_i - I_1]^{1-\beta_i} \end{aligned} \tag{20}$$

where β_j is the seller's bargaining power when meeting a type-j buyer ($j \in \{h, i\}$). The loan amounts a_j are negotiated when buyers and lenders meet, taking into account the impact they will have on property prices negotiated in the future.[26] Lenders and buyers maximize the surplus of their relationship according to the following Nash bargaining rules:

$$\max_{a_h} [L_{h1} - L_{h0}]^{\psi_h} [H_1 - H_0]^{1-\psi_h}, \quad \max_{a_i} [L_{i1} - L_{i0}]^{\psi_i} [I_1 - I_0]^{1-\psi_i} \tag{21}$$

where ψ_j is the seller's bargaining power when meeting a type-j buyer ($j \in \{h, i\}$).

Outright buyers simply negotiate the price with sellers to maximize the transaction surplus:

$$\max_{p_h} [p_h - S_1]^{\beta_h} [H_2 - p_h(1+\tau_h) - H_1]^{1-\beta_h}, \quad \max_{p_i} [p_i - S_1]^{\beta_i} [I_2 - p_i(1+\tau_i) - I_1]^{1-\beta_i} \tag{22}$$

[25] As shown by Rubinstein [1982], sharing the surplus according to the agents' bargaining power is the subgame perfect equilibrium outcome of an infinite-horizon, alternating-offers bargaining game in which every agent has a fixed discount factor. A player's bargaining power monotonically increases with their discount factor.

[26] I assume buyers and lenders negotiate over loan amounts a_j taking mortgage repayment ρ_j as given. For instance, mortgage repayment could be a fixed fraction of the borrower's income: $\rho_j = \lambda y$ where $\lambda \in (0, 1)$. The model is isomorphic if buyers and lenders negotiate over mortgage repayments and take the loan amount as given.

Solving these surplus maximization problems and plugging the equilibrium conditions yield equilibrium equations for prices and loan amounts (see Appendix Section C.1).

The equilibrium values for loan amounts a_j satisfy:

$$\frac{\rho_j}{r+\pi_j} = a_j + \psi_j \left(\frac{R+\varepsilon_j+\pi_j K(e)}{r+\pi_j} - (1+\tau_j)K(e) - \frac{c_j}{(1-\beta_j)m(\theta)} + \frac{\beta_j \chi_j}{(1-\beta_j)q_j(\phi_j)} \right), \quad j \in \{h,i\} \tag{23}$$

The present discounted value of mortgage repayments is equal to the loan amount plus the lender's share of the house transaction surplus net of buyer's search cost. In equilibrium, non-borrowers pay prices:

$$p_j = K(e) + \frac{\beta_j}{1+\tau_j}\left[\frac{\varepsilon_j + R - rK(e) - (r+\pi_j)\tau_j K(e) + c_j}{r+\pi_j+(1-\beta_j)m(\theta)}\right], \quad j \in \{h,i\} \tag{24}$$

In equilibrium, borrowers pay prices:

$$\begin{aligned} p_j^L =& K(e) + \frac{\beta_j}{(1+\tau_j)}\left[\frac{\varepsilon_j + R - rK(e) - (r+\pi_j)\tau_j K(e)}{r+\pi_j} - \frac{\chi_j}{q_j(\phi_j)} - \frac{\rho_j}{r+\pi_j} + a_j\right], \quad j \in \{h,i\} \\ =& K(e) + \frac{\beta_j}{(1+\tau_j)}\left[(1-\psi_j)\left(\frac{\varepsilon_j + R - rK(e) - (r+\pi_j)\tau_j K(e)}{r+\pi_j}\right) - \frac{[1-\beta_j(1-\psi_j)]\chi_j}{(1-\beta_j)q_j(\phi_j)} + \frac{\psi_j c_j}{(1-\beta_j)m(\theta)}\right] \end{aligned} \tag{25}$$

Prices are simply equal to construction cost plus the seller's share of the transaction surplus. Prices for buyers with a mortgage decrease with mortgage repayments (interest rates) and increase with the loan amount borrowers are able to obtain. Intuitively, the average price decreases with credit frictions $\frac{\chi_j}{q_j(\phi_j)}$ and increases with rental price R, construction cost $K(e)$ and housing market tightness θ ceteris paribus. However, we need to solve for the equilibrium values of the endogenous variables $(\phi_i, \phi_h, \theta, R, e)$ to account for general equilibrium effects.

5.4 A financial accelerator

Using the equilibrium expressions for the values of borrowers and lenders (see Appendix Section C.2), we obtain the following equations for buyers' entry and lenders' entry:

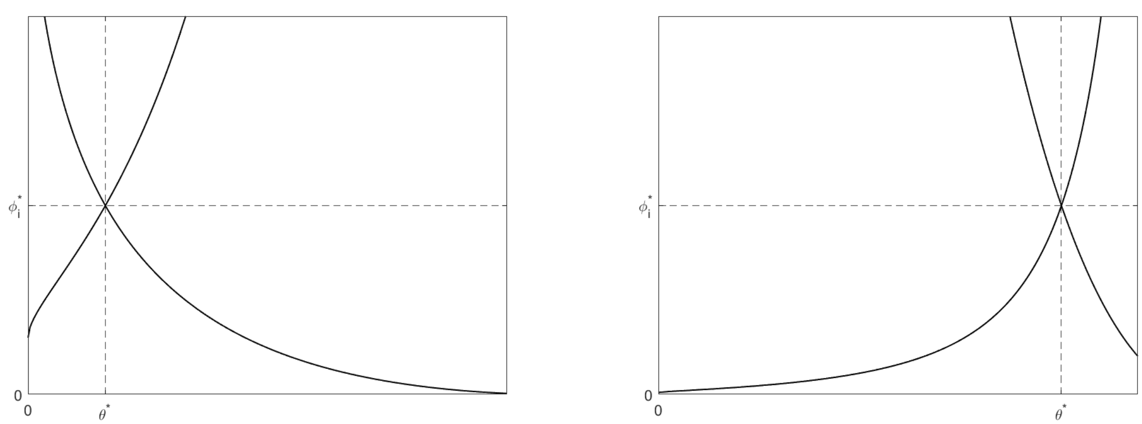
$$\frac{\chi_j}{q_j(\phi_j)} = \frac{(1-\psi_j)}{r+m(\theta)[1-\beta_j(1-\psi_j)]}\left\{-c_j + m(\theta)(1-\beta_j)\left[\frac{\varepsilon_j + R - rK(e) - (r+\pi_j)\tau_j K(e)}{r+\pi_j}\right]\right\} \tag{BE_j}$$

$$\frac{\chi_{lj}}{\phi_j q_j(\phi_j)} = \frac{\psi_j/(1-\beta_j)}{r+m(\theta)[1-\beta_j(1-\psi_j)]}\left\{-c_j + m(\theta)(1-\beta_j)\left[\frac{\varepsilon_j + R - rK(e) - (r+\pi_j)\tau_j K(e)}{r+\pi_j}\right]\right\} \tag{LE_j}$$

For given rental price R and construction cost $K(e)$, borrowers' entry equation (BE_j) defines a downward sloping iso-value curve and lenders' entry equation (LE_j) defines an upward-sloping iso-value curve in the (θ, ϕ_j) plane. If the expected cost of entry for a borrower is lower because the credit market is less tight, then the expected value of entering the property market can go to zero only if housing market tightness (i.e. expected duration of house search) is higher. If the expected cost of entry for a lender is higher because the credit market is less tight, then zero profits can only be achieved by having lower housing market tightness.

Borrowers and lenders' entry curves are represented in Figure 9. As we can see, an increase in credit market efficiency leaves credit market tightness unchanged but increases housing market tightness, for a given rental price R and construction cost $K(e)$. In the limit case in which credit frictions disappear ($q_j(\phi_j) \to \infty$), housing market tightness is maximized at value $\bar{\theta}$.

Figure 9: The effect of a reduction in credit frictions on housing market tightness



(a) Low credit matching efficiency

(b) High credit matching efficiency

Notes: These figures represent credit market tightness for investors in the vertical axis and housing market tightness in the horizontal axes. In panel (a) credit market frictions are high and housing market tightness is low. In panel (b) credit market frictions are low and housing market tightness is high.

As Wasmer and Weil [2004] show for the labor market, credit market frictions can amplify and propagate shocks to the housing market, acting in the form of a *financial accelerator*. A reduction in credit frictions increases the number of lenders, which incentivizes borrowers' entry, further encouraging lenders' entry and so on. Shocks to the credit sector result in an amplified effect on housing market tightness, which can in turn have a strong impact on housing prices. Differently from the labor market, shocks to the credit sector will have an impact on the rental market as well (the rental price R) which must be taken into account when analyzing how credit market frictions affect housing market tightness.

5.5 A recursive equilibrium

To solve the model, we need to find four endogenous variables: the credit market tightness for households ϕ_h, the credit market tightness for investors ϕ_i, the housing market tightness θ and the measure of new constructions e. Given these variables, we can find property prices using Equations (24)-(25) and the rental price using Equation (BE_j). In addition, we can find the equilibrium dwellings stock $D = \mathcal{H} + \frac{e}{\delta}$ and the stock all of agents in steady state using the stocks and flows equations presented in Appendix Section B and C.3.

Solving the surplus maximization problems in (21) and using the equilibrium conditions (19), we obtain equilibrium credit market tightness ϕ_j in each market:

$$\phi_j = \frac{(1-\beta_j)(1-\psi_j)\chi_{lj}}{\psi_j \chi_j}, \quad j \in \{h, i\} \tag{26}$$

As in Wasmer and Weil [2004], credit market tightness is constant in equilibrium and depends only on bargaining powers and search costs. The higher the bargaining powers of buyers in the credit and in the property market and the lower their credit search costs, the higher credit market tightness. The lower the bargaining power of lenders and the higher their credit search costs, the higher credit market tightness.

To find θ and e given ϕ_h and ϕ_i, first we can equalize the rental price in (BE_h) and (BE_i):

$$\begin{aligned}
&\frac{r+\pi_i}{m(\theta)(1-\beta_i)}\left\{\frac{\chi_i\{r+m(\theta)[1-\beta_i(1-\psi_i)]\}}{q_i(\phi_i)(1-\psi_i)}+c_i\right\}-\varepsilon_i+rK(e)+(r+\pi_i)\tau_i K(e)=R= \\
&\frac{r+\pi_h}{m(\theta)(1-\beta_h)}\left\{\frac{\chi_h\{r+m(\theta)[1-\beta_h(1-\psi_h)]\}}{q_h(\phi_h)(1-\psi_h)}+c_h\right\}-\varepsilon_h+rK(e)+(r+\pi_h)\tau_h K(e)
\end{aligned} \tag{27}$$

This two equations represent rental market supply and demand, respectively, and the rental price R instantaneously clears the rental market. For a given construction cost, the rental price decreases in the probability a buyer finds a property to buy because rental demand decreases and rental supply increases.

Secondly, to close the model we use equilibrium sellers' entry from Equation (18):

$$rK(e) = -c_s - \delta K(e) + \theta m(\theta)\Big[\tilde{h}_1^L[p_h^L - K(e)] + \tilde{h}_1[p_h - K(e)] + \tilde{i}_1^L[p_i^L - K(e)] + \tilde{i}_1[p_i - K(e)]\Big] \tag{28}$$

where prices $\{p_h, p_h^L, p_i, p_i^L\}$ and shares of buyers $\{\tilde{h_1}, \tilde{h_1^L}, \tilde{i_1}, \tilde{i_1^L}\}$ can be derived as functions of θ and e from Equations (24)-(25) and Equations (78)-(81), respectively.

The solution of the model depends on the functional form of $K(e)$. Under infinite elasticity of supply, the construction cost $K(e)$ is independent of the number of constructions e and the stationary equilibrium of this model is a recursive equilibrium, in which we can solve for θ using (27) and then we can plug it in (28) to solve for e. In general, the steady-state equilibrium is defined as follows.

Definition 1 *The steady-state equilibrium is a recursive equilibrium that consists of: (i) a credit market tightness for households and investors ϕ_j for $j \in \{h, i\}$ satisfying (26); (ii) housing market tightness and new constructions $\{\theta, e\}$ satisfying simultaneously (27)-(28) ; (iii) property prices $\{p_j, p_j^L\}$ for $j \in \{h, i\}$ satisfying price equations (24)-(25); (iv) rental price R that clears the rental market satisfying (27); (v) type-j shares of buyers $\tilde{j}$ for $\tilde{j} \in \{\tilde{h_1}, \tilde{h_1^L}, \tilde{i_1}, \tilde{i_1^L}\}$ consistent with the stocks and flows of agents in the steady state satisfying (78)-(81).*

5.6 Comparative statics: the short run

In this section, I use the model to show how equilibrium effects can rationalize all the empirical findings of Section 4: an increase in time-to-sell; a decrease in number of transactions; a decrease in prices paid by future owner-occupiers and a larger decrease in prices paid by buy-to-let investors. The effects analyzed in the four years of the post-surcharge period can be interpreted as short- and medium-term effects.[27] In the short run, we can assume the dwellings stock D is fixed. Accordingly, the construction cost K is also fixed.

