The aggregate and distributional implications of credit shocks on housing and rental markets

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Abstract: We build a model of the housing and rental markets where house prices and rents are determined endogenously by the interaction of heterogeneous renters, homeowners and landlords. We study the impact of changes in credit conditions from: *(i)* new policies that limit loan-to-value and loan-to-income ratios of newly originated mortgages and *(ii)* real interest rate shocks. We find that contractionary credit shocks reduce house prices on impact, but increase rents both over the short and long run. Homeownership declines; young and middle-income households are negatively affected while landlords benefit.

Keywords: House Prices, Rental Prices, Homeownership, Life-cycle, Credit Conditions, Macroprudential Policy, Real Interest Rate

JEL classification: D15, E21, E30, E51, G51

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1. Introduction

Housing is the largest asset in most household portfolios and housing-related expenses, such as rental payments, represent a substantial share of households' consumption baskets (Piazzesi and Schneider 2016). Over the last decade, large increases in rental prices and concerns about housing affordability, particularly for the young, have brought housing and rental markets to the forefront of the political debate. At the same time, many countries have introduced macroprudential measures to prevent the buildup of excessive household leverage, potentially constraining the access of many first-time buyers to mortgage credit.

Because housing and rental markets are closely connected, understanding how credit shocks, housing policies or developments in housing supply affect households requires studying how they impact both markets. For example, supply constraints that restrict the building of new housing might generate increases in both housing prices and rents. On the other hand, a credit tightening might keep prospective buyers in the rental market for longer, and thus decrease house prices and increase rents.

In this paper we study how households are affected by a shock that reduces the availability of mortgage credit, both through its direct impact and its equilibrium effects on rents and house prices. To do so, we develop a model of the rental and housing markets with two key features. First, households are heterogenous as they differ in their age, income, and wealth, and make endogenous housing tenure choices which lead them to be renters, homeowners, or landlords of homes of different sizes. To get on and climb the property ladder, households can borrow through long-term mortgages for which downpayment and other constraints only hold at origination. And second, both rental and housing markets must be in equilibrium, which implies that house and rental prices must adjust to clear both markets as a result of potential shocks, but they may do so in different directions.

We use the model to show that restricting credit access to potential mortgagors increases rental prices, reduces house prices and decreases the homeownership rate. In the presence of binding constraints to mortgage credit, prospective homeowners need to either: *(i)* postpone or cancel their home buying decisions and stay renters for longer or *(ii)* downsize and purchase a smaller house with a smaller mortgage. Option *(i)* implies that more landlords need to enter the market, buy housing and provide it for rent. Because the marginal prospective landlord must be compensated above the previous one in order to step in and provide additional rental housing, rents go up to clear the market at a given house price. Option *(ii)*, downsizing, pushes house prices down as the share of low quality/small houses increases. The relative strength of these two channels determines the relative changes of house prices and rents. The more households choose to buy smaller houses rather than become renters, the smaller the effect on rental prices and the larger the house price drop.

Our framework contrasts with macroeconomic models with housing in which the rental sector is non-existent or is owned by a deep-pocketed risk-neutral investor, implying that rents are fixed to a constant fraction of house prices. By allowing households to choose to become landlords in the context of a standard savings and portfolio choice model, we endogenously generate a distribution of landlords who are heterogeneous in their income, wealth and real estate holdings, with many of them being small owners.[1] As a result, the model displays an upward sloping rental supply curve at a given house price, which in turn generates movements in rents (and rent-to-price ratios) in reaction to credit shocks. This result holds irrespective of whether owner- and rental-occupied units are similar, identical or separate goods, i.e., independently of the degree of housing market segmentation as specified in Greenwald and Guren (2025) and of the costs of conversion between housing types.

Although previous literature accounts for endogenous landlords in the analysis of the tax treatment of housing (Chambers, Garriga, and Schlagenhauf 2009, Sommer and Sullivan 2018), they assume that each period a landlord can reoptimise the fraction of their housing stock that they rent out. This flexibility implies low entry and adjustment costs, producing an elasticity of rental supply that exceeds that in the data (Rotberg and Steinberg 2024). As a result, equilibrium movements in rents in response to credit shocks tend to be small in these frameworks. The lumpiness of our housing decision lowers the elasticity of supply by an order of magnitude and allows our framework to replicate the spillovers from housing markets to rents that we measure empirically.

In our main experiment, we analyze a borrower-based macroprudential policy intervention that imposes maximum loan-to-value (LTV) and loan-to-income (LTI) ratios to newly originated mortgages, focusing on the introduction in Ireland in 2015 of

[1] This feature corresponds to the structure of rental markets in many advanced economies. In Ireland, which is the object of our study, more than 50% of all tenancies are held by households who only own one or two rental properties (see Appendix A.1). French administrative data shows that most rental properties are held in lumpy quantities by undiversified, small and home-biased landlords (Levy 2022). Even in the United States, where institutional investors are quite developed, private individual investors own 71.6% of all rental properties, with 14 million of them owning between 1 and 4 properties (Pew Research 2021). Damen, Korevaar, and Van Nieuwerburgh (2025) show that large corporate landlords stay away from large segments of the rental market, particularly low-quality low-rent properties, and argue that they do so because of reputational risk.

a minimum 20% downpayment on a house and a maximum 3.5 ratio of mortgage debt to household income. This intervention, which was largely unanticipated and binding for many prospective buyers, is an excellent case study for the credit shocks we model. Acharya, Bergant, Crosignani, Eisert, and McCann (2022) showed empirically that this policy led to a reduction in house price growth in the areas in which the limits were particularly binding. We extend their analysis to rental prices and find that, consistent with our model mechanism, the reform led to a larger acceleration in rental price growth in those areas where the reform was more constraining.

We use our model, calibrated to the Irish economy, to quantify the short and long-run effects of the reform while keeping all other features of the housing and rental markets fixed. We find that the reform decreases house prices upon impact by 0.9%, but this decrease is temporary, and unwinds in the long run as increased construction brings house prices back to the region of the pre-reform steady state. On the other hand, rents take longer to change, but increase by more (4.5% at their peak, 7 years after the reform) and in a persistent manner (2.6% in the long run). This occurs because both the borrowing limits and the changes in the distribution of wealth that they induce are permanent and are not overcome by the increased activity in the construction sector. Moreover, the reform reduces the homeownership rate by 3 percentage points in the long run and generates an increase in housing wealth concentration as landlords hold a larger fraction of the aggregate housing stock. Our model can very closely replicate the empirical responses of house and rental prices to the reform across Irish regions, which validates its endogenously generated supply and demand elasticities in the rental and housing markets in both the short and medium run.

Our model reveals that constraining housing credit is particularly harmful for renters, young households and those in the bottom and middle of the income distribution not only because they find it harder to obtain a mortgage and need to postpone their buying decision, but also because they face higher rental prices in equilibrium. Prospective landlords, older households and those in the top of the income distribution benefit because they obtain higher returns from their housing investments. Although households are positively impacted by the initial drop in house prices, the benefit is concentrated amongst prospective homebuyers in the upper part of the income distribution. Overall, the welfare loss from the reform is 1.5% of lifetime consumption for newly born households. Our results provide a first measure of the unintended, but large heterogeneous costs imposed on households by macroprudential policies through both the rental and housing sectors and point to a redistribution of resources from poor renters to richer landlords. Nonetheless, we cannot measure the benefits of those policies given that we do not model the cyclical buildup of risk in the financial sector and, as a result, we are silent on optimal LTV or LTI ratios.

In our second exercise, we study the impact of a rise in the real interest rate. Compared to the macroprudential intervention, a higher rate not only affects new buyers, but also existing mortgagors with a floating-rate mortgage who see their payments go up, and savers in financial assets who see their returns increase. We find this credit shock also reduces the homeownership rate, increases rents and reduces the average house price. If the shock is permanent, rental rates remain elevated and house prices are lower also in the long run. Rent-to-price ratios increase more than one-to-one with interest rates at constant aggregate income because, as more constrained households become landlords, they demand comparatively higher returns to engage in a lumpy illiquid investment. If the shock is transitory, rents increase and house prices drop in the short run, but return to their pre-shock levels once the shock unwinds.

The implications we find are consistent with a growing empirical evidence that contractionary monetary policy shocks raise rents (Dias and Duarte 2019), an effect driven by a shift in household demand from the owner-occupier to the rental market, as evidenced by an increased share of home sales accounted for by non-owner-occupiers (Abramson, De Llanos, and Han 2025). Thus, our real interest rate experiment suggests that tightening cycles of monetary policy that raise real interest rates may benefit some households via the reduction in asset prices (including housing), but may also make it harder for low-income households to afford increasing rents. It also provides a theoretical background to the connection between higher policy interest rates and rising rental costs, which has been at the center of the policy debate during the 2022-23 inflationary episode.

Related Literature. Early contributions to the macro-housing literature either assumed that rental supply was fully inelastic or perfectly elastic. In the former case, either there is no rental sector (i.e. the homeownership rate is 100%) or rental housing is completely different from owner-occupied housing, as in Berkovec and Fullerton (1992), and, consequently, there is no link between house prices and rents through an arbitrage condition. In the latter, opposite case of perfectly elastic supply, an arbitrage condition guarantees that investors are indifferent between financial assets and housing. Thus, rent to price ratios follow real interest rates, potentially with a wedge, but do not react to developments in the housing market unless those impact real interest rates (Gervais 2002). This later assumption has frequently been justified with a large, deep-pocketed, risk-neutral foreign investor (or a large rental company owned by households) that owns and rents all the rental housing stock.