First of all, applying the implicit function theorem to Equation (27), we see that the probability of finding a buyer increases with the introduction of a surcharge on investors ($\frac{dm(\theta)}{d\tau_i} > 0$) if

$$\begin{aligned} &-\varepsilon_i + (r+\pi_i)K\tau_i + \frac{(r+\pi_i)[1-\beta_i(1-\psi_i)]}{(1-\beta_i)(1-\psi_i)}\frac{\chi_i}{q_i(\phi_i)} \\ &< -\varepsilon_h + (r+\pi_h)K\tau_h + \frac{(r+\pi_h)[1-\beta_h(1-\psi_h)]}{(1-\beta_h)(1-\psi_h)}\frac{\chi_h}{q_i(\phi_h)} \end{aligned} \tag{29}$$

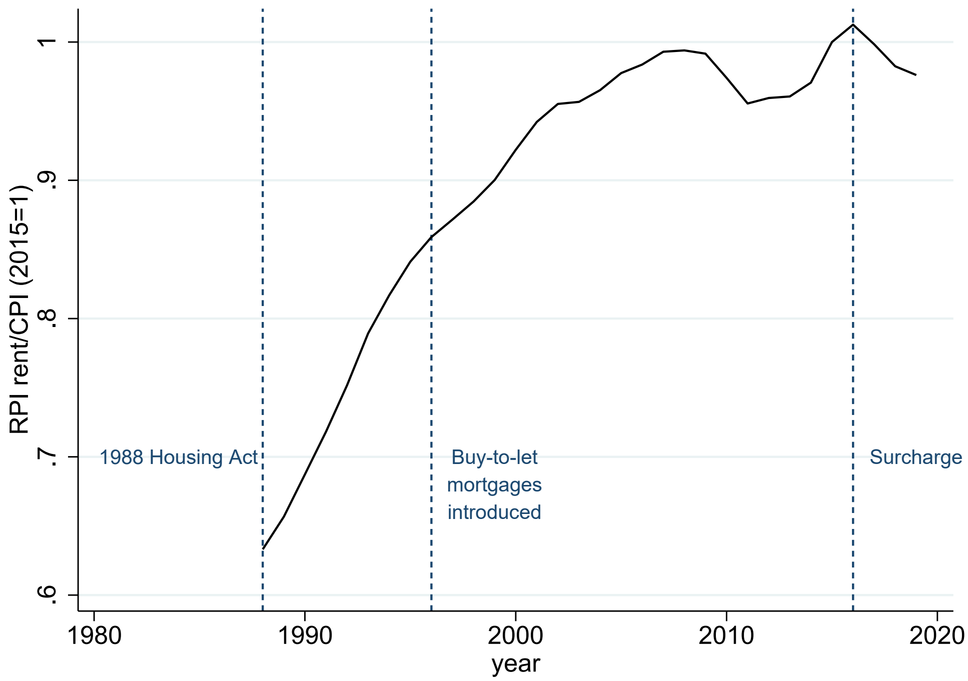
[27] In England, the average construction period is 2.5 years for sites between 100 and 499 units and 5 years for sites over 1,000 units in England [Swan, 2016].

If credit search frictions for households are substantially larger than credit search frictions for investors at the moment of the tax change, we would expect the tax to increase buyer's probability to find a property to buy and to decrease seller's probability to find a buyer, i.e. to reduce housing market tightness. In Section 6, I estimate that the credit market frictions for households are substantially larger than the credit market frictions for investors in 2015 and condition (29) holds. Accordingly, we should observe an increase in time to sell $\frac{1}{\theta m(\theta)}$, as estimated in Section 4. Interestingly, notice that if the surcharge on investors becomes too high ($\tau_i \gg \tau_h$) housing market tightness will *increase* and buyers' probability to find a home will decrease. The intuition is that a very high surcharge increases rental prices at a level that induces most households to seek a property to buy, thus increasing the number of total buyers in the market.

As population $\mathcal{H}$ is fixed, the number of sellers $s_1 = D - \mathcal{H}$ is also fixed in the short run. Since housing market tightness decreases with the surcharge on investors and the number of sellers is fixed, in the short-run we expect a decrease in the number of buyers (in particular buy-to-let investors) and, accordingly, a decrease in the number of transactions: $\frac{dM(h_1+h_1^L+i_1+i_1^L,s_1)}{d\tau_i} < 0$. The tax reduces the number of buyers relative to the number of sellers: this makes it harder for sellers to sell their property and reduces the number of transactions.

The increase in the probability of finding a property to buy results in a reduction in rental prices. From the second equality in (27), it is clear that $\frac{dR}{d\tau_i} = -\frac{(r+\pi_h)r\chi_h}{(1-\beta_h)q_h(\phi_h)(1-\psi_h)m(\theta)^2}\frac{dm(\theta)}{d\tau_i} < 0$ when $\frac{dm(\theta)}{d\tau_i} > 0$. This is due to a reduction in rental demand relative to supply as households find properties to buy more easily and investors find properties to buy and let more easily. Even though the identification strategy does not allow to analyze the impact on rental prices, we see in Figure 10 that the average deflated rental price in England and Wales peaks in 2016 and starts to decrease exactly after the surcharge on investors is introduced.

Figure 10: Rental price over time



Notes: This figure reports the Retail Price Index for Housing Rents deflated by the Consumer Price index in the UK from 1988 to 2019. The ratio is normalized to 1 in 2015.

When housing market tightness decreases, the short-run impact that a surcharge on investors has on property prices is unambiguously negative *for each type of buyer*. To see this, we can use the implicit function theorem on price equations (24)-(25) to obtain:

$$\frac{dp_h}{d\tau_i} = \frac{\beta_h \frac{dR}{d\tau_i} - [(p_h - K)(1-\beta_h)(1+\tau_h)]\frac{dm(\theta)}{\tau_i}}{[r+\pi_h+m(\theta)(1-\beta_h)](1+\tau_h)} < 0 \tag{30}$$

$$\frac{dp_h^L}{d\tau_i} = \frac{\frac{\beta_h(1-\psi_h)}{r+\pi_h}\frac{dR}{d\tau_i} - \frac{\beta_h\psi_h}{(1-\beta_h)}\left[\frac{1}{m(\theta)^2}\right]\frac{dm(\theta)}{\tau_i}}{(1+\tau_h)} < 0 \tag{31}$$

$$\begin{aligned}\frac{dp_i}{d\tau_i} =& \frac{\beta_i \frac{dR}{d\tau_i} - [(p_i - K)(1-\beta_i)(1+\tau_i)]\frac{dm(\theta)}{\tau_i}}{[r+\pi_i+m(\theta)(1-\beta_i)](1+\tau_i)} \\ &- \frac{\{p_i[r+\pi_i+m(\theta)(1-\beta_i)] - (1-\beta_i)K[r+\pi_i+m(\theta)]\}}{[r+\pi_i+m(\theta)(1-\beta_i)](1+\tau_i)} < 0\end{aligned} \tag{32}$$

$$\frac{dp_i^L}{d\tau_i} = \frac{\frac{\beta_i(1-\psi_i)}{r+\pi_i}\frac{dR}{d\tau_i} - \frac{\beta_i\psi_i}{(1-\beta_i)}\left[\frac{1}{m(\theta)^2}\right]\frac{dm(\theta)}{\tau_i}}{(1+\tau_i)} - \frac{\{p_i^L - K[1-\beta_i(1-\psi_i)]\}}{(1+\tau_i)} < 0 \tag{33}$$

The surcharge for multiple-property investors has three negative effects on prices. A *direct tax incidence effect* that has an impact only on properties purchased by investors: the last term on the right-hand side of (32) and (33).[28] In addition, there are *two equilibrium effects* through which the surcharge on investors reduces prices for all buyers:

1. an increase in the probability to find a property to buy ($\frac{dm(\theta)}{d\tau_i}$) which favors buyers over sellers;
2. a decrease in rental price ($\frac{dR}{d\tau_i}$) which pushes down demand for buying properties by households (because renting a house is now cheaper) and by investors (because letting a house is now less profitable).

Thanks to these two equilibrium effects, there is a price decrease even for those transactions that are not directly affected by the surcharge (p_h and p_h^L), namely the transactions for households wanting to buy a home. The direct tax incidence effect on investors explains the stronger impact on buy-to-let transaction prices.

5.7 Comparative statics: the long run

In the long run, the dwellings stock adjusts to reach a new equilibrium. In particular, the equilibrium equation for sellers' entry (28) can be rearranged as:

$$K(e) = \frac{-c_s + \theta m(\theta)}{(r+\delta) + \theta m(\theta)}\bar{p} \tag{34}$$

where $\bar{p}$ is the average price across all types of buyers. Since the surcharge on investors reduces all prices ($\frac{d\bar{p}}{d\tau_i} < 0$) and market tightness ($\frac{d\theta m(\theta)}{d\tau_i} < 0$), the construction cost must decrease for the housing market to reach a new equilibrium ($\frac{dK(e)}{d\tau_i} < 0$). As construction cost is increasing in constructions e, the equilibrium number of constructions and the total dwellings stock should decrease. Indeed, the number of new constructions appears to decrease due to the surcharge especially at the end of the analysed period (Figure D5), even though the total effect is insignificant (Table C3). The adjustment of the dwellings stock should be smaller, the lower the elasticity

[28]This term is unambiguously negative as each price must be larger than the construction cost K in an equilibrium in which each type of buyer is active, otherwise their respective transaction surplus would be negative.

of supply. Malpezzi and Maclennan [2001] estimate a low long-run price elasticity of supply of new residential construction in the UK (between 0 and 1), explaining the lack of a strong supply response to the surcharge.

Ultimately, the decrease in construction cost will amplify the negative effect on prices but also have a feedback effect on housing market tightness, which will lead to a new equilibrium. In Section 6, I calibrate the model to the pre-surcharge period and simulate the new equilibrium after the surcharge on investors is introduced. The comparison between the pre- and post-surcharge equilibrium shows that the model can qualitatively replicate all the main effects estimated in Section 4 and allows to perform a welfare analysis of the surcharge.

6 Identification and calibration

Assume that the housing matching function is Cobb-Douglas ($\theta m(\theta) = \nu\theta^{1-\gamma}$) and that the construction cost has the functional form $K(e) = a - \frac{b}{e}$ with $a, b > 0$. This functional form satisfies the property $K'(e) > 0$ and simplifies the solution of the model as sellers' entry (28) becomes linear in constructions e. The parameters to calibrate in the model are:
$\beta_h, \beta_i, c_h, c_i, c_s, \chi_h, \chi_i, \delta, \varepsilon_h, \varepsilon_i, \gamma, \nu, \pi_h, \pi_i, \psi_h, \psi_i, r, a, b, \sigma_h, \sigma_i, \mathcal{H}, Y, \rho_h, \rho_i$.[29]

I directly match some parameters to analogue moments or quantities in the data and I use previous estimates to calibrate other parameters. I derive the rest of the parameters by plugging data analogues into the model equations at the steady state (Table 3). For the estimation, I target data for 2015, the year before the introduction of the surcharge. I fix the transfer tax rate to the one corresponding to the median price (£204,000) in 2015, which is $\tau_h = \tau_i = 0.0075$. To estimate the housing market matching function parameters, I also target the estimated 4% increase in the time-to-sell caused by the 3% surcharge.

The demolition rate δ is calculated by dividing the number of demolitions over the number of vacant houses in 2015 [Ministry of Housing, 2019]. This yields a demolition rate of 0.019. To compute the moving rate for owner-occupiers and buy-to-let investors, I restrict to the period 2008-2019 in which the indicator to distinguish them is available and compute the hazard rate for properties that already existed in 2008. The total number of properties owned by an investors (rented) and households (owner-occupied) that existed in 2008 is observed. Since the hazard rate is assumed to be constant, the hazard rate for a single property is simply equal to the number of events (number of transactions in 2008-2019) divided by the time lapse (12 years). Since virtually all standard transactions are lodged in the Land Registry, I assume that properties that do not appear

[29] We can also assume Cobb-Douglas matching functions for the credit market: $M_h(h_1, l_{h1}) = \nu_h l_{h1}^{\gamma_h} h_1^{1-\gamma_h}$ and $M_i(i_1, l_{i1}) = \nu_i l_{i1}^{\gamma_i} i_1^{1-\gamma_i}$. The parameters $\chi_{Lh}, \chi_{Li}, \gamma_h, \gamma_i, \nu_h, \nu_i$ are not necessary to obtain the equilibrium variables of interest in the model. They can be used to estimate the measure of lenders and the credit market tightness.

in this dataset had zero events in the period of interest. Then, taking the average of all individual hazard rates, I obtain an average hazard rate for households of $\pi_h = 0.04$ and an average hazard rate for investors $\pi_i = 0.05$.

From model equations, we can estimate the probability a seller finds a buyer $\theta m(\theta)$:

$$\theta m(\theta) = \frac{\mathcal{H}}{D - \mathcal{H}} \left[\pi_h \left(\frac{h_2 + h_2^L}{\mathcal{H}} \right) + \pi_i \left(\frac{i_2 + i_2^L}{\mathcal{H}} \right) \right] \tag{35}$$

where we can observe the number of vacant homes $D - \mathcal{H}$, the number of occupied homes $\mathcal{H}$, the share of owner-occupied properties $\frac{h_2+h_2^L}{\mathcal{H}}$, and the share of privately rented properties $\frac{i_2+i_2^L}{\mathcal{H}}$ in 2015 [EHCS, 2004; Ministry of Housing, 2019]. Using this method, I obtain an estimate of $\theta m(\theta) = 1.62$ or, equivalently, an average time to sell of around seven months. This is reassuringly close to the median of 208 days between the listing date and the sale date observed for properties listed on Zoopla in the period 2012-2019 [Consumer Data Research Centre, 2020a]. In addition, I target an average time-to-buy of one year [Zoopla, 2022] obtain $m(\theta)$ and θ.

To identify σ_h and σ_i, I target the number of households' mortgages h_2^L, the number of buy-to-let mortgages i_2^L as well as the number of total properties occupied by households $h_2 + h_2^L$ and rented $i_2 + i_2^L$ [Ministry of Housing, 2022b; Council of Mortgage Lenders, 2022]. Then, using model equations we can estimate:

$$\sigma_j = \frac{j_2[1 + \frac{m(\theta)}{\pi_j}]}{j_2^L[1 + \frac{m(\theta)}{\pi_j}\frac{m(\theta)}{q_j(\phi_j)}] + j_2[1 + \frac{m(\theta)}{\pi_j}]}, \quad j \in \{h, i\} \tag{36}$$

This yields an estimate for the share of households and investors that search for a property without a mortgage of $\sigma_h = 0.35$ and $\sigma_i = 0.62$, respectively.