Later papers studying the optimal tax treatment of housing introduced an elastic supply curve for rental housing. The first contribution to do so in general equilibirum was Chambers, Garriga, and Schlagenhauf (2009), which features both a corporate rental sector and the possibility for households to rent out part of their homes. The relative sizes of the two sectors determine the elasticity of rental price responses. Other work which also assumes that individual households can become landlords by renting out a flexible share of their homes includes Floetotto, Kirker, and Stroebel (2016) and Sommer and Sullivan (2018), who study the tax treatment of housing, Favilukis, Mabille, and Van Nieuwerburgh (2022), who study local housing markets, and Gete and Zecchetto (2018), who, closer to our work, study the removal of government mortgage guarantees. In contrast, in our paper households become landlords by buying additional discrete housing units. This more realistic feature introduces an additional friction to rental supply through the discreteness of housing, and implies reduced rental supply elasticities. As Rotberg and Steinberg (2024) show in recent work, replicating these elasticities is key to understand the responses of rents to shocks or policies such as the mortgage interest deduction.

In contrast with this literature, the papers that study the role of credit in driving the house price cycle have frequently modelled a more stylised rental sector. Favilukis, Ludvigson, and Van Nieuwerburgh (2017), Greenwald (2018) and Justiniano, Primiceri, and Tambalotti (2019) all maintain the assumption that there are no rental markets and homeownership is always 100%, while Kaplan, Mitman, and Violante (2020) assume that the rental supply is fully elastic, although they incorporate household-landlords in an alternative version of their model. Recently, Greenwald and Guren (2025) show that the implications of this class of models for the dynamics of house price-to-rent ratios depend on their assumptions about rental markets. In particular, if rental and owner-occupied properties are identical, an increase in the homeownership rate does not impact house prices as households buy these additional houses from deep-pocketed landlords that do not use credit. Instead, when markets for rental and owner-occupied housing are segmented, an increase in housing demand raises house prices.

In our model, heterogeneity in age, income and wealth, together with financing constraints and the lumpiness of housing, provide a micro-foundation for the upward-sloping rental supply curve, driven by the marginal landlord requiring additional compensation to buy more housing. This approach contrasts with upward-sloping rental supply curves generated by exogenous preference distributions (Greenwald and Guren 2025) or intermediary rental supply companies (Dias and Duarte 2022, Rotberg and Steinberg 2024). Moving away from reduced form mechanisms allows us to study the impact of policy changes on this supply curve differentiating between shocks that mostly impact rental demand (borrower-based macroprudential measures) and those that impact both demand and supply (real interest rate shocks). Our setup also allows us to separately study the impact of shocks on house prices and rents, contrasting them with the empirical evidence on each dimension. This distinction matters because the welfare consequences of a given change in the rent-to-price ratio depend on the underlying source of that movement – whether it reflects shifts in rents, prices, or both. In our model, credit shocks generate an increase in rents, even with a sizable house price drop, and are associated with a transfer of welfare from young renters towards older landlords.

In this way, our paper also contributes to the relatively less developed literature that studies the impact of credit shocks on rents. Gete and Reher (2016), in a two-period model, provide theoretical support to the idea that restricting mortgage credit increases the demand for rental housing, which is consistent with the empirical evidence in Gete and Reher (2018) that the contraction of mortgage supply after the Great Recession increased housing rents. Recently, Dias and Duarte (2019) and Abramson, De Llanos, and Han (2025) have also found empirically that contractionary monetary policy shocks increase rental prices. We are the first to rationalize these empirical findings in a rich model with endogenous rents, heterogeneous landlords and house lumpiness which allows us not only to provide a theoretical underpinning, but also to compute counterfactual house price and rent evolutions as well as to measure the welfare impact of credit access reforms, including its transitional dynamics.

Garriga, Manuelli, and Peralta-Alva (2019) argue that, even in a representative agent framework, a reduction in the mortgage rate may increase house prices and reduce rents in the short run. Lower borrowing rates induce both a positive income effect and a housing investment boom. If the latter is strong enough, the relative price of housing services (rents) might decrease in the short run. Our heterogeneous agent framework generates a complementary channel via the portfolio decisions of the owners of rental properties that leads to rents moving in the same direction as mortgage rates, even in the short run.

Dias and Duarte (2022) develop a model in which monetary policy shocks increase the demand for renting with respect to home-owning, and as a result, rents tend to rise. Unlike in ours, in their framework the changes in rent-to-price ratios are driven by the different relative stickiness of prices and rents. Amaral, Dohmen, Kohl, and Schularick (2024) study the effect of a persistent decline in the real interest rate across geographical areas and highlight that it can have different impacts on rents and house prices depending on the initial rent to price ratio in a given location.

Finally, since our results uncover some costs imposed by mortgage regulation on heterogeneous households, we complement the broad theoretical literature that shows that macroprudential frameworks are welfare improving as they enhance financial and macroeconomic stability by correcting pecuniary (Dávila and Korinek 2018) or aggregate demand externalities (Lambertini, Mendicino, and Punzi 2013, Farhi and Werning 2016, Korinek and Simsek 2016). Our paper is also related to the recent empirical literature that has shown that the introduction of LTV and LTI limits reduces mortgage leverage (Van Bekkum, Irani, Gabarro, and Peydró 2023) and cools down tensioned housing markets (Acharya et al. 2022, Peydró, Rodriguez-Tous, Tripathy, and Uluc 2024).[2] In recent work, Ferrero, Harrison, and Nelson (2023) and Muñoz and Smets (2022) focus on countercyclical borrower-based macroprudential rules and show how these interact with either monetary policy or credit to large institutional investors in the rental market, respectively. Kvaerner, Pavanini, and Peng (2024) study the introduction of loan-to-income limits in Norway and their effects on mobility and housing demand and supply of different qualities.

2. The Model Economy

Our model economy is populated by households that differ in their age, income and wealth. They supply labor inelastically to a competitive production sector during their working life and make decisions about non-durable consumption, savings and housing tenure. Although owning a house provides higher utility than renting, some households are forced or choose to rent because of binding credit constraints and up-keeping costs. At the other end of the spectrum, there are some households that own more than one house to lease them out and earn extra income. These heterogenous renters and landlords meet in a competitive market and determine the equilibrium rental rate. The housing stock is built by a construction sector that uses land permits and structures. The latter are produced, together with the final consumption good, by a competitive

[2] See Peydró, Rodriguez-Tous, Tripathy, and Uluc (2025) for a full literature review on the rationale and the effects of these tools.

firm that uses labor as its only factor of production. The final good's price acts as the *numeraire*, while the house price is determined by the intersection between the supply from the construction sector and the demand from households. In what follows, time subscripts, unless needed, are omitted to ease notation.

2.1. Households

Demographics. Household's age is indexed by $j = 1, \ldots, J$. In the first $J^{ret} - 1$ periods they work. Thereafter they are retired until they die with certainty at age $J + 1$.

Preferences. Households derive utility from non-durable consumption and housing services. They value these streams of consumption according to

$$\mathbb{E}_0 \left\{ \sum_{j=1}^{J} \beta^{j-1} \frac{\left(c_j f\left(h_j, \tilde{h}_{n,j}\right)\right)^{1-\gamma}}{1-\gamma} \right\} \tag{1}$$

where $\beta \in (0, 1)$ is the discount factor, $\gamma > 0$ captures both risk aversion and intertemporal elasticity of substitution, $c > 0$ is consumption of non-durables, and f is a function of the number of houses owned h and the housing quality of the house in which household lives $\tilde{h}_n$ given by

$$f(h, \tilde{h}_n) = \begin{cases} \left(\tilde{h}_n/\tilde{h}_1\right)^{\alpha_h} & \text{if} \quad h = 0 \\ \theta \left(\tilde{h}_n/\tilde{h}_1\right)^{\alpha_h} & \text{if} \quad h \geq 1 \end{cases} \tag{2}$$

which reflects that the housing service flow for homeowners is larger than for renters, $\theta > 1$, and the utility flow of better quality housing is higher than that of the lowest quality available $\tilde{h}_1$, but with diminishing returns $\alpha_h < 1$.

Endowments. Working-age households receive an idiosyncratic labor income endowment. We assume that it has a deterministic component that depends on age and a stochastic, persistent component. That is

$$\log y = \log A_c + g(j) + \eta \tag{3}$$

where A_c is an index of aggregate productivity, $g(j)$ is a polynomial in age and η represents the stochastic persistent component of earnings. We estimate the earnings process non-linearly as in De Nardi, Fella, and Paz-Pardo (2020) – see Section 3.1 for details. Retired households receive a fixed fraction of their last working period income for the rest of their lifetime. Households are also born with an initial endowment of liquid wealth that is drawn from a log-normal distribution. We also assume that they start their life as renters and thus have no housing wealth.

Liquid assets. Households can save in a one-period risk-free bond, $a \geq 0$ that yields a constant interest rate $r_s = r$, which is determined in the world market and is therefore exogenous.

Housing choices. Households decide on the quantity h and the quality $\tilde{h}_n$ of the housing they acquire. Households that do not own a house ($h = 0$) must rent one in the market at a unit rental rate p_r. We assume that the quality of the rental unit is the lowest $\tilde{h}_1$, while owner occupiers ($h = 1$) can choose the quality of the house that they live in across all other possible $\tilde{h}_n$. Each housing quality is available at equilibrium price $p(\tilde{h}_n)$. Therefore, when a homeowner buys additional houses as an investment ($h > 1$), she purchases houses of quality $\tilde{h}_1$, rents them out and receives p_r per period and per house.

Housing is illiquid. For both homeowners and landlords, there are some costs associated with housing purchases beyond the transaction price. Consequently, we assume that households pay a proportional transaction cost that depends on the value of the house being sold or bought, $\tau_h\, p(\tilde{h}_n)$. This cost captures real estate agent fees, taxation and other administrative costs. Houses are also costly to maintain. Therefore, homeowners and landlords pay maintenance costs to keep up with their depreciation, $\delta_h\, p(\tilde{h}_n)$, where δ_h is the housing depreciation rate.

Mortgages. The purchase of a house can be financed through a mortgage at a fixed rate $r_b = r(1+\kappa)$, where $(1+\kappa)$ is the is the intermediation wedge between the mortgage rate and the risk-free rate. To reduce the dimensionality of the household problem, we treat mortgages as negative asset holdings $a \leq 0$, which prevents mortgagors from simultaneously having liquid assets. In other words, a denotes the net asset position.

The borrower must satisfy two constraints. First, a maximum loan-to-value (LTV) limit, which imposes that the size of the mortgage has to be smaller than a fraction of the value of the house. And second, a loan-to-income (LTI) requirement that limits household's borrowing to a multiple of its current (annual) income. Formally,

$$a' \geq -\lambda_{LTV}\; p(\tilde{h}'_n)\, h' \tag{4}$$

$$a' \geq -\lambda_{LTI}\; y \tag{5}$$

where λ_{LTV} and λ_{LTI} are parameters. These two constraints only hold at origination, and could be different for owner-occupiers and buy-to-let investors. After the mortgage contract is signed and the house is purchased, the borrower chooses the repayment schedule freely. We make this modeling choice, instead of allowing for mortgage default, because in the European context delinquency – contract being breached by underpaying – is more frequent than foreclosure – contract being terminated (Hannon 2023). Nonetheless, we impose that: *(i)* all debts must be paid before the terminal age J, i.e. $a_J = 0$ and *(ii)* interest payments and a minimum amortization payment must be made in each period. As in Kaplan, Mitman, and Violante (2020), the minimum payment is determined by the constant-amortization formula

$$m_j = \frac{r\,(1+\kappa)\,(1+r\,(1+\kappa))^{J-j}}{(1+r\,(1+\kappa))^{J-j}-1}\,. \tag{6}$$

In steady state, r is fixed and hence there is no notion of fixed or adjustable-rate mortgages. Whenever we introduce a shock to the economy that moves the real interest rate, we assume that all mortgages are adjustable-rate.

Optimization Problem. A household of age j, income y, with h houses of quality $\tilde{h}_n$ and a assets solves the following dynamic programming problem [3]

$$V(a,\underbrace{\{h,\tilde{h}_n\}}_{=s},y,j) = \max_{c,a',s'}\left\{\frac{(c\,f\,(s))^{1-\gamma}}{1-\gamma} + \sigma_\varepsilon\varepsilon(s) + \beta\mathbb{E}V\left(a',s',y',j+1\right)\right\}$$

$$\begin{aligned}
&\text{s.t.}\\
&c + a' + p(\tilde{h}'_n)h' + \mathbb{1}_{\text{sell}}\tau_h\,p(\tilde{h}_n)h + \mathbb{1}_{\text{buy}}\tau_h\,p(\tilde{h}'_n)h' + \delta_h\,p(\tilde{h}_n)h \leq\\
&\quad y + (1+r\,(1+\mathbb{1}_{a<0}\kappa))\,a + p(\tilde{h}_n)h + p_r(h-1)\\
&a' \geq \begin{cases}\max\left\{-\lambda_{LTV}\;p(\tilde{h}'_n)\,h', -\lambda_{LTI}\;y\right\} & \text{if purchase home}\\ a(1+r(1+\kappa)-m(j)) & \text{if have mortgage}\\ 0 & \text{otherwise}\end{cases}
\end{aligned} \tag{7}$$

where $\sigma_\varepsilon\varepsilon(s)$ are choice-specific random taste shocks that are *i.i.d.* Extreme Value Type I distributed with scale parameter σ_ε. These represent shocks to the utility of

[3] We surpress dependence of the value function on the aggregate states for notational simplicity.

homeownership (i.e., they are alike to moving shocks), but are also computationally convenient as they help to smooth out expected value functions (Iskhakov, Jørgensen, Rust, and Schjerning 2017).

2.2. Production

2.2.1. Final-good sector

The final-good sector operates a linear technology

$$Y_c = A_c N \tag{8}$$

where A_c is the constant aggregate labor productivity and N are the units of labor services. These firms hire labour in a competitive labour market, so their profit maximization yields an equilibrium wage $w = A_c$. Final goods, whose price is normalized to 1, can be used both for household consumption, C, or as an intermediate input for the production of the housing good, in which case we label them structures, S. That is,

$$Y_c = C + S \ . \tag{9}$$

2.2.2. Construction sector

The construction sector operates a Cobb-Douglas technology

$$Y_h = A_h L^{\alpha_L} S^{1-\alpha_L} \tag{10}$$

where S is the quantity of structures, L is the amount of buildable land or housing permits in a given period, $\alpha \in (0,1)$ is the constant share of land in production, and Y_h is the quantity of the housing good produced. We assume that the total amount of housing permits every period is fixed and they are priced competitively. Hence, the housing developer solves the following static problem

$$\max_{S,L} \ p_h A_h L^{\alpha_L} S^{1-\alpha_L} - p_L L - S \tag{11}$$

where p_L is the equilibrium price of buildable land and p_h is the per-unit price of construction sector output. The first order conditions of the competitive housing developers' problem imply the following relation between housing production Y_h and the house price:

$$Y_h = A_h^{1/\alpha_L} \left((1-\alpha_L)\ p_h\right)^{(1-\alpha_L)/\alpha_L} \bar{L} \tag{12}$$

where $\bar{L}$ is the aggregate amount of housing permits every period. Consequently, the elasticity of aggregate housing supply to house prices is:

$$\epsilon_{Y_h, p_h} \equiv \frac{\partial Y_h}{\partial p_h} \frac{p_h}{Y_h} = \frac{(1-\alpha_L)}{\alpha_L} \tag{13}$$

As discussed, housing comes in different qualities that represent different bundles or aggregations of the housing good. We denote them as $\tilde{h}_n = \{\tilde{h}_1, \ldots, \tilde{h}_N\}$. We follow most papers in this literature who assume (explicitly or implicitly) that houses of different qualities can be freely converted between one another. This implies that *(i)* the price of each housing type is a linear function of housing quality, i.e., $p(\tilde{h}_n) = \tilde{h}_n\, p_h$, *(ii)* in practice we do not need to find prices that clear the market for each individual housing type; instead, we simply need to clear the market for the aggregate housing stock. We present a model of costly conversion between types in Appendix D.1 where the relative price of each type can change in a manner that remains tractable. In our baseline setup, however, these conversion costs end up having very little impact. As such, we maintain the assumption of free conversion for our main results.[4]

The aggregate housing stock, i.e. the aggregate amount of the housing good, can be measured as the quality-weighted sum of all housing units in the economy. If we let $H^{sh}_{n,t}$ denote the share of houses of quality n,

$$H_t = \sum_{n=1}^{N} H^{sh}_{n,t} \tilde{h}_n \ . \tag{14}$$

The construction sector's output is used for two purposes: the upkeep of existing houses and the production of new houses. Upkeep costs are both for regular maintenance, amounting to δ_h per unit of housing in every period, and for the refurbishment of houses occupied by a terminal-age household after the occupant dies. The latter force implies that in every period $1/J$ of the housing stock needs to be rebuilt, where $1/J$ is the population share of terminal-age households.[5] As a result, the law of motion for

[4] This is due to the fact that in our transitions, the number of needed conversions is small, and most of them can be covered by allocating the flow of newly constructed houses to the most demanded house types.

[5] This assumption also captures the fact that frequently elderly households occupy housing that,

the housing stock is akin to a standard capital accumulation equation:

$$H_{t+1} = \left(1 - \delta_h - \frac{1}{J}\right) H_t + Y_{h,t} \tag{15}$$

To aid intuition, we report results for two versions of the model with alternative assumptions about the housing good.[6]

Single housing quality. In the simplest version of the model, $\tilde{h} = \{\tilde{h}_1\}$. In this case, the aggregate housing stock H, housing production Y_h and p_h are always constant. The reason is that, in our framework, every household must live in a house, and the total number of households is always constant. If these houses are of constant quality, that means the aggregate housing stock H does not change as a result of a credit or other shocks. This means that $Y_{h,t} = \left(\delta_h + \frac{1}{J}\right) H_t$ in every period. As a result, following Equation (12), the house price p_h is also constant.

Although the assumption that the house price is always constant is very strong, this restricted version of the model will help us gain intuition about our key mechanisms in the rental market. Namely, we show that *rental prices* can move (as a result of changes in housing tenure and in the distribution of landlords) even if house prices do not.

Housing quality ladder. In the more general version of the model with $N > 1$, households can upsize or downsize as a result of a credit shock (or, for example, as a result of a shock to their income). These changes in housing qualities may generate changes in the housing stock, housing production and housing prices.

2.3. Equilibrium

For a given sequence of exogenous fundamentals $\{z_t\}_{t=0}^{T}$ (e.g. borrowing limits, the risk-free rate), a competitive equilibrium in this economy consists of: *(i)* sequences of value functions, housing, consumption and asset policy functions for the households: $\{V_t, s_{t+1}, c_t, a_{t+1}\}_{t=0}^{T}$, *(ii)* a sequence of (generally non-stationary) distributions over households' state: $\{\mathcal{D}_t\}_{t=0}^{T}$, *(iii)* sequences of policy functions for the firms: $\{N_t, L_t, S_t\}_{t=0}^{T}$, and

because of its characteristics and location, may have become less desirable over time. Hence, it is also a simple way of taking into account that there is additional housing production in the economy e.g. because of aggregate trends of urbanisation and geographical reallocation, without assuming that housing depreciation δ_h, which in our model is paid directly by homeowners every period, is unreasonably high.