I calibrate the ratio of the search cost for sellers to the average price to be 0.01 in order to account for a 1% maintenance cost [BCIS, 2022]. In absence of data, the estimated search cost for investors c_i is assumed to be equal to the cost for sellers. The estimated search cost for households c_h is based on the opportunity cost of the time spent searching a property, following the approach by Ngai and Sheedy [2020]. I assume one property viewing entails the loss of half a day of average annual income y in 2015 [ONS, 2022]. The value of c_h and c_i is equal to the opportunity cost of making the expected number of viewings. According to leading estate and letting agents [LSL property services plc, 2022], the average number of viewings before buying is $V_b = 9$. To buy a property the average cost is $c_h = V_b \frac{y}{2 \cdot 365}$. As the time to buy a property is $1/m(\theta)$, the expected annual search cost for a buyer is set to $m(\theta) V_b \frac{y}{2 \cdot 365}$, which corresponds to 1.2% of annual income.

Construction cost for each year t is identified by using sellers' entry equation

$$K = \left(\frac{\theta m(\theta) - \frac{c_s}{\bar{p}}}{r + \delta + \theta m(\theta)} \right) \bar{p} \tag{37}$$

where $\bar{p}$ is the observed median price in 2015. Targeting an elasticity of supply of $\eta = 0.1$ [Malpezzi and Maclennan, 2001], I can estimates $a = K(1 + \frac{1}{\eta})$ and $b = \frac{\delta(D - \mathcal{H})K}{\eta}$.

For lack of data, I assume a symmetric bargaining power both in the credit market $\psi_h = \psi_i = 0.5$, as in Petrosky-Nadeau and Wasmer [2013], and in the housing market $\beta_h = \beta_i = 0.5$, as in Ngai and Sheedy [2020]. As it takes between two and six weeks to obtain a mortgage (Barclays plc, 2021), I target an average mortgage-search duration of one month: $\frac{1}{q_h(\phi_h)} = \frac{1}{q_i(\phi_i)} = \frac{1}{12}$.

To estimate buyers' expected credit search costs, I use buyers' entry (BE_j) and price equations (24)-(25) which yield:

$$\frac{\chi_j}{q_j(\phi_j)} = \frac{(1+\tau_j)(\bar{p}_j - K)m(\theta)\frac{(1-\beta_j)}{\beta_j} - c_j}{\left(\frac{j_1}{j^L + j_1}\right) \frac{(r+\pi_j)\{r + m(\theta)[1 - \beta_j(1-\psi_j)]\}}{[r + \pi_j + (1-\beta_j)m(\theta)](1-\psi_j)} + \left(1 - \frac{j_1^L}{j^L + j_1}\right) r}, \quad j \in \{h, i\} \tag{38}$$

where $\bar{p}_j$ is the observed median price paid by type-j buyer, and $\frac{j_1}{j^L + j_1}$ is the share of type-j buyer that buys properties without a mortgage.[30]

Rearranging (BE_j) we obtain the home-owning utility for households and investors:

$$\varepsilon_j = -R + rK(e) + (r+\pi_j)\tau_j K(e) + \frac{r + \pi_j}{m(\theta)(1-\beta_j)} \left(\frac{\frac{\chi_j}{q_j(\phi_j)}\{r + m(\theta)[1 - \beta_j(1-\psi_j)]\}}{(1-\psi_j)} + c_j \right), \quad j \in \{h, i\} \tag{39}$$

I estimate that households receive an annual intrinsic utility of $£5,277$, whereas investors lose $£2,180$ per year from owning a property (e.g. maintenance costs, agency fees, income tax) which is more than compensated by the rental price of $£9,456$ they receive.

I match households' income Y with the average earnings in 2015 in the UK from the Annual survey of hours and earnings [ONS, 2022]. For mortgage repayments ρ_h and ρ_i, I target the average loan-to-value ratios for residential and for buy-to-let mortgages using loan equation (23) [Bank of England, 2021; ONS, 2021]. Finally, I estimate the housing matching function parameters ν and γ by minimizing the sum of squares between the simulated change in equilibrium time-to-sell after the surcharge is introduced in the model and the 4% increase in time-to-sell estimated in the quasi-experimental analysis of Section 4.[31]

[30]Note that using the observed values for h_2, h_2^L, i_2 and i_2^L we can estimate h_1, h_1^L, i_1 and i_1^L from Equations (50) and (51) as $j_1 = \frac{\pi_j j_2}{m(\theta)}$ and $j_1^L = \frac{\pi_j j_2^L}{m(\theta)}$ for $j \in \{h, i\}$.

[31]This is the average of the estimates across the different regression specifications in Table C6 after adjusting for the average share of rented properties.

Table 3: Calibration

Parameter	Identification	Dataset/estimate	Value
Depreciation rate δ	Target percentage of UK vacant stock that in 2015.	Author's estimates using Ministry of Housing [2022b]	$\delta = 0.019$
Number of non-vacant privately owned dwellings $\mathcal{H}$	Target non-vacant privately owned dwellings in 2015.	Ministry of Housing [2022b] and EHCS [2004]	$\mathcal{H} = 18.96m$
Moving rate for households π_h and investors π_i	Average ratio between number of transactions and years observed across owner-occupiers' and investors' properties in 2008-2019.	Author's estimates using HM Land Registry [2019] and Department for Levelling Up, Housing and Communities [2022a]	$\pi_h = 0.04$, $\pi_i = 0.05$
Sellers'and investors' search cost c_s, c_i	Target maintenance cost as a percentage of price.	Author's estimates using BCIS [2022] and HM Land Registry [2019]	$c_s = c_i = 2049.5$
Households' search cost c_h	Target house visits before buying and median income.	Author's estimates using [LSL property services plc, 2022; ONS, 2022]	$c_h = 340.5$
Parameters of the construction cost function a, b	Previous estimate of elasticity of supply	Author's estimates using Malpezzi and Maclennan [2001]	$a = 20.2m$, $b = 0.19m$
Lenders' bargaining power with households ψ_h and investors ψ_i.	Previous calibration	Petrosky-Nadeau and Wasmer [2013]	$\psi_h = \psi_i = 0.5$
Housing matching function elasticity γ and efficiency ν	Model equations. Target vacant and occupied homes, shares of owner-occupied and rented properties in 2015. Target time to buy and post-surcharge 4% increase in time-to-sell.	Author's estimates using Zoopla [2022], Ministry of Housing [2022b]	$\gamma = 0.96$, $\nu = 1.59$
Sellers' bargaining power with households β_h and investors β_i.	Previous calibration	Ngai and Sheedy [2020]	$\beta_h = \beta_i = 0.5$
Shares of searchers without a mortgage σ_h, σ_i	Model equations. Target households' and investors' mortgages, owner-occupied and rented properties.	Author's estimates using Ministry of Housing [2022b]; Council of Mortgage Lenders [2022]	$\sigma_h = 0.35$, $\sigma_i = 0.62$
Discount rate r	Target average 1-month Gilt repo interest rate in 2015	Bank of England [2018]	$r = 0.01$
Investors' expected credit search costs $\frac{\chi_i}{q_i(\phi_i)}$	Model equations. Target median price paid by investors, rental price, number of investors' mortgages and rented properties in 2015.	Council of Mortgage Lenders [2022], HM Land Registry [2019], Department for Levelling Up, Housing and Communities [2022a]	$\frac{\chi_i}{q_i(\phi_i)} = 27,075$
Households' expected credit search costs $\frac{\chi_h}{q_h(\phi_h)}$	Model equations. Target median price paid by households, rental price, households' mortgages and properties in 2015.	Council of Mortgage Lenders [2022], HM Land Registry [2019], Department for Levelling Up, Housing and Communities [2022a]	$\frac{\chi_h}{q_h(\phi_h)} = 83,042$
Households' house utility ε_h	Model equations. Target median rental price in 2015.	Valuation Office Agency [2019]	$\varepsilon_h = 5,277$
Investors' house utility ε_i	Model equations. Target median rental price in 2015.	Valuation Office Agency [2019]	$\varepsilon_i = -2,180$
Households' income Y	Average earnings in 2015.	Annual survey of hours and earnings [ONS, 2022]	$Y = 27,615$
Mortgage repayments ρ_i, ρ_h	Average loan-to-value ratios for residential and buy-to-let mortgages.	ONS [2021], Bank of England [2021]	$\rho_h = 15,189$, $\rho_i = 11,429$

7 Quantitative results

7.1 Model validation

In Table 4, I compare housing market outcomes under three scenarios:

1. the outcome simulated before the surcharge and perfectly matched with data in 2015;
2. the outcome obtained by multiplying the pre-surcharge outcome with the estimated surcharge effect in the reduced-form estimates of Section 4;
3. the outcome simulated after introducing the surcharge in the model.

Table 4: Comparison between pre-surcharge data, post-surcharge reduced-form estimates and model simulation.

	Pre-surcharge	Post-surcharge (estimates)	Post-surcharge (model)
Transactions	804,978	722,870	767,963
Property price, investors (£)	204,950	199,416	44,386
Property price, households (£)	204,950	200,646	44,460
Dwellings stock (millions)	19.458	19.446	19.454
Rental price (£)	9,456	9,097	7,702
Homeownership rate	0.75	0.77	0.95
Welfare (million £)	48,521		49,654
Welfare, households per capita (£)	13,159		15,225
Welfare, investors per capita (£)	4,448		2,971

Notes: The column 'Pre-surcharge' reports the pre-surcharge outcome value simulated before the introduction of the surcharge and perfectly matched with data in 2015. The column 'Post-surcharge (estimates)' reports the post-surcharge outcome obtained by multiplying the pre-surcharge outcome with the surcharge effect estimated in Section 4. The column 'Post-surcharge (estimates)' reports the post-surcharge outcome obtained by simulating the model after introducing the surcharge. Reduced-form estimates are not available for the post-surcharge rental price and home-ownership rate, so I use aggregate UK data in 2019 for these outcomes.

By construction, the model replicates exactly the 4% increase in the number of days to sell a property estimated in Section 4, which rises from 225 to 234. The model is also able to capture qualitatively all the other effects. In the post-surcharge equilibrium, simulated transactions fall by 4.6% compared to the estimated reduction of 10.2%. The dwellings stock shows a very small decrease both in the simulated post-surcharge equilibrium (-0.02%) and in the insignificant estimates (-0.06%). Simulated prices for both buy-to-let investors and owner-occupiers decrease and the simulated price decrease is larger for buy-to-let investors. However, the model excessively amplifies the magnitude of the impact on prices relative to the reduced-form estimates. The puzzle that large changes in property prices are necessary to generate the observed fluctuations in housing market tightness is analogue to the 'unemployment volatility puzzle' described by Shimer [2005] for classical labor search models of the business cycle.[32]

The model allows to predict outcomes that cannot be estimated using the empirical strategy described in Section 3. The model predicts a reduction in annual rental prices from $£9,456$ to $£7,702$, which is not far from the fall in average rents to $£9,097$ observed in aggregate data in the entire UK from 2016 to 2019. Intuitively, the surcharge has an unambiguously positive effect on home-ownership: owner-occupiers increases their share of private dwellings from 75% to 95% in the new model equilibrium at the expense of investors. In Figure D7, indeed we see that the UK home-ownership rate declined steadily after the introduction of buy-to-let mortgages, but the surcharge inverted the trend and the share was higher in 2019 relative to 2016.

7.2 Welfare analysis

Assume the government equally redistributes all tax revenues from stamp-duty taxes τ_h and τ_i to the agents in the economy. Also assume that the social planner is utilitarian and evaluates each agent's welfare equally. The total flow value of utility net of costs over all agents in the economy is:

$$\begin{aligned} rW = &\mathcal{H}y - h_0^L \chi_h - h_1^L c_h + h_2^L \varepsilon_h - h_1 c_h + h_2 \varepsilon_h - i_0^L \chi_i - i_1^L c_i + i_2^L \varepsilon_i - i_1 c_i + i_2 \varepsilon_i \\ &- l_{h0} \chi_{lh} - l_{i0} \chi_{li} - s c_s - eK \end{aligned} \tag{40}$$

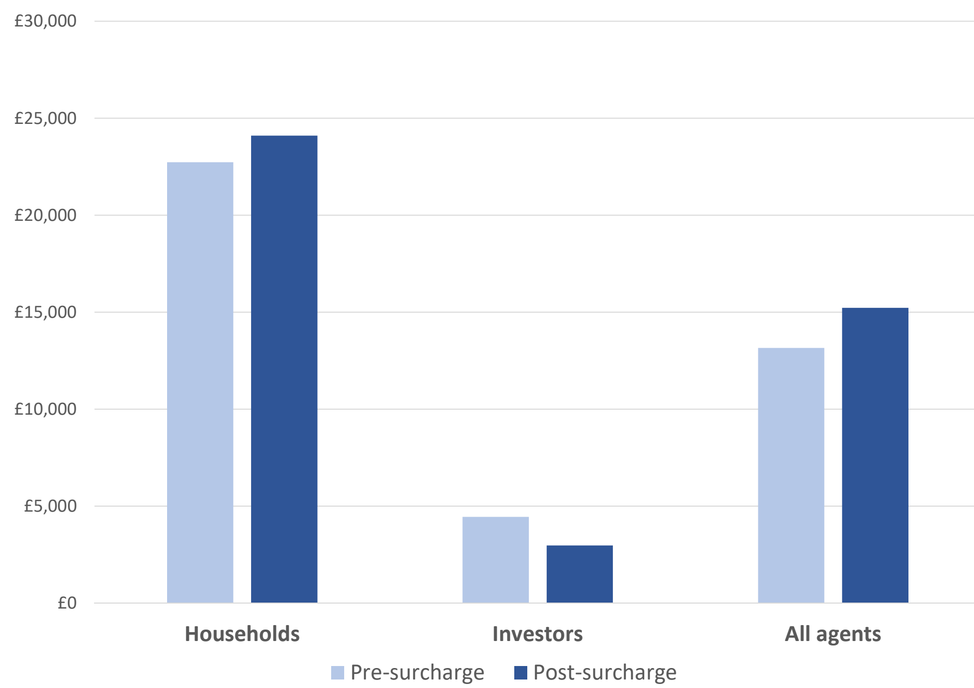
I compare the flow welfare rW before and after introducing the surcharge to understand whether the surcharge was welfare-improving. As we can see in Table 4, the surcharge on investors increased total welfare by 2.3%. The main reason behind the welfare increase is the rise in households' home-ownership at the expense of investors' ownership. The flow utility households receive from owning the property in which they live is positive ($\varepsilon_h = £5,277$), whereas the utility investors receive from letting the property they own is negative ($\varepsilon_i = -£2,180$). Investors are active in the property market because the rental price makes it a profitable investment ($R - \varepsilon_i > 0$) , but they do not take into account that their competition in the property market reduces households' utility by making it longer and more expensive to find a property to buy, thus reducing the number of owner-occupied properties. The surcharge on investors increased welfare because it partially offset the negative externality that investors imposed on households, by reducing their number.