[6] In Section 6.2 we also consider the case of rental and owner-occupied housing as separate goods.

(iv) sequences of prices: $\{w_t, p_{L,t}, p_{h,t}, p_{r,t}\}_{t=0}^T$, such that they jointly solve the household, final-good firm and construction firm problems at each t, are consistent with rational expectations about future prices, and satisfy the following conditions:

1. *Household optimization.* At each t, given prices $\{w_t, p_{r,t}, p_{L,t}, p_{h,t}, r_t\}$ and expectations over future prices, households solve their intertemporal problem and choose (c_t, a_{t+1}, s_{t+1}) to maximize lifetime utility subject to the budget, borrowing, housing, and transition constraints. This yields the value function V_t, the policy functions $\{c_t, a_{t+1}, s_{t+1}\}$, and the housing choice probabilities $\mathbb{P}_t(h, \tilde{h})$ induced by integrating over taste shocks.

2. *Firm optimization.* At each t, final-good and construction firms solve their static problems given prices, delivering factor demands (N_t, L_t), intermediate input demand S_t, and housing output $Y_{h,t}$ as in Section 2.2.

3. *Law of motion for the distribution.* The distribution evolves according to the endogenous transition implied by household policies:

$$\mathcal{D}_{t+1} = \Gamma_t(\mathcal{D}_t), \qquad t = 0, \dots, T-1, \tag{16}$$

   where Γ_t is the mapping induced by the policy functions and the exogenous income/aging processes. Given an initial distribution $\mathcal{D}_0$ (e.g. the pre-reform steady state), (16) pins down $\{\mathcal{D}_t\}_{t=1}^T$. The stationary steady-state ensures $\mathcal{D} = \Gamma(\mathcal{D})$

4. *Market clearing.* For each $t = 0, \dots, T$, prices adjust so that rental, housing, goods, and land markets clear:

$$\sum_{h=0}^{X} (h-1)\left(\int\int \sum_{j=1}^{J} \mathcal{D}_t(a, s, y, j)\, da\, dy\right) = 0 \tag{17}$$

$$\underbrace{\sum_{n=1}^{N} \tilde{h}_n H_{n,t+1}^{sh}}_{=H_{t+1}} = \left(1 - \delta_h - \frac{1}{J}\right) \underbrace{\sum_{n=1}^{N} \tilde{h}_n H_{n,t}^{sh}}_{=H_t} + Y_{h,t} \tag{18}$$

$$Y_{c,t} = C_t + S_t \tag{19}$$

$$\bar{L} = L_t \tag{20}$$

   where (17) guarantees equilibrium in the rental market period-by-period, (18) describes housing-market clearing together with the law of motion for the aggregate housing stock, and (19) and (20) clear goods and land permits.

2.4. Model intuition: a supply & demand explanation

Before we turn to the quantitative experiments performed with the help of our model economy, we present here the intuition for how reducing credit access, either through tighter borrowing limits or via higher interest payments, affects the homeownership rate as well as house and rental prices.

Panel A of Figure 1 plots rental prices on the y-axis against the quantity/share of rental houses in a model with a single housing type. The demand curve, depicted by the blue line, captures the share of households who want to rent at any given rental rate. It is downward sloping as high rents incentivize homeownership rather than renting. The supply curve represents the number of houses that landlords are willing to rent out in the market at a given price. In our framework, this curve is endogenously upward sloping, as opposed to flat (perfectly elastic supply) or vertical (perfectly inelastic supply). The reason is that, as rental rates go up, more households are willing to become landlords. Intuitively, the richest households will be prepared to enter the market at rents only slightly above those that would make a frictionless investor indifferent between housing and financial assets – that is, the rents implied by a simple user cost formula – as the amount of consumption they would need to sacrifice today to make this lumpy investment is small. Expanding the supply of rental housing, however, eventually requires entry by less rich households, for whom the large investment is more onerous and credit constraints may be more binding. As a result, they demand higher rents in compensation, as we represent in Figure 2.

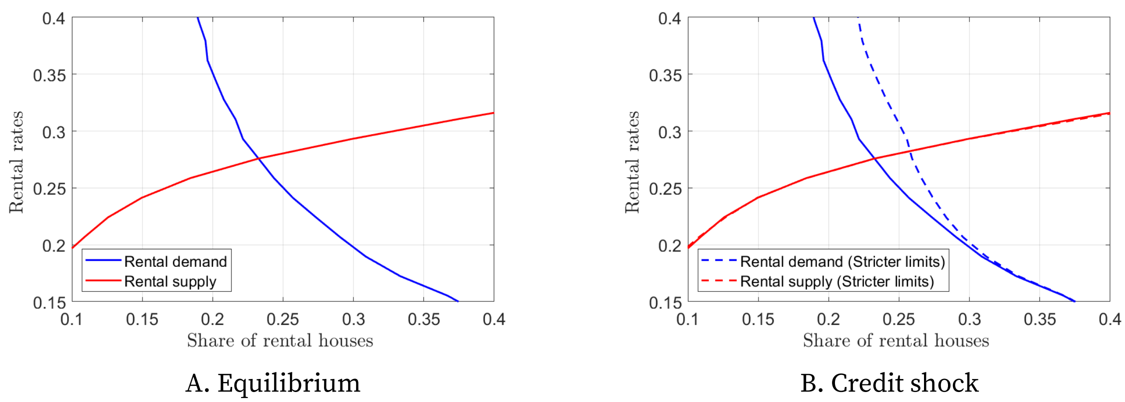


FIGURE 1. Supply and demand in the rental market, constant house prices

NOTE. This figure shows the main mechanisms of the model through a supply and demand illustration. The demand and supply curves are computed numerically using a suitable parameterization of the model economy with a *single housing quality* and hence without house price movements by assumption.

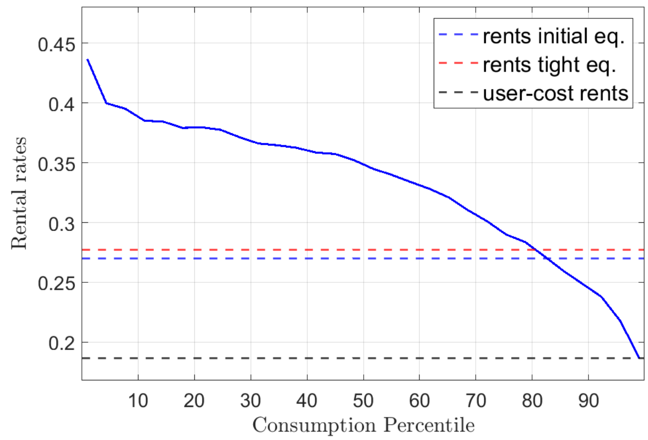
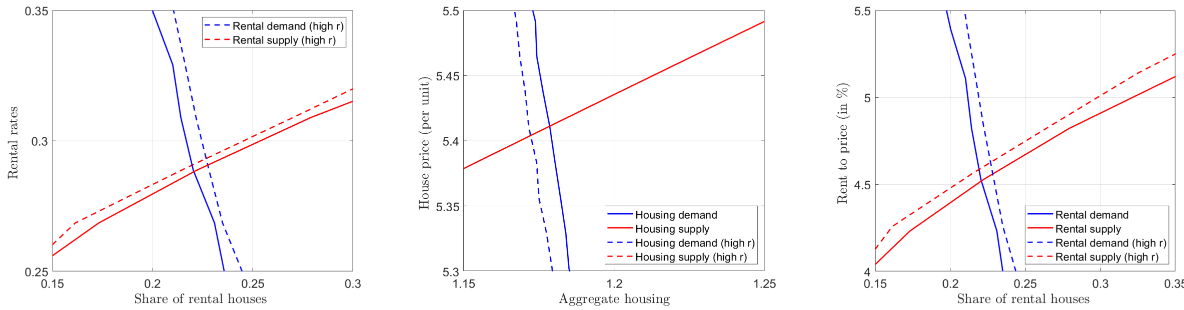


FIGURE 2. Rent threshold by consumption percentile

NOTE. This figure plots households' place within the distribution of consumption - here taken as a proxy for lifetime resources - against the threshold rent required to induce them to supply a unit of housing to the rental market. The downward slope shows poorer households demand higher rents to become landlords. The curve is computed numerically using the model economy with a *single housing quality*.

Now consider the impact of a negative credit shock associated, for example, with the introduction of macroprudential mortgage limits. The negative credit shock shifts the rental demand curve outwards, as shown by the blue dashed line in Panel B of Figure 1: some potential buyers no longer qualify for a mortgage after the reform, so they cannot buy a house anymore and are pushed back into rental market. This increase in rental demand interacts with the upward sloping supply curve: the negative credit shock not only leads to a reduction in the homeownership rate, but also to an increase in the rental prices these new renters must pay. Figure 2 shows where the movement along the supply curve comes from: the new additional rental units must be provided by new landlords with higher rent supply thresholds than the existing ones.