Note that property and rental prices do not appear in the welfare function, as they are transfers between agents, who are equally weighted in the calculation of social welfare. If society values

[32] These models require very large wage changes to generate the magnitude of observed employment fluctuations. To increase responses of tightness to prices, recent models use different methods that ultimately diminish the fundamental surplus fraction, the proportional difference between productivity and workers' value of leisure [Ljungqvist and Sargent, 2017].

households more than investors, the estimated welfare increase would be a lower bound of the welfare change. This is because, thanks to the surcharge, households pay lower rental prices to investors, and investors have to pay a higher stamp-duty tax than households but revenues are equally distributed. In Section C.5, I compute the welfare per capita for households and for investors separately, taking into account the effect of the tax on rental and property prices. Figure 11 shows that the surcharge increases utility per capita for households by $£1,366$ ($+6.0\%$), but it decreases utility per capita for investors by $£1,477$ (-33.2%), resulting in an overall welfare increase.

Figure 11: Welfare per capita (£ per year)



Notes: From lighter to darker color, the histogram represents the pre-surcharge and the post-surcharge welfare per capita for households, investors and all agents, obtained by simulating the model and plugging the outcomes into Equations (89) and (90) and (91).

8 Conclusions

This paper studies the effects of an unusual transfer tax surcharge in the UK that targets property investors, but not owner-occupiers. Using an incremental difference-in-differences estimator, I document equilibrium effects that can hardly be reconciled with a frictionless and perfectly competitive housing market. The surcharge reduced pre-tax property prices for all buyers, but more for buy-to-let investors than for future owner-occupiers. The decline in prices was larger than the tax itself. This overshifting can be explained by search frictions in the property market. The tax increased time-to-sell and reduced the volume of transactions which amplified the effect on prices, even if the housing supply was not affected in the medium run.

Using a tractable search model with ownership, rental and credit markets, I show that equilibrium effects can rationalize the empirical findings. The surcharge reduces housing market tightness, which in turn decreases rental prices and construction costs leading to a new equilibrium in which housing becomes more affordable for owner-occupiers and the home-ownership rate rises. The model offers an important caveat for policymakers: if the surcharge becomes excessively high, the effects are reversed. Not enough buy-to-let investors will enter the market, the rental price will increase and too many households will search for a property to buy, inducing property prices to rise.

Most previous papers find that unconditional transfer taxes lead to deadweight losses. My study shows that a moderate transfer tax targeting investors can increase social welfare by offsetting the crowding-out externality that investors impose on owner-occupiers while competing for the same properties. An interesting avenue for future research is to check whether the normative implications hold in a richer theoretical framework in which the moving decision is endogenous and housing quality is heterogeneous. The results of this analysis have first-order relevance for policymakers because increasing home-ownership and decreasing property prices without discouraging housing supply is among the main objectives of current housing policies in many countries.

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Appendix A Robustness checks

The 3% Stamp-Duty Land Tax (SDLT) surcharge on purchases of additional properties was part of a Five-Point-Plan to support home ownership in the UK [HM Treasury, 2015, 2016]. The other points of the plan were: to deliver 400,000 affordable housing starts by 2020-21; to accelerate housing supply and get more homes built (e.g. by releasing public sector land); to prolong the already existing 'Help to Buy' Equity Loan scheme until 2021 and to create a London 'Help to Buy' scheme; to extend the 'Right to Buy' scheme to Housing Association tenants.

These factors would bias the estimates of the impact of the surcharge if their effects were correlated with the share of private rented properties. To account for this, I run several robustness checks. Regarding the first two points, I do not observe any differential impact in terms of housing supply, using changes in the construction of new private buildings as a dependent variable in the main regressions (Table C3 and Figure D5). The creation of the London 'Help to Buy' scheme is controlled in the main regressions by including the interaction of the region London with an indicator for the post-policy period. The extension of the 'Right to Buy' scheme to Housing Association tenants was never rolled-out at a national level, but only through a pilot in the Midlands in August 2018. Tables C7-C12 show that controlling for the interaction of the region Midlands with an indicator of the period after the introduction of the 'Right to Buy' scheme does not qualitatively affect the main results.

An additional policy that could affect the estimates is the change in deductions from rental income that occurred in April 2017. Before April 2017, landlords could deduct finance costs (mainly mortgage interest payments) from rental income before their income was taxed. After that date, deductions from rental income were restricted to:

- 75% for 2017 to 2018 with the remaining 25% taken as a basic rate tax reduction
- 50% for 2018 to 2019 with the remaining 50 % taken as a basic rate tax reduction
- 25% for 2019 to 2020 with the remaining 25% taken as a basic rate tax reduction
- 0% for 2020 to 2021 with the remaining 100% taken as a basic rate tax reduction.

The basic rate tax reduction consists in a tax credit equal to 20% times their finance costs.

To account for this policy change, I add to the main regressions the additional control $Post_t \cdot$ *BTL mortgages*$_{j,2015}$, where *BTL mortgages*$_{j,2015}$ is the share of total transactions under a buy-to-let mortgage in local authority j in 2015. If the change in deductions was responsible for the estimated effects in Section 4, the effects should disappear once we account for buy-to-let mortgages because outright buy-to-let transactions were not affected by the policy change. Tables C7-C12 show that the sign of all the estimated effects remain qualitatively unchanged and the magnitude of the effects is very similar.

Appendix B Stocks and flows

Let j_n be the number of type $j \in \{h, i\}$ agents at stage $n \in \{1, 2\}$ without need of a mortgage to buy a property. Let h_0 be households who rent, but do not search for a mortgage or for a property to buy. Let j_n^L be the number of type $j \in \{h, i\}$ agents at stage $n \in \{0, 1, 2\}$ with need of a mortgage to buy a property. Let l_{jn} be the number of lenders to type $j \in \{h, i\}$ agents at stage $n \in \{0, 1, 2\}$.

Housing market tightness is:

$$\theta = \frac{h_1 + h_1^L + i_1 + i_1^L}{s_1} \tag{41}$$

Credit market tightnesses for households and investors are:

$$\phi_h = \frac{h_0^L}{l_{h0}}, \quad \phi_i = \frac{i_0^L}{l_{i0}} \tag{42}$$

The existing dwellings stock in steady state is:

$$D = s_1 + h_2^L + h_2 + i_2^L + i_2 \tag{43}$$

The measures of households is fixed at:

$$\mathcal{H} = h_0 + h_1 + h_2 + h_0^L + h_1^L + h_2^L \tag{44}$$

A fraction σ_h (σ_i) of households (investors) that search does not need a mortgage:

$$h_1 + h_2 = \sigma_h(h_1 + h_2 + h_0^L + h_1^L + h_2^L), \quad i_1 + i_2 = \sigma_i(i_1 + i_2 + i_0^L + i_1^L + i_2^L) \tag{45}$$

The rental market clears instantaneously. Therefore, the measure of renters must be equal to measure of investor-owners:

$$h_1 + h_0^L + h_1^L = i_2 + i_2^L \tag{46}$$

Lenders must be equal to the number of buyers with a mortgage in each stage:

$$l_{h1} = h_1^L, \quad l_{i1} = i_1^L, \quad l_{h2} = h_2^L, \quad l_{i2} = i_2^L \tag{47}$$

The laws of motion are:

$$\dot{s_1} = e + \pi_h(h_2^L + h_2) + \pi_i(i_2^L + i_2) - \delta s_1 - (h_1^L + h_1)m(\theta) - (i_1^L + i_1)m(\theta) \tag{48}$$

where e is the measure of new sellers (i.e. newly built houses).

$$\dot{h_1^L} = h_0^L q_h(\phi_h) - h_1^L m(\theta), \quad \dot{i_1^L} = i_0^L q_i(\phi_i) - i_1^L m(\theta) \tag{49}$$

$$\dot{h_2^L} = h_1^L m(\theta) - \pi_h h_2^L, \quad \dot{h_2} = h_1 m(\theta) - \pi_h h_2 \tag{50}$$

$$\dot{i_2^L} = i_1^L m(\theta) - \pi_i i_2^L, \quad \dot{i_2} = i_1 m(\theta) - \pi_i i_2 \tag{51}$$

In steady state, the 19 Equations in (41)-(51) pin down the 19 variables $(e, h_0^L, h_1^L, h_2^L, h_0, h_1, h_2, i_0^L, i_1^L, i_2^L, i_1, i_2, l_{h0}, l_{h1}, l_{h2}, l_{i0}, l_{i1}, l_{i2}, s_1)$ as functions of $(D, \theta, \phi_h, \phi_i)$ which are determined by the equilibrium equations in Section 5.5.

Appendix C Derivations

C.1 Prices and loans

Borrower-buyers and lenders solve the following maximization problems, taking as given loan amounts a_h and a_i:

$$\max_{p_h^L} [p_h^L - S_1]^{\beta_h} [H_2 - (p_h^L(1+\tau_h) - a_h) - H_1]^{1-\beta_h}, \quad \max_{p_i^L} [p_i^L - S_1]^{\beta_i} [I_2 - (p_i^L(1+\tau_i) - a_i) - I_1]^{1-\beta_i}$$

The first-order conditions are:

$$\begin{aligned} &\beta_h[H_2^L - H_1^L - p_h^L(1+\tau_h) + a_h] = (1+\tau_h)(1-\beta_h)[p_h^L - S_1], \\ &\beta_i[I_2^L - I_1^L - p_i^L(1+\tau_i) + a_i] = (1+\tau_i)(1-\beta_i)[p_i^L - S_1] \end{aligned} \tag{52}$$

Using the equilibrium conditions, we can rewrite the first-order-conditions as:

$$\begin{aligned} &\beta_h[H_2^L - H_0^L - \frac{\chi_h}{q_h(\phi_h)} - p_h^L(1+\tau_h) + a_h] = (1+\tau_h)(1-\beta_h)[p_h^L - S_1], \\ &\beta_i[I_2^L - I_0^L - \frac{\chi_i}{q_i(\phi_i)} - p_i^L(1+\tau_i) + a_i] = (1+\tau_i)(1-\beta_i)[p_i^L - S_1] \end{aligned} \tag{53}$$

Subtracting Equation (5) from (7) and plugging the equilibrium conditions (19), we obtain

$$H_2^L - H_0^L = \frac{R - rK + \varepsilon_h - \rho_h}{r + \pi_h} \tag{54}$$

Subtracting Equation (8) from (10) and plugging the equilibrium conditions (19), we obtain

$$I_2^L - I_0^L = \frac{R - rK + \varepsilon_i - \rho_i}{r + \pi_i} \tag{55}$$

Plugging (19), (54) and (55) into (53) and rearranging, we obtain the first equality in (25):

$$p_j^L = K + \frac{\beta_j}{(1+\tau_j)}\left[\frac{\varepsilon_j + R + \pi_j K}{r + \pi_j} - (1+\tau_j)K - \frac{\chi_j}{q_j(\phi_j)} - \frac{\rho_j}{r+\pi_j} + a_j\right], \quad j \in \{h, i\}$$

To obtain expressions for mortgage repayments, solve the surplus maximization problems taking into account the effect that a_j has on p_j^L according to equation (25):

$$\max_{a_h}[L_{h1} - L_{h0}]^{\psi_h}[H_1 - H_0]^{1-\psi_h}, \quad \max_{a_i}[L_{i1} - L_{i0}]^{\psi_i}[I_1 - I_0]^{1-\psi_i}$$

The first-order conditions are:

$$\psi_h[H_1^L - H_0^L] = (1-\psi_h)(1-\beta_h)[L_{h1} - L_{h0}], \quad \psi_i[I_1^L - I_0^L] = (1-\psi_i)(1-\beta_i)[L_{i1} - L_{i0}] \tag{56}$$

Plugging the equilibrium conditions 19, we obtain equilibrium credit market tightness in each market:

$$\phi_j^* = \frac{(1-\beta_j)(1-\psi_j)\chi_{lj}}{\psi_j \chi_j}, \quad j \in \{h, i\} \tag{57}$$

Subtracting Equation (5) from (6), plugging the equilibrium conditions 19 and rearranging, we obtain

$$H_1^L - H_0^L = -\frac{c_h}{r + m(\theta)} + \frac{m(\theta)}{r + m(\theta)}\left[\frac{R + \pi_h K + \varepsilon_h - \rho_h}{r + \pi_h} - p_h^L(1+\tau_h) + a_h\right] \tag{58}$$

Plugging the price equation (25):

$$H_1^L - H_0^L = -\frac{c_h}{r + m(\theta)} + \frac{(1-\beta_h)m(\theta)}{r + m(\theta)}\left[\frac{R + \pi_h K + \varepsilon_h - \rho_h}{r + \pi_h} - (1+\tau_h)K + a_h + \frac{\beta_h \chi_h}{(1-\beta_h)q_h(\phi_h)}\right] \tag{59}$$

Subtracting Equation (15) from (16), plugging the equilibrium conditions 19 and rearranging, we obtain

$$L_{h1} - L_{h0} = \frac{m(\theta)}{r + m(\theta)} \left[\frac{\rho_h}{r + \pi_h} - a_h \right] \tag{60}$$

Then can substitute out $H_1^L - H_0^L$ and $L_{h1} - L_{h0}$ in the first-order condition (56) using (59) and (60) to obtain:

$$\frac{\rho_h}{r + \pi_h} = a_h + \psi_h \left(\frac{R + \varepsilon_h + \pi_h K}{r + \pi_h} - (1 + \tau_h) K - \frac{c_h}{(1 - \beta_h) m(\theta)} + \frac{\beta_h \chi_h}{(1 - \beta_h) q_h(\phi_h)} \right) \tag{61}$$

which is the equation for loan amounts a_h in (23).

By a similar reasoning, we have:

$$I_1^L - I_0^L = -\frac{c_i}{r + m(\theta)} + \frac{(1 - \beta_i) m(\theta)}{r + m(\theta)} \left[\frac{R + \pi_i K + \varepsilon_i - \rho_i}{r + \pi_i} - (1 + \tau_i) K + a_i + \frac{\beta_i \chi_i}{(1 - \beta_i) q_i(\phi_i)} \right] \tag{62}$$

$$L_{i1} - L_{i0} = \frac{m(\theta)}{r + m(\theta)} \left[\frac{\rho_i}{r + \pi_i} - a_i \right] \tag{63}$$

and the loan amount a_i satisfies:

$$\frac{\rho_i}{r + \pi_i} = a_i + \psi_i \left(\frac{R + \varepsilon_i + \pi_i K}{r + \pi_i} - (1 + \tau_i) K - \frac{c_i}{(1 - \beta_i) m(\theta)} + \frac{\beta_i \chi_i}{(1 - \beta_i) q_i(\phi_i)} \right) \tag{64}$$

which is the equation for a_i in (23). If we substitute out the loan amounts in (25) using 61 and 64, we obtain the second equality in (25).

Buyers without a mortgage agreement and lenders solve the following maximization problems:

$$\max_{p_h} [p_h - S_1]^{\beta_h} [H_2 - p_h(1 + \tau_h) - H_1]^{1 - \beta_h}, \quad \max_{p_i} [p_i - S_1]^{\beta_i} [I_2 - p_i(1 + \tau_i) - I_1]^{1 - \beta_i} \tag{65}$$

The first-order conditions are:

$$\beta_h [H_2 - H_1 - p_h(1 + \tau_h)] = (1 + \tau_h)(1 - \beta_h)[p_h - S_1], \quad \beta_i [I_2 - I_1 - p_i(1 + \tau_i)] = (1 + \tau_i)(1 - \beta_i)[p_i - S_1] \tag{66}$$

Plugging the values for $H_2 - H_1$ and $I_2 - I_1$ we obtain (24).

C.2 The financial accelerator

Equalize $H_1^L - H_0^L$ and $I_1^L - I_0^L$ in the equilibrium conditions (19) to the forward expressions in equations (59) and (62) to obtain:

$$\frac{\chi_j}{q_j(\phi_j)} = -\frac{c_j}{r+m(\theta)} + \frac{(1-\beta_j)m(\theta)}{r+m(\theta)}\left[\frac{R+\pi_j K+\varepsilon_j-\rho_j}{r+\pi_j} - (1+\tau_j)K + a_j + \frac{\beta_j\chi_j}{(1-\beta_j)}\right]$$

$$\frac{\chi_{lj}}{\phi_j q_j(\phi_j)} = \frac{m(\theta)}{r+m(\theta)}\left[\frac{\rho_j}{r+\pi_j} - a_j\right]$$

Plug Equation (23) into the two equations above to obtain borrowers and lenders' entry equations (BE_j) and (LE_j).

To obtain the graph in Figure 9, note that (BE_j) and (LE_j) represent a negative and a positive relationship between ϕ_j and θ for given R and K, respectively. When $\theta \to 0$, (BE_j) and (LE_j) yield level of credit market tightness ϕ_j^B and ϕ_j^L such that:[33]

$$\frac{\chi_j}{q_j(\phi_j^B)} = \frac{(1-\psi_j)(1-\beta_j)\left[\frac{\varepsilon_j+R+\pi_j K(e)}{(r+\pi_j)} - (1+\tau_j)K(e)\right]}{[1-\beta_j(1-\psi_j)]} \tag{67}$$

and

$$\frac{\chi_{lj}}{\phi_j q_j(\phi_j^L)} = \frac{\psi_j\left[\frac{\varepsilon_j+R+\pi_j K(e)}{(r+\pi_j)} - (1+\tau_j)K(e)\right]}{[1-\beta_j(1-\psi_j)]} \tag{68}$$

When $\phi_j \to 0$ in (BE_j) and when $\phi_j \to \infty$ in (LE_j) market tightness is $\theta = \bar{\theta}$ such that:

$$c_j = m(\bar{\theta})(1-\beta_j)\left[\frac{\varepsilon_j+R+\pi_j K(e)}{r+\pi_j} - (1+\tau_j)K(e)\right] \tag{69}$$

Note that minimizing credit frictions ($q_j(\phi_j) \to \infty$ at any ϕ_j) yields the supremum of housing market tightness $\bar{\theta}$.

C.3 Shares of buyers' types

If we equalize Equations (44) and (46), we obtain:

$$\mathcal{H} = h_2 + h_2^L + i_2 + i_2^L \tag{70}$$

[33]For the existence of an equilibrium, assume that the parameter values are such that $\phi_j^B > \phi_j^L$.

Since there are no homeless people in the model, the number of households must be equal to the number of non-empty houses (owner-occupied or rented). In steady state, plugging Equations (50)-(51) into (48) yields

$$e = \delta s \tag{71}$$

The number of new houses equals the number of demolished houses in steady state. From Equations (43), (70) and (71), we can find:

$$s_1 = \frac{e}{\delta} = D - \mathcal{H}, \tag{72}$$

Then, using the definition of housing market tightness:

$$h_1 + h_1^L + i_1 + i_1^L = \theta(D - \mathcal{H}) \tag{73}$$

Now note from Equations (45), (50) and (51)

$$h_1 + h_1^L = \frac{\pi_h}{\pi_i - \pi_h}\left[\frac{\pi_i \mathcal{H}}{m(\theta)} - \theta(D - H)\right] \tag{74}$$

$$i_1 + i_1^L = \frac{\pi_i}{\pi_i - \pi_h}\left[\theta(D - H) - \frac{\pi_h \mathcal{H}}{m(\theta)}\right] \tag{75}$$

Also,

$$h_1 = \frac{\sigma_h\left[1 + \frac{m(\theta)}{\pi_h} + \frac{m(\theta)}{q_h(\phi_h)}\right]}{(1 - \sigma_h)\left[1 + \frac{m(\theta)}{\pi_h}\right]} h_1^L \tag{76}$$

$$i_1 = \frac{\sigma_i\left[1 + \frac{m(\theta)}{\pi_i} + \frac{m(\theta)}{q_i(\phi_i)}\right]}{(1 - \sigma_i)\left[1 + \frac{m(\theta)}{\pi_i}\right]} i_1^L \tag{77}$$

Finally, using Equations (74)-(77) and (72) we can find the shares of buyers:

$$\frac{h_1}{h_1^L + h_1 + i_1^L + i_1} = \frac{\sigma_h\left[1 + \frac{m(\theta)}{\pi_h} + \frac{m(\theta)}{q_h(\phi_h)}\right]}{\left[1 + \frac{m(\theta)}{\pi_h} + \frac{\sigma_h m(\theta)}{q_h(\phi_h)}\right]} \frac{\pi_h}{(\pi_i - \pi_h)}\left[\frac{\pi_i \mathcal{H}\delta}{\theta m(\theta) e} - 1\right] \tag{78}$$

$$\frac{i_1}{h_1^L + h_1 + i_1^L + i_1} = \frac{\sigma_i\left[1 + \frac{m(\theta)}{\pi_i} + \frac{m(\theta)}{q_i(\phi_i)}\right]}{\left[1 + \frac{m(\theta)}{\pi_i} + \frac{\sigma_i m(\theta)}{q_i(\phi_i)}\right]} \frac{\pi_i}{(\pi_i - \pi_h)}\left[1 - \frac{\pi_h \mathcal{H}\delta}{\theta m(\theta) e}\right] \tag{79}$$

$$\frac{h_1^L}{h_1^L + h_1 + i_1^L + i_1} = \frac{(1-\sigma_h)\left[1+\frac{m(\theta)}{\pi_h}\right]}{\left[1+\frac{m(\theta)}{\pi_h}+\frac{\sigma_h m(\theta)}{q_h(\phi_h)}\right]}\frac{\pi_h}{(\pi_i-\pi_h)}\left[\frac{\pi_i \mathcal{H}\delta}{\theta m(\theta)e}-1\right] \tag{80}$$

$$\frac{i_1^L}{h_1^L + h_1 + i_1^L + i_1} = \frac{(1-\sigma_i)\left[1+\frac{m(\theta)}{\pi_i}\right]}{\left[1+\frac{m(\theta)}{\pi_i}+\frac{\sigma_i m(\theta)}{q_i(\phi_i)}\right]}\frac{\pi_i}{(\pi_i-\pi_h)}\left[1-\frac{\pi_h \mathcal{H}\delta}{\theta m(\theta)e}\right] \tag{81}$$

C.4 Wealthy households' and investors' mortgage choice

In this section, we compare the equilibrium values of household buyers searching for a seller with and without a mortgage agreement. Denote H_1^M the value of a household buyer. First, note that in equilibrium:

$$H_2 = \frac{y+\varepsilon_h+\pi_h K+\pi_h H_1}{r+\pi_h} \tag{82}$$

$$H_2^L + a_h = \frac{y+\varepsilon_h-\rho_h+\pi_h K+\pi_h H_1^L}{r+\pi_h} + a_h \leq \frac{y+\varepsilon_h+\pi_h K+\pi_h H_1^L}{r+\pi_h} \tag{83}$$

where the inequality stems from the fact that the present discounted value of a loan for a bank has to be positive $\frac{\rho_h}{r+\pi_h} - a_h > 0$. This is a necessary condition for the existence of an equilibrium in which lenders participate. Then, from the first-order-condition in the Nash bargaining and (82)

$$\begin{aligned} rH_1 &= y - R - c_h + m(\theta)[H_2 - H_1 - p_h] = y - R - c_h + m(\theta)(1-\beta_h)[H_2 - H_1 - K] \\ &= y - R - c_h + m(\theta)(1-\beta_h)\left[\frac{y+\varepsilon_h+\pi_h K - rH_1}{r+\pi_h} - (1+\tau_h)K\right] \end{aligned} \tag{84}$$

Rearranging:

$$H_1 = \frac{y - R - c_h + m(\theta)(1-\beta_h)\left[\frac{y+\varepsilon_h+\pi_h K}{r+\pi_h} - (1+\tau_h)K\right]}{r + \frac{m(\theta)(1-\beta_h)r}{r+\pi_h}} \tag{85}$$

Likewise, from the first-order-condition in the Nash bargaining and (83):

$$\begin{aligned} rH_1^L &= y - R - c_h + m(\theta)[H_2^L - H_1^L - p_h + a_h] = y - R - c_h + m(\theta)(1-\beta_h)[H_2^L + a_h - H_1^L - K] \\ &\leq y - R - c_h + m(\theta)(1-\beta_h)\left[\frac{y+\varepsilon_h+\pi_h K - rH_1^L}{r+\pi_h} - (1+\tau_h)K\right] \end{aligned} \tag{86}$$

Rearranging:

$$H_1^L \leq \frac{y - R - c_h + m(\theta)(1-\beta_h)\left[\frac{y+\varepsilon_h+\pi_h K}{r+\pi_h} - (1+\tau_h)K\right]}{r + \frac{m(\theta)(1-\beta_h)r}{r+\pi_h}} = H_1 \tag{87}$$

A wealthy buyer will always prefer to search and buy without a mortgage, as long as the search value is positive and the lender's bargaining power is not 0. The intuition is that the buyer prefers not share any of the transaction surplus with the lender and therefore will never ask for a mortgage in case she has sufficient wealth to purchase a property outright.

C.5 Welfare analysis for households and investors

Assume depreciation affects investors and households at the same rate. In the steady state, the number of entry sellers must be equal to the number of demolished homes for each type: $e_j = \delta s_j,\ j \in \{i, h\}$. As investor- and household-sellers have the same probability to find a buyer, their number depends only on the type-specific rate at which owners become sellers and the number of owners of each type. Therefore, the steady state number of household-sellers is $s_h = \frac{\pi_h(h_2^L+h_2)}{\pi_h(h_2^L+h_2)+\pi_i(i_2^L+i_2)}s$ and the number of investor-sellers is $s_i = \frac{\pi_i(i_2^L+i_2)}{\pi_h(h_2^L+h_2)+\pi_i(i_2^L+i_2)}s$. Finally, let G denote per-capita tax revenues which are equally redistributed across households and investors. They are equal to:

$$G = \frac{m(\theta)[(h_1 p_h + h_1^L p_h^L)\tau_h + (i_1 p_i + i_1^L p_i^L)\tau_i]}{\mathcal{H} + i_0^L + i_1^L + i_2^L + i_1 + i_2} \tag{88}$$

Per capita net flow utility for households is:[34]

$$\begin{aligned} rW_h = G + \{ &- h_0^L \chi_h - h_1^L[c_h + m(\theta) * (p_h^L(1+\tau_h) - a_h)] + h_2^L(\varepsilon_h + R - \rho_h) - h_1[c_h + m(\theta)p_h(1+\tau_h)] \\ &+ h_2(\varepsilon_h + R) + s_h[-c_s + \theta m(\theta)\overline{p}] - e_h K\}/\mathcal{H} \end{aligned} \tag{89}$$

Per capita net flow utility for investors is:

$$\begin{aligned} rW_i = G + \{ &- i_0^L \chi_i - i_1^L[c_i + m(\theta) * (p_i^L(1+\tau_i) - a_i)] + i_2^L(\varepsilon_i + R - \rho_i) - i_1[c_i + m(\theta)p_i(1+\tau_i)] \\ &+ i_2(\varepsilon_i + R) + s_i[-c_s + \theta m(\theta)\overline{p}] - e_i K\}/\{i_0^L + i_1^L + i_2^L + i_1 + i_2\} \end{aligned} \tag{90}$$

[34] Sellers are not included in the denominator to avoid double-counting, as sellers are also simultaneously buyers or owners.