This simple illustration with a single housing quality implies that house prices do not change in response to changes in the availability of credit. We now turn to our baseline model with a quality ladder, in which both house and rents can adjust endogenously in response to shocks (Figure 3). When we focus on rental prices alone, the same intuition holds as in the single quality model (panel A). However, house prices move in this framework, which is captured in Panel B by plotting the aggregate quality-weighted housing demand (x axis) against the per-unit housing price (y axis). After the credit shock, housing demand drops because more households turn to living in smaller properties and house prices go down. Finally, panel C shows that the rent-to-price ratio also increases. In contrast, in a model with perfectly elastic rental supply, the increase



A. Rents B. House prices C. Rent-to-price ratio

FIGURE 3. Supply and demand in the rental and housing markets, baseline model

NOTE. The supply and demand curves are computed numerically varying rents off their equilibrium levels while house prices stay constant (panels A and C) and varying house prices while rents stay constant (panel B), based on the permanent interest rate shock experiment described in Section 5.1.

in rental demand only translates into a reduction of the homeownership rate, and prices do not move because deep-pocketed landlords are willing to buy as many houses as needed at the present value of rents to meet rental demand.

This section shows that our key mechanism is present both in models that assume that owner-occupied housing and rental housing are identical (for instance, in our illustration with a single housing quality) and in those who do not (in our baseline the smallest house quality can only be rented). In that sense, and although the degree of owner-occupied and rental market segmentation governs the effect of credit shocks on house prices (Greenwald and Guren 2025), it does not govern its effects on rents.[7]

While we have focused on an illustration that compares steady states, the same effects on rental and house prices take place, and in a stronger manner, after the economy is hit by an unexpected credit shock. The reason is that both the demand and, particularly, the supply curves for both rental accommodation and housing are much more inelastic in the short run, thus leading to sharper changes in prices and slower adjustments in quantities. We show the corresponding supply-demand illustrations in Appendix C.1.

3. Calibration and model fit

Our first experiment focuses on a macroprudential reform that took place in Ireland in 2015. We parametrize our model economy to be consistent with the cross-sectional

[7] We return to this point in Section 6.3 and show that the mechanism also applies if rental and owner-occupied properties are traded in two separate markets.

features of the Irish economy. Then, we also use this same calibrated version of the model to study the impact of a permanent and transitory rise in real interest rates.

As standard in the macroeconomic literature, we assign some of these parameters externally, while others are chosen internally with the objective of minimizing the distance between a collection of data and model moments.

3.1. Externally calibrated parameters

Demographics and Preferences. The model period is one year. Households enter the economy at age 25, they retire with certainty at age 65 and live until age 95. This means that $J^{ret} = 41$ and $J = 71$. There is no population growth. We set the CRRA risk aversion coefficient γ to 2, a common value in the literature. The scale parameter of the taste shock σ_{ε} is within the range suggested by Iskhakov et al. (2017) and equal to 0.05.

Earnings process. Our measure of income in the data is disposable household income after both taxes and transfers. We estimate our earnings process following De Nardi, Fella, and Paz-Pardo (2020), which allows us to incorporate rich and age-dependent features of earnings dynamics in a parsimonious way. Appendix B.4 gives further details about its estimation.

Housing. We set the maximum amount of houses that a household can own X to 3 both for simplicity and computational considerations. However, this choice implies that we can capture the vast majority of landlords in Ireland: over 80% of them have only 1 or 2 rental properties, and they represent over half of all tenancies. Indeed, around 37% of all rental properties are owned by households with just one buy-to-let property – see Figure A2 – and over 60% of non-occupier transactions in 2015 involve household buyers – see Figure A1. Large institutional investors (non-household buyers) have grown in relevance over the past decade, but they were still relatively small players when the reform took place. [8] Since then, institutional investors have been mostly concentrated in a set of particular rental submarkets (e.g. new builds in highly sought-after areas). Given that we do not model this spatial heterogeneity, we abstract from them. [9]

[8] Oosthuizen (2023) explains this upward trend in the US by the decreasing operating costs of larger institutional investors, while Muñoz and Smets (2022) argue that it is associated to the lack of regulatory lending limits to real estate funds.

[9] Our household-landlords could also be understood as representing relatively small corporate investors that are sensitive to credit conditions. Garriga, Gete, and Tsouderou (2023) show that small and medium sized real estate investors grew more than very large corporate investors in the US after the financial crisis.

TABLE 1. Parameter values

Parameter	Interpretation	Value
Externally calibrated		
J^{ret}	Working life (years)	41
J	Length of life (years)	71
γ	Risk aversion coefficient	2.0
σ_ε	Taste shock scale parameter	0.05
X	Maximum amount of houses owned	3
α_h	Curvature in utility premium function $f(\cdot)$	0.5
δ_h	Housing depreciation rate	0.012
τ_h	Proportional transaction cost	0.03
λ_{LTV}	Maximum loan-to-value ratio	1.0
λ_{LTI}	Maximum loan-to-income ratio	6.0
r	Risk-free rate	0.02
κ	Intermediation wedge	1
A_c	Aggregate labor productivity	1.2055
$\bar{L}$	Amount of land	1.0
α_L	Share of land in production	0.33
Internally calibrated		
β	Discount factor	0.955
θ	Utility ownership premium	1.14
A_h	Productivity of construction sector	0.13

NOTE. This table shows the value of the parameters used for solving our model economy and to carry out the experiments. For the macroprudential intervention, λ_{LTV} and λ_{LTI} will change; while for the increase in rates, r and κ will be adjusted.

We assume that there are four house qualities and normalize the lowest quality $\tilde{h}_1$ to 1. We assume that utility from living in houses of higher quality is increasing and concave with $\alpha_h = 0.5$ controlling the curvature of this function. The housing depreciation rate δ_h is set to be 1.2% per year, within the range of typical values used in the literature. The transaction cost for selling and buying a house τ_h equals 3% of its value. The maximum loan-to-value, λ_{LTV}, and loan-to-income, λ_{LTI}, ratios before the macroprudential reform are 1.0 and 6.0, respectively. This is consistent with the evidence in Kelly, McCann, and O'Toole (2018) that estimate the 98*th* percentile of observed LTI and LTVs ratios on quarterly mortgage data during the period 2003 to 2011. Prior to the 2015 reform, there were no institutional limits. Therefore, these limits correspond to those that were imposed by Irish banks based on their own risk assessment.

Financial instruments. The risk-free rate on liquid savings r_s is set to 2% per annum. The proportional wedge κ is set to 1, implying a mortgage rate r_b of 4% per annum. This is consistent with the gap between the average mortgage rate and the 10-year yield on government debt.

Production. The amount of buildable land $\bar{L}$ is normalized to 1, and the share of land used in production in the housing sector α_L is fixed to 0.33, which implies an elasticity of housing supply of approximately 2.

3.2. Internally calibrated parameters, targets, and model fit

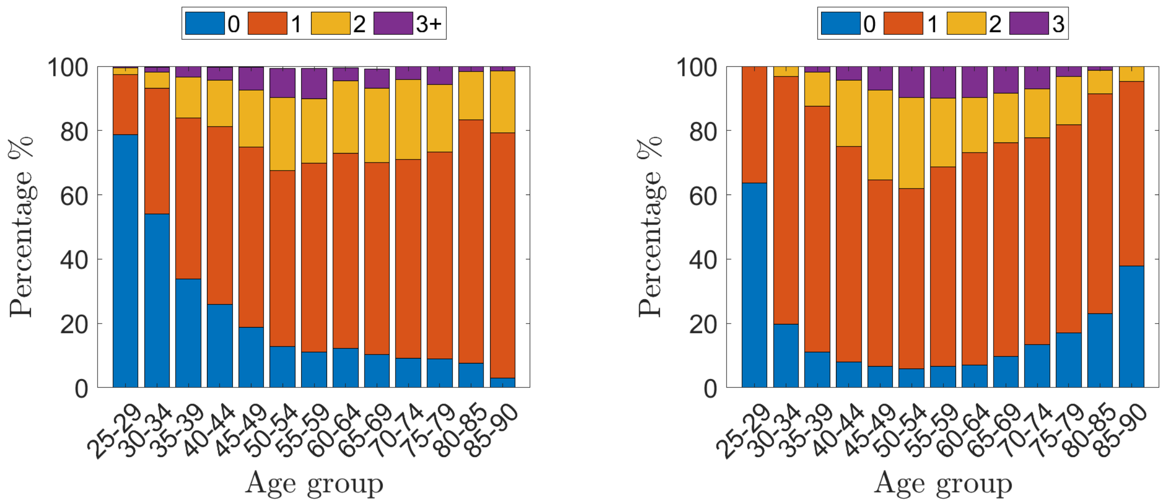
The remaining three parameters: the discount factor β, the homeownership utility premium θ, and the productivity scaling factor in housing production A_h, are jointly chosen to match four moments of the data: the average wealth to income ratio, the homeownership rate, the house price to income ratio and the house price to rent ratio. The first block of Table 2 shows the value of these four moments in the data as well as their model counterparts, which were obtained using the parameters in the last block of Table 1.