Finally, per capita net flow utility for all agents is:

$$
\begin{aligned}
rW =& \{\mathcal{H}y - h_0^L\chi_h - h_1^L c_h + h_2^L \varepsilon_h - h_1 c_h + h_2 \varepsilon_h - i_0^L \chi_i - i_1^L c_i + i_2^L \varepsilon_i - i_1 c_i + i_2 \varepsilon_i \\
& - l_{h0}\chi_{lh} - l_{i0}\chi_{li} - sc_s - eK\}/\{\mathcal{H} + i_0^L + i_1^L + i_2^L + i_1 + i_2 + l_{h0} + l_{i0} + l_{h1} + l_{i1} + l_{h2} + l_{i2}\}
\end{aligned} \tag{91}
$$

Appendix D Additional tables

Table C1: Effect of stamp-duty surcharge on log listing price

	(1)	(2)	(3)	(4)	(5)	(6)
Post*Share Rented	0.061	0.039	0.038	0.058	-0.101	-0.101
	(0.073)	(0.062)	(0.063)	(0.074)	(0.086)	(0.074)
Ant.*Share Rented			-0.005			
			(0.018)			
N	1,959,855	1,959,855	1,959,855	1,598,444	1,598,444	1,598,444
LA controls	NO	YES	YES	YES	YES	YES
Donut hole	NO	NO	NO	YES	YES	YES
Post*London	YES	YES	YES	YES	YES	YES
Post*Second shares	YES	YES	YES	YES	YES	YES
Post*EU shares	NO	NO	NO	NO	YES	YES
S.E.	Clustered at LA	Clustered at LA	Clustered at LA	Clustered at LA	Clustered at LA	Spatial HAC (100km)

Notes: This table reports results from OLS regressions of Equation (1) using the log listing price as the dependent variable. Controls (property level): quadratics in latitude and longitude, size, number of rooms, energy performance, type of property, new, leasehold, fireplace, type of wall, extensions. Controls (LA level): lagged population, GDP per capita, housing stock, council total expenditures, council housing expenditures, council tax. In columns (1)-(5), s.e. are clustered at local authority level. In column (6), I allow spatial HAC s.e. to be serially correlated over the entire period. Spatial weighting kernels are assumed to decay linearly. Zero spatial correlation is assumed beyond 100km. ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

Table C2: Differential effect on paid prices by type of buyer

	(1)	(2)	(3)	(4)	(5)	(6)
Buy-to-let	0.001*	0.001*	0.001*	0.001	0.001	0.001
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Post*Share Rented	-0.053***	-0.087***	-0.084***	-0.092***	-0.108***	-0.108***
	(0.022)	(0.016)	(0.016)	(0.019)	(0.021)	(0.019)
Buy-to-let*	-0.008***	-0.008***	-0.008***	-0.007**	-0.007**	-0.007**
Post*Share Rented	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
N	1,569,552	1,569,552	1,569,552	1,261,945	1,261,945	1,261,945
LA controls	NO	YES	YES	YES	YES	YES
Donut hole	NO	NO	NO	YES	YES	YES
Post*London	YES	YES	YES	YES	YES	YES
Post*Second shares	YES	YES	YES	YES	YES	YES
Post*EU shares	NO	NO	NO	NO	YES	YES
S.E.	Clustered at LA	Clustered at LA	Clustered at LA	Clustered at LA	Clustered at LA	Spatial HAC (100km)

Notes: This table reports results from OLS regressions of Equation (1) using the log paid price as the dependent variable. An indicator for a buy-to-let transaction and the interaction with $Post * Rented$ is added to the right-hand side. Controls (property level): log listing price, quadratics in latitude and longitude, size, number of rooms, energy performance, type of property, new, leasehold, fireplace, type of wall, extensions. Controls (LA level): lagged population, GDP per capita, housing stock, council total expenditures, council housing expenditures, council tax. In columns (1)-(5), s.e. are clustered at local authority level. In column (6), I allow spatial HAC s.e. to be serially correlated over the entire period. Spatial weighting kernels are assumed to decay linearly. Zero spatial correlation is assumed beyond 100km. ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

Table C3: Effect of stamp-duty surcharge on number of quarterly constructions of private buildings

	(1)	(2)	(3)	(4)	(5)
Post*Share	25.660	-16.705	-27.203	-25.026	-27.152
Rented	(70.549)	(55.080)	(67.707)	(61.221)	(70.672)
Ant.*Share			-59.983		
Rented			(95.508)		
N	8,108	8,108	8,108	6,804	6,804
LA controls	NO	YES	YES	YES	YES
Donut hole	NO	NO	NO	YES	YES
Post*London	YES	YES	YES	YES	YES
Post*Second shares	YES	YES	YES	YES	YES
Post*EU shares	NO	NO	NO	NO	YES
S.E.	Clustered at LA	Clustered at LA	Clustered at LA	Clustered at LA	Clustered at LA

Notes: This table reports results from OLS regressions of Equation (1) using the log of the number of days between the transaction date and the listing date as the dependent variable. Controls (LA level): lagged population, GDP per capita, housing stock, council total expenditures, council housing expenditures, council tax. ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

Table C4: Effect of stamp-duty surcharge on number of demolitions

	(1)	(2)	(3)	(4)	(5)
Post*Share	10.797	16.832	-6.425	-1.230	-29.874
Rented	(60.546)	(55.562)	(64.844)	(58.650)	(69.736)
Ant.*Share			23.368		
Rented			(61.507)		
N	8,094	8,094	8,094	6,790	6,790
London*Quarter FE					
LA controls	NO	YES	YES	YES	YES
Donut hole	NO	NO	NO	YES	YES
Post*EU shares	NO	NO	NO	NO	YES
S.E.	Clustered	Clustered	Clustered	Clustered	Clustered
S.E.	at LA	at LA	at LA	at LA	at LA

Notes: This table reports results from OLS regressions of Equation (1) using number of demolitions in each local authority as the dependent variable. Controls (LA level): lagged population, GDP per capita housing stock, council total expenditures, council housing expenditures, council tax. All regressions include local authority and quarter fixed effects. ***< 0.01, **< 0.05, *< 0.1.

Table C5: Effect of stamp-duty surcharge on log paid price

	(1)	(2)	(3)	(4)	(5)	(6)
Post*Share Rented	-0.060***	-0.094***	-0.091***	-0.097***	-0.112***	-0.112***
	(0.022)	(0.017)	(0.017)	(0.019)	(0.022)	(0.020)
Ant.*Share Rented			0.025***			
			(0.009)			
N	1,950,769	1,950,769	1,950,769	1,590,874	1,590,874	1,590,874
LA controls	NO	YES	YES	YES	YES	YES
Donut hole	NO	NO	NO	YES	YES	YES
Post*London	YES	YES	YES	YES	YES	YES
Post*Second shares	YES	YES	YES	YES	YES	YES
Post*EU shares	NO	NO	NO	NO	YES	YES
S.E.	Clustered at LA	Clustered at LA	Clustered at LA	Clustered at LA	Clustered at LA	Spatial HAC (100km)

Notes: This table reports results from OLS regressions of Equation (1) using the log price paid buy all buyers as dependent variables. Controls (property level): log listing price, quadratics in latitude and longitude, size, number of rooms, energy performance, type of property, new, leasehold, fireplace, type of wall, extensions. Controls (LA level): lagged population, GDP per capita, housing stock, council total expenditures, council housing expenditures, council tax. In columns (1)-(5), s.e. are clustered at local authority level. In column (6), I allow spatial HAC s.e. to be serially correlated over the entire period. Spatial weighting kernels are assumed to decay linearly. Zero spatial correlation is assumed beyond 100km. ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

Table C6: Effect of stamp-duty surcharge on log days to sell

	(1)	(2)	(3)	(4)	(5)	(6)
Post*Share Rented	0.166	0.258**	0.269**	0.315***	0.284*	0.284**
	(0.112)	(0.103)	(0.105)	(0.121)	(0.147)	(0.127)
Ant.*Share Rented			0.080*			
			(0.041)			
N	1,994,783	1,994,783	1,994,783	1,628,019	1,628,019	1,628,019
LA controls	NO	YES	YES	YES	YES	YES
Donut hole	NO	NO	NO	YES	YES	YES
Post*London	YES	YES	YES	YES	YES	YES
Post*Second shares	YES	YES	YES	YES	YES	YES
Post*EU shares	NO	NO	NO	NO	YES	YES
S.E.	Clustered at LA	Clustered at LA	Clustered at LA	Clustered at LA	Clustered at LA	Spatial HAC (100km)

Notes: This table reports results from OLS regressions of Equation (1) using the log of the number of days between the transaction date and the listing date as the dependent variable. Controls (property level): quadratics in latitude and longitude, size, number of rooms, energy performance, type of property, new, leasehold, fireplace, type of wall, extensions. Controls (LA level): lagged population, GDP per capita, housing stock, council total expenditures, council housing expenditures, council tax. In columns (1)-(5), s.e. are clustered at local authority level. In column (6), I allow spatial HAC s.e. to be serially correlated over the entire period. Spatial weighting kernels are assumed to decay linearly. Zero spatial correlation is assumed beyond 100km. $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

Table C7: Effect of stamp-duty surcharge on number of log quarterly transactions, controlling for *Post August 2018* $*$ $Midlands$ and *Post* $*$ *Buy-to-let mortgage share*

	(1)	(2)	(3)	(4)	(5)
Post*Share Rented	-0.853***	-0.868***	-0.639***	-0.825***	-0.667***
	(0.128)	(0.130)	(0.164)	(0.182)	(0.217)
Ant.*Share Rented			0.637***		
			(0.187)		
N	8,700	8,700	8,700	7,308	7,308
LA controls	NO	YES	YES	YES	YES
Donut hole	NO	NO	NO	YES	YES
Post*London	YES	YES	YES	YES	YES
Post*Second shares	YES	YES	YES	YES	YES
Post*EU shares	NO	NO	NO	NO	YES
S.E.	Clustered at LA	Clustered at LA	Clustered at LA	Clustered at LA	Clustered at LA

Notes: This table reports results from OLS regressions of Equation (1) using the log of the number of days between the transaction date and the listing date as the dependent variable. Controls (LA level): lagged population, GDP per capita, housing stock, council total expenditures, council housing expenditures, council tax. $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

Table C8: Effect of stamp-duty surcharge on number of quarterly constructions of private buildings, controlling for *Post August 2018* $* \; Midlands$ and *Post* $*$ *Buy-to-let mortgage share*

	(1)	(2)	(3)	(4)	(5)
Post*Share Rented	26.625	-16.590	-27.250	-24.809	-27.048
	(70.458)	(54.664)	(67.047)	(60.650)	(69.842)
Ant.*Share Rented			-59.994		
			(95.421)		
N	8,108	8,108	8,108	6,804	6,804
LA controls	NO	YES	YES	YES	YES
Donut hole	NO	NO	NO	YES	YES
Post*London	YES	YES	YES	YES	YES
Post*Second shares	YES	YES	YES	YES	YES
Post*EU shares	NO	NO	NO	NO	YES
S.E.	Clustered at LA	Clustered at LA	Clustered at LA	Clustered at LA	Clustered at LA

Notes: This table reports results from OLS regressions of Equation (1) using the number of quarterly constructions of private buildings as the dependent variable. Controls (LA level): lagged population, GDP per capita, housing stock, council total expenditures, council housing expenditures, council tax. ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

Table C9: Effect of stamp-duty surcharge on number of demolitions, controlling for *Post August 2018* $* \; Midlands$ and *Post* $*$ *Buy-to-let mortgage share*

	(1)	(2)	(3)	(4)	(5)
Post*Share Rented	49.834	50.959	21.182	43.770	6.827
	(61.559)	(57.126)	(64.658)	(60.677)	(69.243)
Ant.*Share Rented			19.875		
			(61.603)		
N	8,094	8,094	8,094	6,790	6,790
London*Quarter FE					
LA controls	NO	YES	YES	YES	YES
Donut hole	NO	NO	NO	YES	YES
Post*EU shares	NO	NO	NO	NO	YES
S.E.	Clustered	Clustered	Clustered	Clustered	Clustered
S.E.	at LA	at LA	at LA	at LA	at LA

Notes: This table reports results from OLS regressions of Equation (1) using annual number of demolitions in each local authority as the dependent variable. Controls (LA level): lagged population, GDP per capita housing stock, council total expenditures, council housing expenditures, council tax. All regressions include local authority, quarter fixed effects, the interaction between Midlands and indicator for the period after the implementation of the Right-to-buy Scheme, the interaction between pre-policy buy-to-let shares and Post.

Table C10: Effect of stamp-duty surcharge on log days to sell, controlling for *Post August 2018* $*$ $Midlands$ and *Post* $*$ *Buy-to-let mortgage share*

	(1)	(2)	(3)	(4)	(5)	(6)
Post*Share Rented	0.432	0.487**	0.496**	0.564***	0.464*	0.464**
	(0.100)	(0.098)	(0.099)	(0.118)	(0.126)	(0.109)
Ant.*Share Rented			0.68*			
			(0.040)			
N	1,994,783	1,994,783	1,994,783	1,628,019	1,628,019	1,628,019
LA controls	NO	YES	YES	YES	YES	YES
Donut hole	NO	NO	NO	YES	YES	YES
Post*London	YES	YES	YES	YES	YES	YES
Post*Second shares	YES	YES	YES	YES	YES	YES
Post*EU shares	NO	NO	NO	NO	YES	YES
S.E.	Clustered at LA	Clustered at LA	Clustered at LA	Clustered at LA	Clustered at LA	Spatial HAC (100km)

Notes: This table reports results from OLS regressions of Equation (1) using the log of the number of days between the transaction date and the listing date as the dependent variable. Controls (property level): quadratics in latitude and longitude, size, number of rooms, energy performance, type of property, new, leasehold, fireplace, type of wall, extensions. Controls (LA level): lagged population, GDP per capita, housing stock, council total expenditures, council housing expenditures, council tax. In columns (1)-(5), s.e. are clustered at local authority level. In column (6), I allow spatial HAC s.e. to be serially correlated over the entire period. Spatial weighting kernels are assumed to decay linearly. Zero spatial correlation is assumed beyond 100km. $***p < 0.01$, $**p < 0.05$, $*p < 0.1$.