The model is able to match the average homeownership rate, the average house price to income ratio and the house price to rent ratio reasonably well. However, it slightly under-predicts the average wealth to income ratio. More importantly, the model

TABLE 2. Targets and model fit

Moment	**Model**	**Data**	**Source**
Targeted			
Wealth to income ratio	5.57	6.78	HFCS
Homeownership rate	77.97%	80%	EU-SILC
Avg. house price to income ratio	5.29	5.0	CSO
House price to rents ratio	22.09	22.58	RTB/CSO
Untargeted			
Rents to avg. income ratio	0.2395	0.2216	RTB/CSO
Share of households with 3+ properties	4.45%	5.11%	HFCS

NOTE. This table shows the model ability to capture certain features of the Irish economy. The top block corresponds to the targets used in a minimum distance estimation, while the bottom block show the performance of the model relative to untargeted moments. Data sources: Household Finance and Consumption Survey (HFCS), EU Statistics on Income and Living Conditions (EU-SILC), Irish Central Statistics Office (CSO), Residential Tenancies Board (RTB)



A. Data

B. Model

FIGURE 4. Number of properties along the life-cycle

NOTE. This figure shows the number of properties owned by households in the data (panel A) and in the model (panel B) at different age brackets.

is able to replicate the share of landlords in the economy, both at the aggregate level and along the age distribution (see Figure 4). At the aggregate, the share of landlords with two rented out properties (the upper bound) is 4.45% in the model; while 5.11% of landlords own two or more rental properties in the data. Along the life-cycle, it is only at mid age when a significant faction of households can afford to buy a second or third home, consistently with the data. Later in life, households in the model, unlike those in real life, sell these properties to finance retirement. This mismatch is a standard feature of life-cycle models which do not include a set of relevant features of retiree saving behavior, such as precautionary savings related to medical costs or long-term care and bequest motives (Nakajima and Telyukova 2020). As also shown in Figure 4, the share of renters decreases with age in both the model and in the data. However, this happens more quickly in the model than in real life. In any case, these life-cycle patterns are endogenously captured by the model without explicitly targeting them, which is reassuring about the validity of the model as a laboratory to study the distributional effects of the macroprudential reform discussed above.

An additional moment that is informative about the ability of the model to generate realistic changes in house prices and rents as a response to policies and shocks is the elasticity of rental supply. We defer this discussion to Section 4.4, after we have introduced our main results and their empirical counterparts.

4. Tighter borrowing limits: the Irish macroprudential reform

4.1. Institutional context

Macroprudential regulations that limit household leverage in the residential mortgage market have been widely used by policymakers to smooth the house price and credit cycles. We study the case of Ireland, whose central bank introduced these mortgage measures for the first time in February 2015 after a first discussion in October 2014. At that time, the Central Bank of Ireland established a maximum Loan-To-Income (LTI) limit of 3.5, which only applied to first-time-buyers (FTBs), and several Loan-To-Value (LTV) limits depending on the borrower and property type. For primary dwellings the limit was set to 80% of the value of the house; for FTBs, the limit was more generous: 90% for the first €220,000 and 80% for the excess amount; and for buy-to-let (BTL) properties the threshold was more stringent and set to 70%. Banks and other lenders were allowed to lend certain amounts above those limits. Specifically, for LTVs, 15% of all lending could take place above the limits, while for LTIs there was a 20% allowance. These measures have been reviewed on an annual basis since then and were broadly unchanged with minor alterations until 2022, when a more significant change was introduced. We focus on the 2015 regulation because of its implementation, which, paired with data availability, makes it a compelling case study to analyze the effects of these measures on house prices and rents in the data.[10]

4.2. Empirical evidence

Using data for the universe of originated mortgages in Ireland, Acharya et al. (2022) study the 2015 reform and find that it generated a reduction in house price growth. In order to control for potentially confounding effects in macroeconomic aggregates, they develop a distance measure that correlates with the exposure to the macroprudential reform. In counties where house prices were high with respect to incomes, many mortgages signed before the reform were at or above the limits: these are categorized as *low-distance* areas. One would expect that the reform would have stronger effects in these areas. In contrast, in counties where house prices were relatively low with respect to incomes, the reform was closer to non-binding and thus expected to have low to no effects. Consistently, Acharya et al. find that the distance measure positively correlates with house price growth around the reform. In other words, house prices grew more

[10] Appendix B.2 details how we implement the different LTI and LTV limits in our model.

in areas where the constraints were less binding (high distance), while house price growth moderated in areas where the intervention was more binding (low distance). Non-parametric evidence of these positive correlations across Irish counties are shown in the first two panels of Figure A3.

We extend their empirical framework to analyze the effects of the reform on rental prices. We use the same distance measure and combine it with house price and rental data extracted from the property website daft.ie (Lyons 2018). Following Acharya et al.'s empirical strategy, we regress changes in house prices and rents between the third quarter of 2014 and the last quarter of 2016 on the aforementioned distance measure. Formally, we estimate the following two regressions

$$\Delta \text{ House Prices}_i = \beta_0 + \beta_1 \text{Distance}_i + \epsilon_i \tag{21}$$

$$\Delta \text{ Rents}_i = \gamma_0 + \gamma_1 \text{Distance}_i + \nu_i \tag{22}$$

where i denotes the county, Δ is the growth rate over a 9 quarter window, and β_1 and γ_1 are the coefficients of interest. Table 3 shows the results of these two regressions. The first column replicates the positive coefficient that Acharya et al. obtain for house prices. The second column shows that the impact of the reform on rents had the opposite sign: rents increased by more in areas where the macroprudential intervention was more binding (low distance). Quantitatively, a one standard deviation in the county-level distance measure is associated with 4.2% higher house prices and 2.5% lower rental rates. As for house prices, non-parametric evidence of these negative correlations between distance and rental price growth across counties are shown in Figure A3.

To establish whether these opposite effects on rents and house prices might be the result of contrasting long-run trends in different local housing and rental markets, which could be correlated with the distance measure, rather than the impact of the

TABLE 3. Effect of lending limits on house and rental prices

	Δ House Prices	**Δ Rents**
Distance	0.289	-0.171
	(0.068)	(0.039)
Obs.	54	54
R^2	0.34	0.31

NOTE. This table shows the OLS coefficients from the regressions of house price and rental price changes on the distance measure that captures the exposure to the borrowing limits.

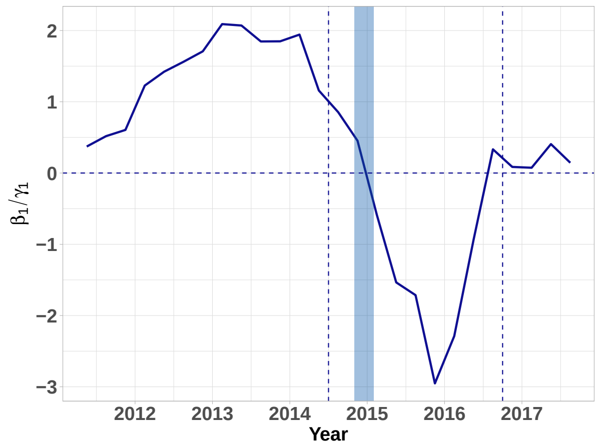


FIGURE 5. Placebo regression

NOTE. This figure represents the ratio of coefficients β_1 and γ_1, as defined in equations (21) and (22), while keeping the distance measure fixed at its reform level but varying the estimation window (x-axis). When this ratio is positive, house prices and rents co-move with the distance measure; when negative, they move in opposite directions.

reform, we re-estimate equations (21) and (22) for different time windows. As in the main regression, we use the changes in house prices and rents between 9 consecutive quarters as our dependent variables while keeping the distance measure fixed to its value in 2014, and we report their ratio β_1/γ_1 (y-axis) for the central part of each rolling window (x-axis) in Figure 5. Outside of the period of the reform, the ratio of the coefficients is positive, reflecting that house prices and rents tend to co-move, which is consistent with the theory as the value of a house should equal the expected discounted value of future rents. However, when the credit shock hits, rents and house prices move in opposite directions in relation to the distance measure. As described in Section 2.4, we argue that this break in their co-movement occurs because the marginal buyer and seller of rental services change, affecting the stochastic discount factor used to price rental housing.

In short, this placebo test confirms that our findings are not driven by time-invariant omitted variables which are correlated with the distance measure and reinforces the idea that the credit shock induced a decoupling of the usually positive relationship between the evolution of house prices and rents.

4.3. Model results

We study the effects of the macroprudential reform under the assumption that it is a permanent change. We begin by comparing two steady state equilibria that only differ in their mortgage borrowing limits.[11] Then, we consider the effects of the transition from the (initial) *pre-reform* steady state to the (final) *post-reform* steady state. That is, agents unexpectedly observe that borrowing limits permanently become more stringent. Finally, we use these results to evaluate the welfare effects of the reform on our heterogenous households.

4.3.1. Steady state comparison

In the *pre-reform* economy, households are able to borrow up to 100% of the value of their house and up to 6 times their annual income. Equilibrium quantities and prices under these credit conditions are reproduced in the first column of Table 4. The second column presents the equilibrium outcomes in the *post-reform* economy where these limits correspond to those introduced by the 2015 reform: *(i)* a 80% loan-to-value limit if they buy an owner-occupied property, *(ii)* a 70% loan-to-value limit if they purchase a buy-to-let home, and *(iii)* a 3.5 loan-to-income limit for first-time buyers.

As a result of these changes, and following the intution in Section 2.4, the homeownership rate falls by more than 3 percentage points.[12] The rent-to-price ratio increases by around 2.5% in the long-run. Such increase in the rent-to-price ratio could be explained by either an increase in rents or a fall in house prices: our model is able to disentangle these two effects. We find that it is driven by the rental price as it increases by 2.6%, while the average house price in the economy actually increases slightly by 0.1%, reflecting different housing quality choices by households in the new equilibrium and moderating the overall increase in rent-to-price ratios.

These rental price dynamics arise because the marginal landlord needs to be compensated even more, via higher rental prices, to meet the increased rental demand coming from households that do not qualify for a mortgage at the new borrowing limits. As a result, the concentration of housing wealth rises in two ways. First, the increase in the number of renters implies that their homes are now owned by landlords, who are already homeowners themselves. In fact, landlords hold 45.4% of the total housing stock in the post-reform – almost a 14 percent increase relative to the pre-reform. And second, the number of landlords that hold two rental properties, which in our framework proxies relatively larger owners, also increased by 15 percent, reaching 15.3% ownership share.

[11] Appendix C.2 shows the effects of tightening LTV and LTI limits in isolation. For this reform, the LTI limit has a stronger effect than the LTV but there are interactions between the two.