Table C11: Effect of stamp-duty surcharge on number of log price paid by future owner-occupiers, controlling for *Post August 2018* $* \ Midlands$ and *Post* $*$ *Buy-to-let mortgage share*

	(1)	(2)	(3)	(4)	(5)	(6)
Post*Share Rented	-0.036*	-0.066***	-0.063***	-0.069***	-0.086***	-0.086***
	(0.021)	(0.017)	(0.017)	(0.020)	(0.023)	(0.023)
Ant.*Share Rented			0.022**			
			(0.010)			
N	1,226,749	1,226,749	1,226,749	978,144	978,144	978,144
LA controls	NO	YES	YES	YES	YES	YES
Donut hole	NO	NO	NO	YES	YES	YES
Post*London	YES	YES	YES	YES	YES	YES
Post*Second shares	YES	YES	YES	YES	YES	YES
Post*EU shares	NO	NO	NO	NO	YES	YES
S.E.	Clustered at LA	Clustered at LA	Clustered at LA	Clustered at LA	Clustered at LA	Spatial HAC (100km)

Notes: This table reports results from OLS regressions of Equation (1) using the log price paid by future owner-occupiers as the dependent variable. Controls (property level): log listing price, quadratics in latitude and longitude, size, number of rooms, energy performance, type of property, new, leasehold, fireplace, type of wall, extensions. Controls (LA level): lagged population, GDP per capita, housing stock, council total expenditures, council housing expenditures, council tax. In columns (1)-(5), s.e. are clustered at local authority level. In column (6), I allow spatial HAC s.e. to be serially correlated over the entire period. Spatial weighting kernels are assumed to decay linearly. Zero spatial correlation is assumed beyond 100km. $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

Table C12: Effect of stamp-duty surcharge on log price paid by buy-to-let investors, controlling for *Post August 2018* $*$ $Midlands$ and *Post* $*$ *Buy-to-let mortgage share*

	(1)	(2)	(3)	(4)	(5)	(6)
Post*Share Rented	-0.082***	-0.112***	-0.107***	-0.108***	-0.120***	-0.120***
	(0.025)	(0.019)	(0.020)	(0.023)	(0.026)	(0.025)
Ant.*Share Rented			0.032**			
			(0.015)			
N	342,803	342,803	342,803	283,801	283,801	283,801
LA controls	NO	YES	YES	YES	YES	YES
Donut hole	NO	NO	NO	YES	YES	YES
Post*London	YES	YES	YES	YES	YES	YES
Post*Second shares	YES	YES	YES	YES	YES	YES
Post*EU shares	NO	NO	NO	NO	YES	YES
S.E.	Clustered at LA	Clustered at LA	Clustered at LA	Clustered at LA	Clustered at LA	Spatial HAC (100km)

Notes: This table reports results from OLS regressions of Equation (1) using the log price paid by buy-to-let investors as the dependent variable. Controls (property level): log listing price, quadratics in latitude and longitude, size, number of rooms, energy performance, type of property, new, leasehold, fireplace, type of wall, extensions. Controls (LA level): lagged population, GDP per capita, housing stock, council total expenditures, council housing expenditures, council tax. In columns (1)-(5), s.e. are clustered at local authority level. In column (6), I allow spatial HAC s.e. to be serially correlated over the entire period. Spatial weighting kernels are assumed to decay linearly. Zero spatial correlation is assumed beyond 100km. ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

Table C13: Effect of stamp-duty surcharge on size of transacted properties

	(1)	(2)	(3)	(4)	(5)	(6)
Post*Share Rented	1.008	1.307	1.601	1.743	2.628**	2.628**
	(0.994)	(1.049)	(1.041)	(1.118)	(1.272)	(1.263)
Ant.*Share Rented			2.088*			
			(1.142)			
N	3,696,699	3,696,699	3,696,699	2,967,141	2,967,141	2,967,141
LA controls	NO	YES	YES	YES	YES	YES
Donut hole	NO	NO	NO	YES	YES	YES
Post*London	YES	YES	YES	YES	YES	YES
Post*Second shares	YES	YES	YES	YES	YES	YES
Post*EU shares	NO	NO	NO	NO	YES	YES
S.E.	Clustered at LA	Clustered at LA	Clustered at LA	Clustered at LA	Clustered at LA	Spatial HAC (100km)

Notes: This table reports results from OLS regressions of Equation (1) using the size of transacted property (in square meters) as the dependent variable. I do not include controls at property level in this regression. Controls (LA level): lagged population, GDP per capita, housing stock, council total expenditures, council housing expenditures, council tax. In columns (1)-(5), s.e. are clustered at local authority level. In column (6), I allow spatial HAC s.e. to be serially correlated over the entire period. Spatial weighting kernels are assumed to decay linearly. Zero spatial correlation is assumed beyond 100km. ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

Table C14: Effect of stamp-duty surcharge on energy cost (£ per square meter per year)

	(1)	(2)	(3)	(4)	(5)	(6)
Post*Share Rented	0.403	0.368	0.282	0.282	0.274	0.274
	(0.266)	(0.261)	(0.264)	(0.295)	(0.353)	(0.302)
Ant.*Share Rented			-0.613			
			(0.296)			
N	3,696,699	3,696,699	3,696,699	2,967,141	2,967,141	2,967,141
LA controls	NO	YES	YES	YES	YES	YES
Donut hole	NO	NO	NO	YES	YES	YES
Post*London	YES	YES	YES	YES	YES	YES
Post*Second shares	YES	YES	YES	YES	YES	YES
Post*EU shares	NO	NO	NO	NO	YES	YES
S.E.	Clustered at LA	Clustered at LA	Clustered at LA	Clustered at LA	Clustered at LA	Spatial HAC (100km)

Notes: This table reports results from OLS regressions of Equation (1) using the energy cost (£) required for lighting, space and water heating per square meter per year of the transacted property as the dependent variable. I do not include controls at property level in this regression. Controls (LA level): lagged population, GDP per capita, housing stock, council total expenditures, council housing expenditures, council tax. In columns (1)-(5), s.e. are clustered at local authority level. In column (6), I allow spatial HAC s.e. to be serially correlated over the entire period. Spatial weighting kernels are assumed to decay linearly. Zero spatial correlation is assumed beyond 100km. ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