[12] These results are consistent with Garriga, Gete, and Hedlund (2020), who find that contractionary credit shocks negatively impact homeownership.

TABLE 4. A credit crunch – tightening LTI & LTV limits

	Pre-Reform	Post-Reform	Percentage Change
Rent-to-Price	4.53 %	4.64 %	2.45 %
Average house price to income	5.29	5.30	0.13 %
Rent to Income	0.239	0.246	2.58 %
Homeownership rate	77.97 %	74.79 %	-3.18 p.p.
Share of households with 3 properties	4.45 %	5.12 %	0.67 p.p.

NOTE. This table show the equilibrium prices and quantities for the two economies considered: *(i)* the pre-reform economy in which borrowing limits are loose ($\lambda_{LTV} = 1$ and $\lambda_{LTI} = 6$), and *(ii)* the post-reform economy in which tighter borrowing limits are imposed ($\lambda^{oo}_{LTV} = 0.8$, $\lambda^{btl}_{LTV} = 0.7$ and $\lambda_{LTI} = 3.5$).

4.3.2. Transition dynamics & welfare

Transition paths. Figure 6 illustrates the path of rental and house prices as well as the evolution of the homeownership rate during the transition to the steady state in which borrowing limits are set to those imposed by the Central Bank of Ireland in 2015. Following the macroprudential reform, prospective homeowners cancel or postpone their buying decisions and stay renters, increasing the demand for rental accommodation. As a result, rent-to-price ratios need to increase to incentivize the (endogenous) landlord formation necessary to meet this excess demand. At the beginning, where both renters and landlords are surprised by the reform, this occurs both through a substantial decrease in house prices (-0.9%) and a small increase in rents. However, as relatively richer households start to save to buy houses and become landlords, house prices recover, but rents stay elevated to keep the incentives in place. Thus, rents peak 7 years after the reform at a level which is around 4.5% higher than the initial steady state, and then slowly decrease to their new and higher steady state level.

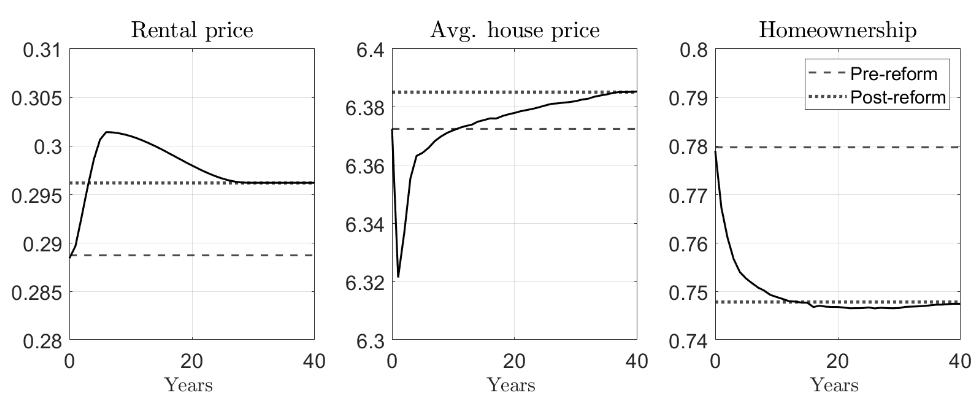
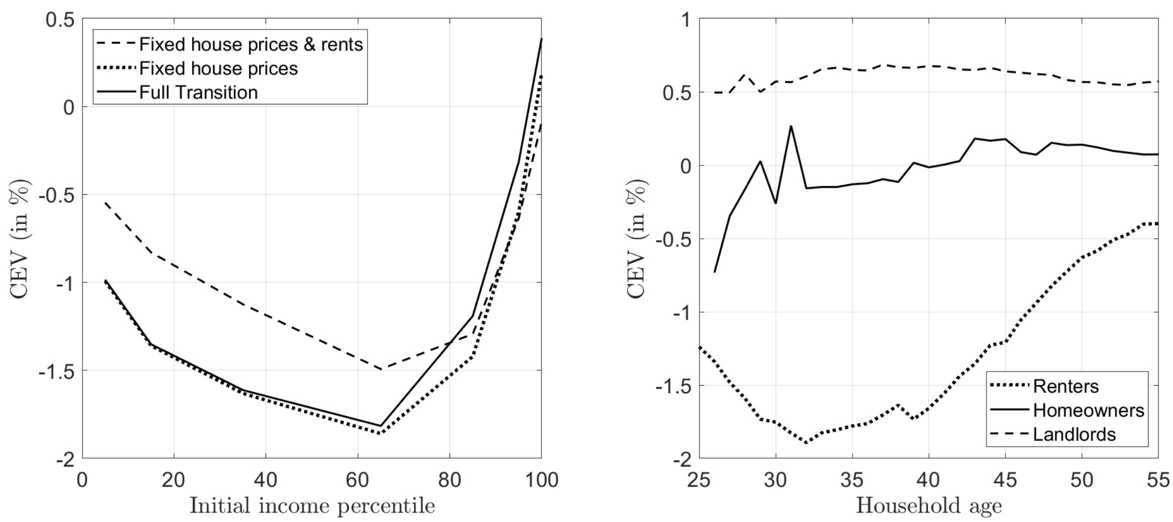


FIGURE 6. Transition paths: from loose to tight credit limits

Welfare. We evaluate the distributional effects of the reform through the traditional lifetime consumption equivalent variation (CEV) measure.[13] Figure 7 depicts the value of this metric along the income distribution (panel A) and household's age and housing tenure status (panel B). We decompose the CEV into partial and general equilibrium effects because welfare is affected by the tighter limits as well as by the associated price movements. The dashed line depicts the welfare effects of the macroprudential reform in absence of price movements. As expected, the tightening of borrowing limits in itself is welfare reducing for all agents in this economy as we are constraining the feasible set. Young and middle-income households bear most of the costs given that they are prospective homeowners.



A. Income distribution B. Life-cycle & housing tenure

FIGURE 7. Price adjustments, household heterogeneity & welfare

NOTE. Panel A depicts the value of the CEV along the income distribution and decomposes the overall welfare effect (solid line) between the contribution of the reform itself (dashed line), the rental price adjustment (dashed vs. dotted line) and the house price drop (dotted vs. solid line). On the other hand, Panel B plots the overall welfare effect for households of different ages and housing tenure statuses.

Turning now to the price effects, higher rents generate a further welfare loss for young, poor and middle income households because they reduce their cash available for consumption and constrain their ability to save for a downpayment. Graphically, this effect is shown by the gap between the dashed and the dotted line in Panel A of Figure 7, which is shrinking along the income distribution and it is even positive, and hence welfare improving, for the very rich. Those at the top of the income distribution benefit

[13] Appendix B.3 provides more details about the computation of this measure.

from the increase in rents because they are typically landlords and hence receive a larger cash flow from their real estate investment. Finally, the drop in house prices along the transition benefits prospective homebuyers, mostly those who are above the median of the income distribution. Graphically, this is shown by the difference between the solid and the dotted lines in Panel A of Figure 7.

Panel B of Figure 7 decomposes the CEV based on households' housing tenure, which turns out to be a great indicator to disentangle the winners and losers of constraining credit. In a nutshell, renters lose, homeowners are indifferent or lose slightly because of the temporary drop in house prices, and landlords benefit. Consequently, a welfare neutral policy would require a redistribution of consumption from landlords to renters to compensate for the unintended effects of the macroprudential reform.

4.4. Replicating our empirical evidence

A key element for the validation of our model is whether it generates reasonable reactions of rental prices (and house prices) to any given shock. In our model, rental demand and supply elasticities (and housing demand elasticities) are endogenous objects, which depend on the distribution of income and wealth of landlords, renters and homeowners as well as on their policy functions. We do not target them explicitly or replicate them with a single parameter. We begin by comparing our model-implied long-run elasticities with those reported in the literature and then move to our key empirical validation, in which we replicate our empirical analysis using model simulated data.

First, we look at the elasticity of rental supply in the long run, i.e., by how much rental prices need to increase in order to encourage landlords to supply 1% more units of rental housing when comparing steady states, which is closely related to the slope of the rental supply curve that we represent in Figure 3. Identifying rental supply elasticities in the data requires, ideally, a shock that affects rental demand alone. While we do not have such estimates for Ireland, Rotberg and Steinberg (2024) estimate this parameter for the United States using the incidence of property taxes, and find that it is 1.4 in the long run (a 1% increase in rental prices leads to a 1.4% increase in quantity supplied). In comparison, they show that this elasticity is infinite in models with rental sectors in which prices are determined by a user-cost formula (as price to rent ratios are independent of quantities), and that it is very large in models in which landlords are homeowners that choose every period how much of their housing stock to rent out (e.g. 38 in Floetotto, Kirker, and Stroebel (2016)).

The elasticity of rental supply in our model is 3.5 in our pre-reform steady state – larger than that in Rotberg and Steinberg (2024), but an order of magnitude smaller than in other models with endogenous landlords. The reason is that, in our model, housing is lumpy and illiquid also for landlords, who need to buy one complete house to be able to rent it out. Thus, there are frictions associated with becoming a landlord, which makes them less responsive to changes in rent-to-price ratios than those in Floetotto, Kirker, and Stroebel (2016) or Sommer and Sullivan (2018). Additionally, and compared to the rental company in Rotberg and Steinberg (2024), our model generates a nonlinear rental supply function with elasticities varying along the curve, derived from the fact that the wealth, income and age of the marginal landlord vary along the supply curve.