Appendix E Additional figures

Figure D1: Real housing price growth in OECD countries

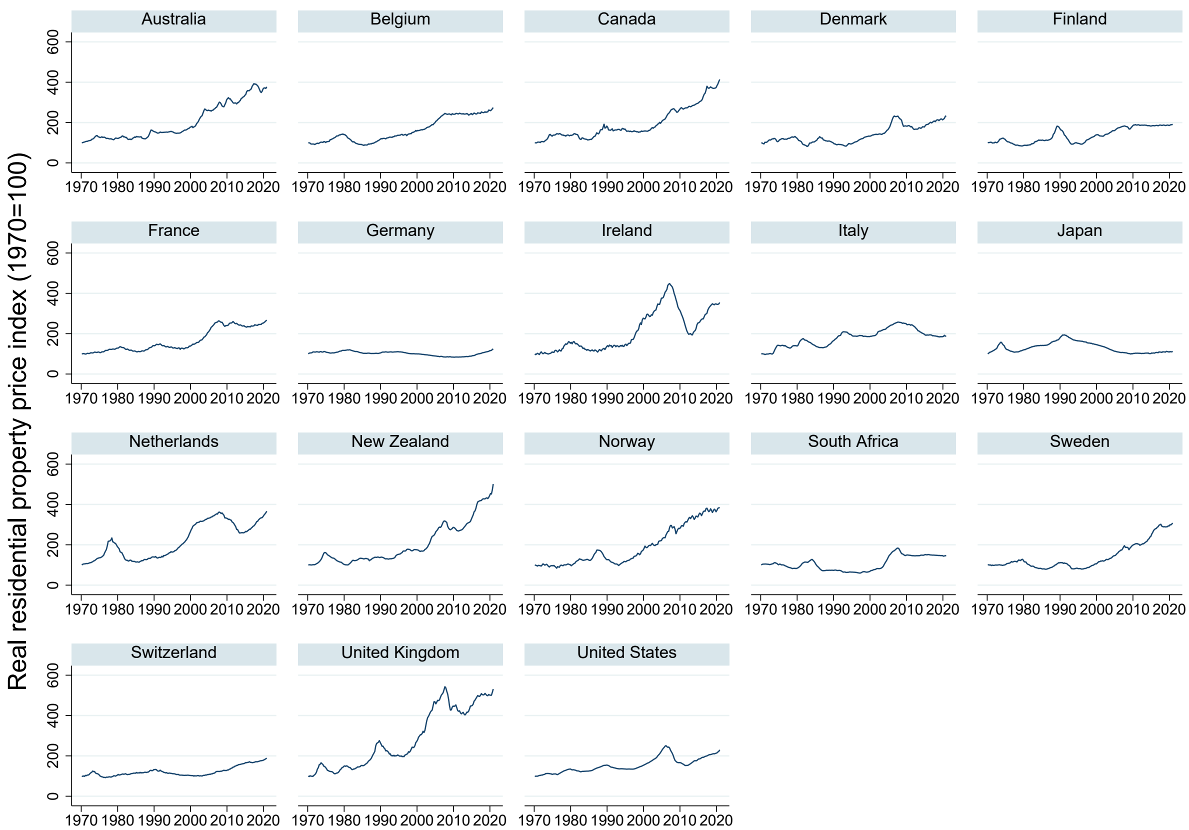


Figure D2: Stamp-duty surcharge liability

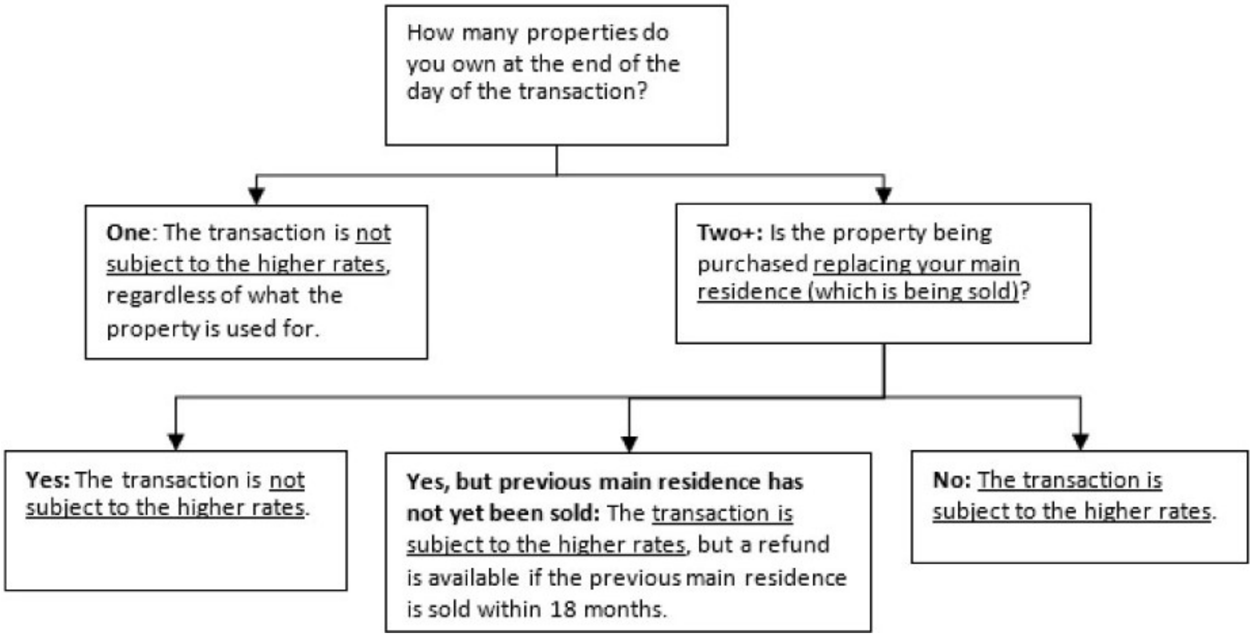


Figure D3: Stamp duty anticipation effects

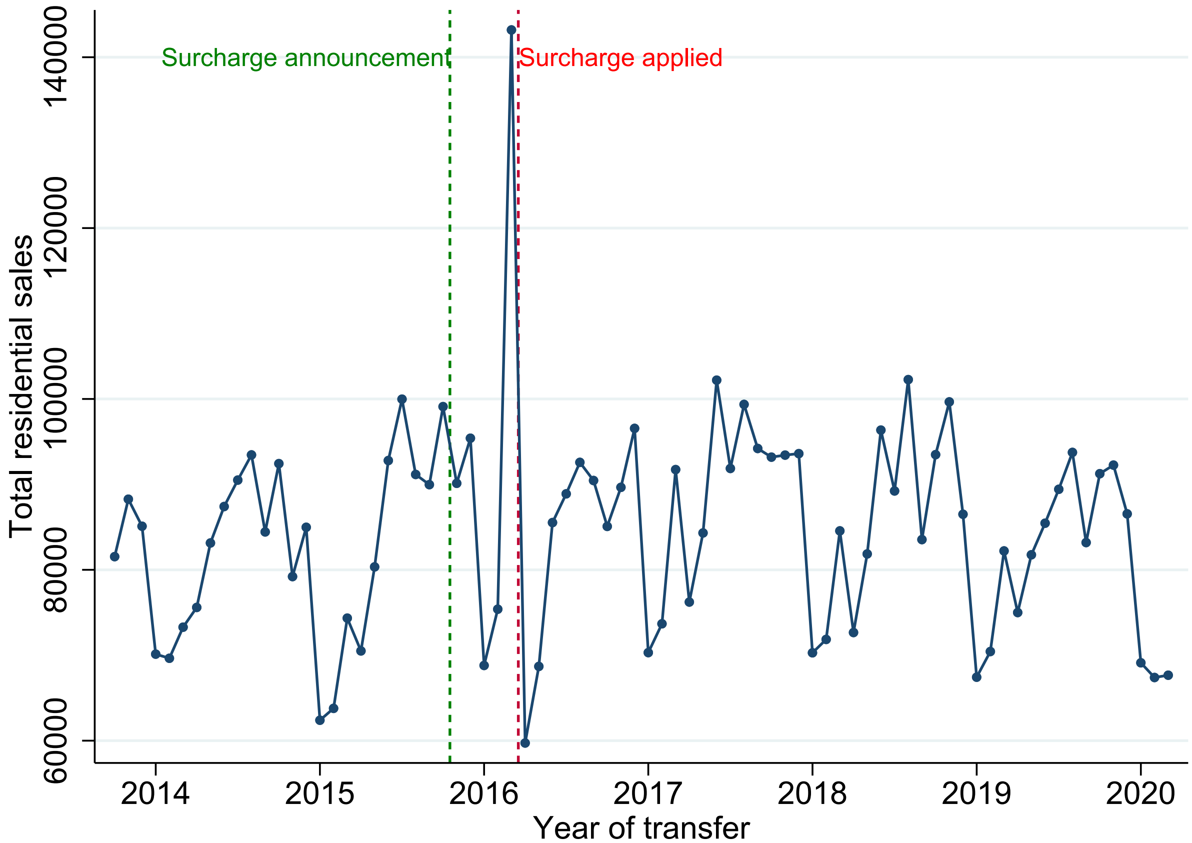
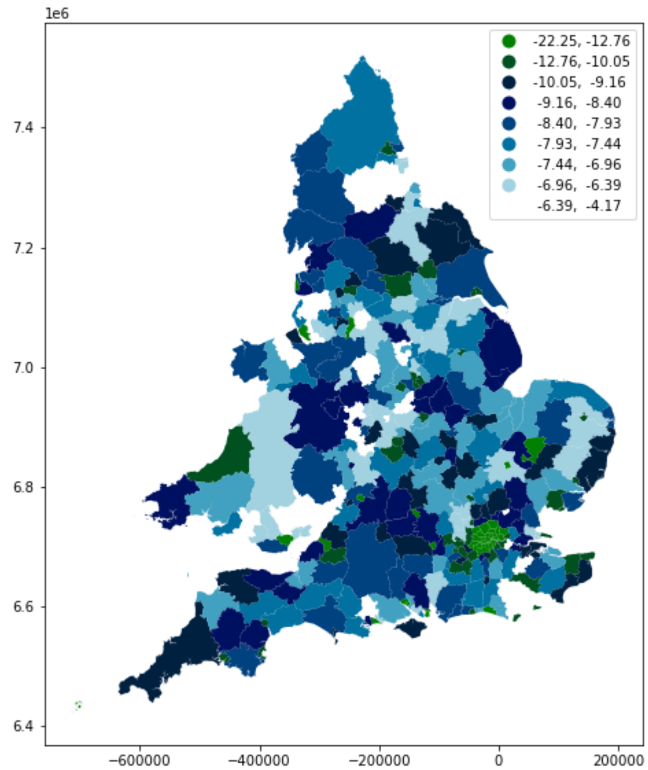


Figure D4: Heterogeneous effects of the SDLT surcharge

(a) Heterogeneous effects on transactions



(b) Heterogeneous effects on paid prices

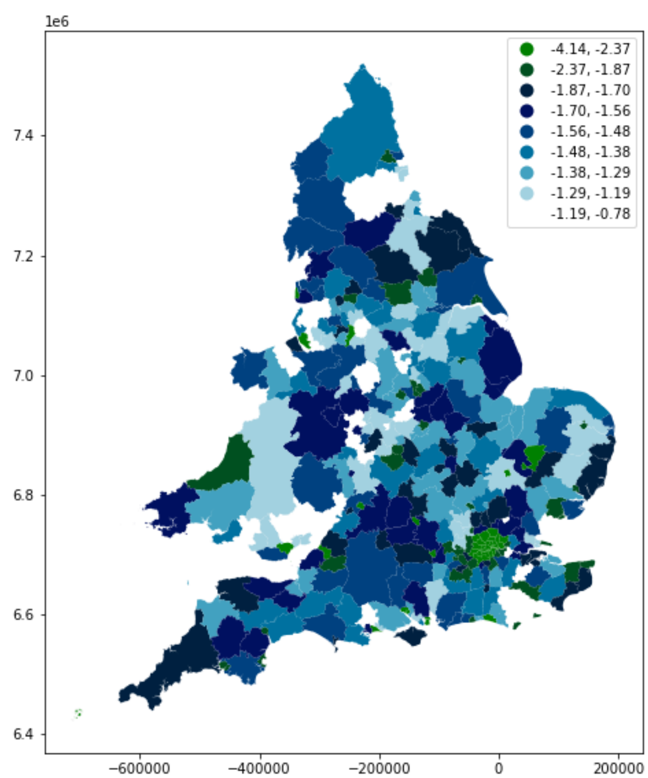
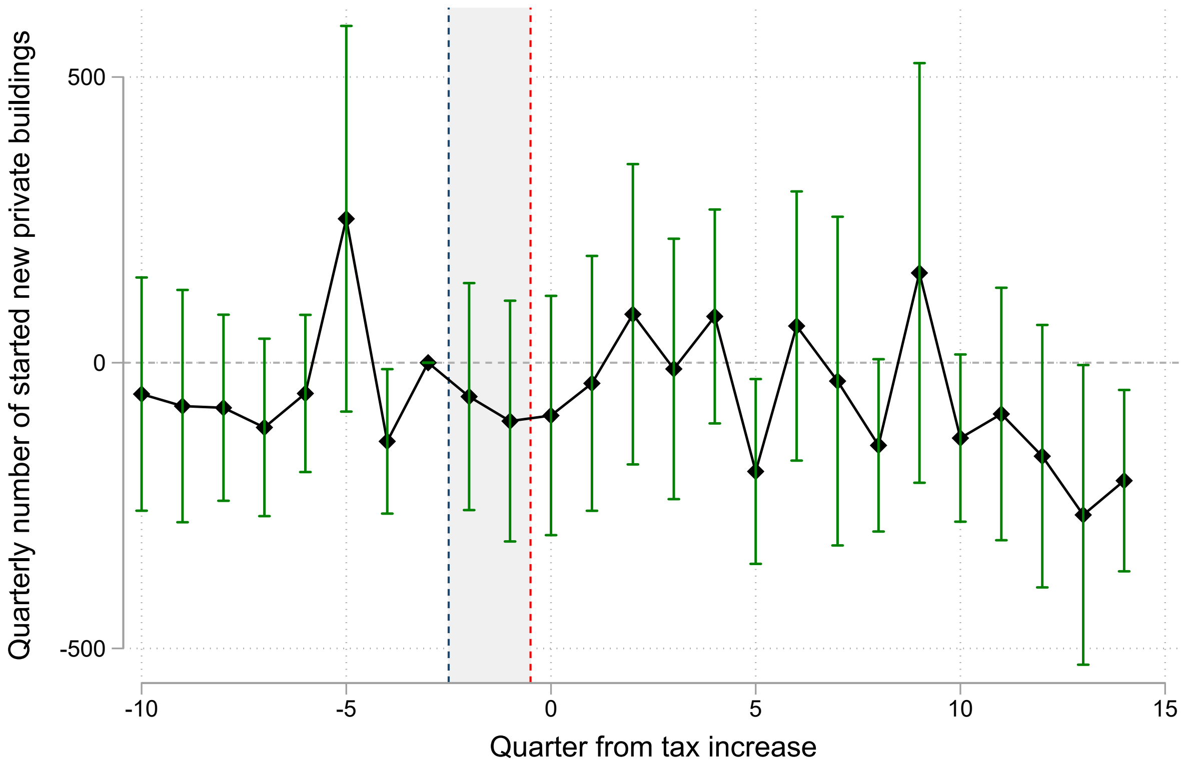
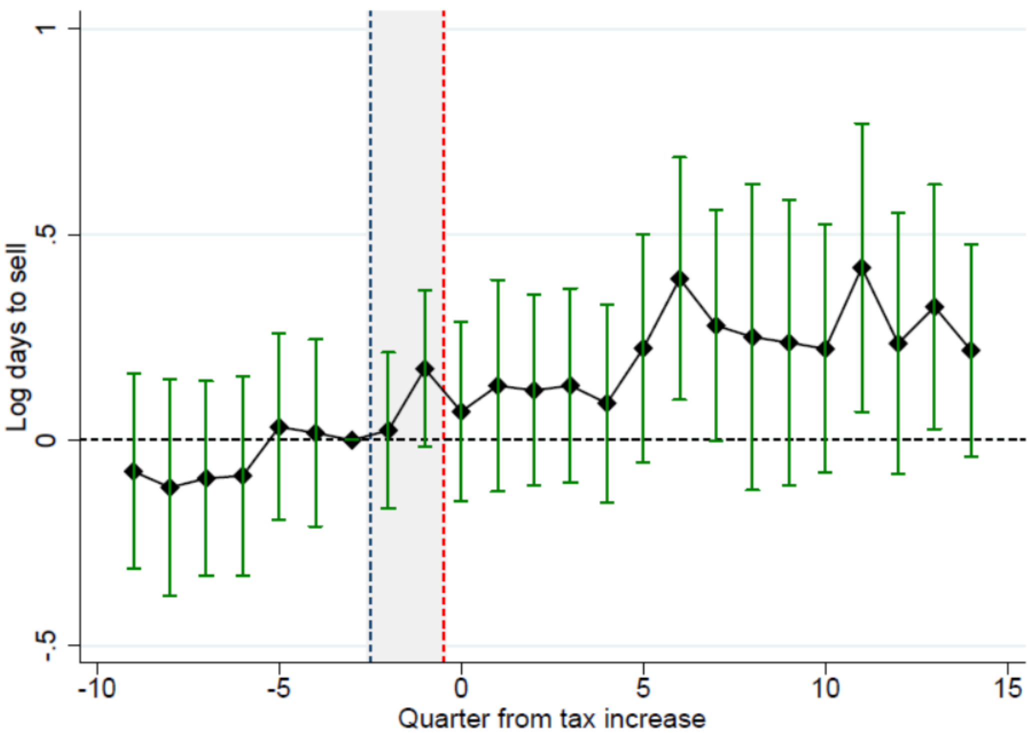


Figure D5: Quarterly effect on new private buildings



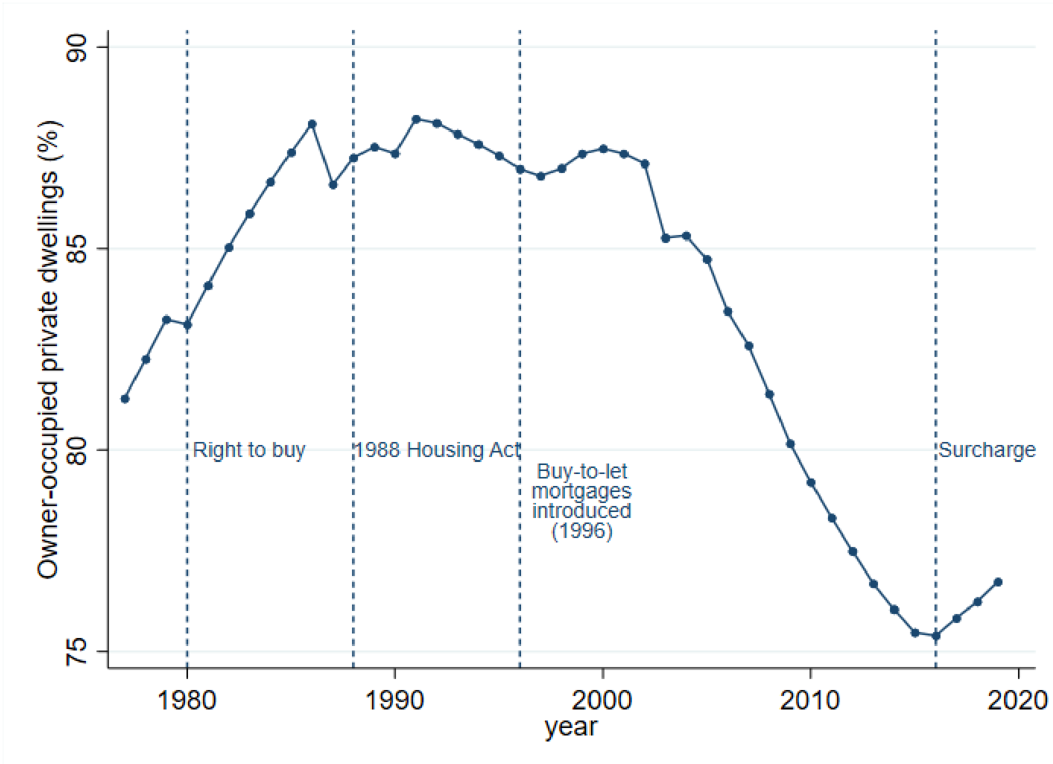
Notes: This figure reports point-estimates and 90% confidence intervals for θ_t from the OLS regression of Equation (2) using the quarterly number of new private residential buildings as the dependent variable. The horizontal axis shows the number of quarters from the introduction of the 3% surcharge. The shaded area represents the period between the surcharge announcement and its introduction.

Figure D6: Effect on log days to sell



Notes: This figure reports point-estimates and 90% confidence intervals for θ_t from the OLS regression of Equation (2) using the log days to sell as the dependent variable. The horizontal axis shows the number of quarters from the introduction of the 3% surcharge. The shaded area represents the period between the surcharge announcement and its introduction.

Figure D7: Home-ownership rate



Notes: This figure reports the share of private residential properties that were owner-occupied in the UK from 1977 to 2019.