However, this comparison is imperfect for several reasons. First, it relies on US data, where rental contracts, the construction sector and the availability of land may be different to Ireland. Second, it is estimated based on a policy (property taxes) which is different to our focus (credit shocks). Third, and most importantly, they are long-run elasticities, while in our model we are mostly concerned with the effects of a credit tightening over the first few years after the reform. Therefore, we move to replicating the empirical analysis of the Irish macroprudential reform, which we described in Section 4.2 and which is precisely the reform that we simulate in our model. While these empirical estimates are not rental supply elasticities, they relate very closely to it, as rents will respond more to a given shock if rental supply is more inelastic.

The empirical analysis relies on the cross-sectional variation of the reform intensity across different housing markets, while our main model results are based on a single, nationally aggregated version of the Irish housing market. We address this issue by simulating different economies with different house price to income ratios, which aim to replicate the geographical heterogeneity that we observe in the Irish economy. Then, we apply the same macroprudential reform across all of them and use these results to regress the region-specific changes in house prices and rental rates on a model-based pre-reform distance measure that follows the conventions described in Section 4.2.[14]

We find that the reaction of rents to the reform is, as in the data, stronger in those counties in which house price to income ratios are initially higher and, thus, many households are constrained as a result of the reform. The coefficient, -0.174, is very close to that in the data (Table 5). This reassures us that our main empirical estimates of the national effects of the reform are based on a model that generates reasonable

[14] For computational feasibility, this experiment assumes that all counties have fully separate housing and rental markets.

TABLE 5. Effect of lending limits on house and rental prices

	Δ House Prices	**Δ Rents**
Data	0.289	-0.171
	(0.068)	(0.039)
Model	0.366	-0.174

NOTE. This table shows the OLS coefficients from the regressions of house price and rental price changes on the distance measure that captures the exposure to the borrowing limits.

reactions of both rental supply and demand as we vary house price to income ratios, and therefore that we are closely replicating the relevant rental supply elasticities. We also report the coefficient on house prices which, at 0.366, is slightly larger than the estimate in the data, but still within a 90% confidence band. Reassuringly, this coefficient is both of the opposite sign to that of rents, implying a stronger drop in house prices in cities, where the reform is more binding, and of a larger absolute value.

Put together, the success of our model in getting closer to these empirical estimates reassures us that our heterogeneous households and housing lumpiness help to generate reasonable price reactions to shocks. Importantly, the introduction of institutional landlords would tend to increase rather than reduce rental supply elasticities, as large investors tend to be more price elastic.

5. A rise in the real interest rate

In this section, we use the model presented in Section 2 to study the effects of a different credit shock: an exogenous and unexpected rise in the real interest rate. We distinguish between a *persistent* increase, which could be driven by structural factors pushing up the natural rate of interest, and a *transitory* rise, which is more closely connected with, for example, a conventional monetary policy shock.

In either case, an increase in the interest rate has a direct impact on prospective homeowners as it makes mortgage credit more expensive. In this regard, this experiment is similar to the tightening of LTV and LTI limits studied in Section 4. Unlike the macroprudential reform, however, the increase in interest rates also has a direct impact on savers because the return on bonds increases, and on current mortgagors because their mortgage interest payments also increase. In what follows, we analyze the role of these channels in the long and in the short run.

TABLE 6. Long run effects of increasing the real interest rate

	Low Int. Rate	Decomposition	High Int. Rate	
	$r^s = 2\%, r^b = 4\%$	$r^s = 2.2\%, r^b = 4\%$	$r^s = 2.2\%, r^b = 4.2\%$	
Income effect compensation		No	No	Yes
Rent-to-Price	4.52 %	4.57 %	4.62 %	4.91%
Average house price to income	5.29	5.27	5.26	5.48%
Rent to Income	0.239	0.241	0.243	0.269
Homeownership rate	77.97 %	77.73 %	77.49 %	76.07%

NOTE. This table show the equilibrium quantities and prices for three economies: *(i)* low interest rate, *(ii)* high interest rate and *(iii)* a counterfactual economy that help us decompose the effects of the return on savings and the borrowing rate.

5.1. Long-run effects: steady state comparisons

We find that that a small permanent increase of 20 basis points in the real interest rate leads to a reduction of 0.5 percentage points in the homeownership rate and a 10 basis point increase in the rent-to-price ratio. This increase is mostly driven by the rise in rental rates (1.4%) and to a lesser extend to the fall in average house prices (-0.6%), as we show in Table 6, comparing the first and third columns. The effects go in the same direction as those of the LTI/LTV intervention that we studied in Section 4.

The return on savings vs. the mortgage rate. To better understand the different channels at play, we now turn to study the effects of the increase in the savings rate and the mortgage rate, each in isolation.

The rise in the return on savings – comparing the first and second columns of Table 6 – makes financial assets relatively more profitable than housing, ceteris paribus. Hence, there is a substitution effect that decreases the incentives to own a house. However, the higher returns from savings allow prospective homeowners to save for downpayment at a faster rate (income effect), which pulls the homeownership rate in the opposite direction. Overall, the substitution effect dominates and we observe a small drop in the homeownership rate of -0.24 p.p.. Landlords need to be compensated further in order to hold housing as an investment, which results in a small rise in rents (0.6%). However, the rise in returns for savings also generates a positive income effect for landlords, who become less financially constrained. As a result, the return they demand on housing (rent-to-price ratio) grows less than one-to-one with the change in interest rates.

On the other hand, the income and substitution effects associated with the rise in the mortgage rate – comparing the second with the third column of Table 6 – pull in the same direction because it increases the interest payments of current mortgagors (income effect) and the cost of accessing credit (substitution effect).[15] As a result, the homeownership rate and the average house price decrease further, while rental prices increase slightly more (0.85%).

Results without aggregate income effects. In the last column of Table 6 we report a version of the steady state with higher interest rates in which the aggregate amount of resources in the economy is equivalent to that of the low-r steady state.[16] In this scenario, the increase in rent to price ratios is much larger – around 40bp for a 20bp permanent interest rate change. This result shows that the additional income landlords received because of the higher interest rate was key to explain the relatively small increase in rents that we found in our uncompensated high interest rate equilibrium. But, at the same time, it also highlights that our landlords are subject to financial constraints, which introduce wedges to the model that affect the transmission of shocks to asset returns. In the low-r steady state, the rent-to-price ratio is already higher than both the liquid asset and mortgage interest rate, reflecting that landlords demand additional compensation to invest in a lumpy, illiquid asset. As r increases and the homeownership rate drops, comparatively more constrained households, with higher stochastic discount factors, become landlords, and the additional return they demand to hold housing goes up. In comparison, a simple portfolio choice model with an unconstrained investor would imply that rent to price ratios move one to one with interest rates.

5.2. Short run effects: transition dynamics

We now turn to study how an increase in the real interest rate impacts rents and house prices over the transition. To understand the role of shock persistence, we analyze the same permanent 20 basis points shock studied in Section 5.1, and a 100 basis points transitory shock that dies out after 4 years.[17]

[15] In our model we assume that all mortgagors have a variable rate and thus the adjustment to their mortgage payments happens immediately after the shock. This assumption is consistent with the Irish institutional framework, in which around 80% of mortgages were de facto on adjustable rates, either fully or with short fixation periods of just one or two years (Badarinza, Campbell, and Ramadorai 2018).

[16] This experiment corrects for the additional income flow generated by the higher exogenous world interest rate in an economy that has aggregate positive net worth. We implement it with a proportional labour tax, which does not per se generate distortions in our model given that labour supply is exogenous.

[17] We model our transitory shock as an AR(1) process with 0.10 persistence at the annual level.

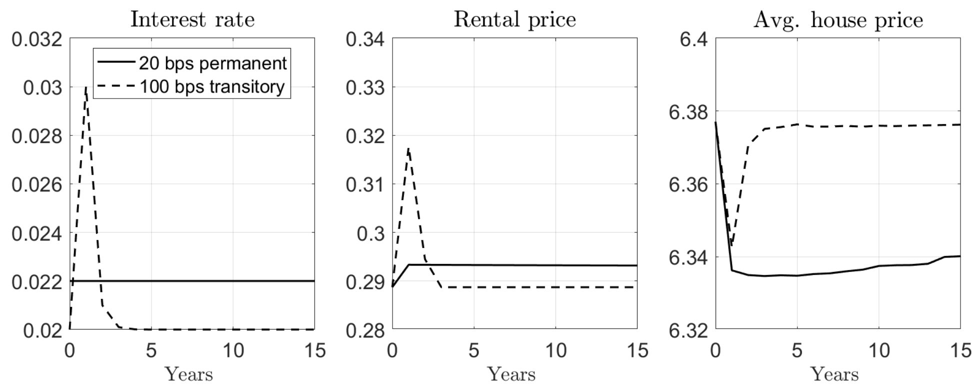


FIGURE 8. Transition paths: from low to high real interest rates

NOTE. This figure shows the evolution of the interest rate, the rental price and the average house price after the pre-reform economy is shocked with a permanent (solid line) or a transitory (dashed line) increase in the real interest rate. The size of the shocks is chosen such that they generate a comparable drop in house prices upon impact.

As shown in Figure 8, the permanent shock in the interest rate leads to a prompt reaction of rental and house prices which reach their new steady state levels almost immediately. This contrasts with the permanent change in credit conditions in which only house prices react upon impact and rents reach their peak 7 years after the reform. This difference can be attributed to the fact that the rise in rates directly affects all households, including landlords, who are quick to reoptimise their investments. Instead, the macroprudential reform only affects prospective home buyers on impact.

The transitory shock impacts rents and house prices immediately and does not have persistent effects. The 100 basis point increase in rates leads to a 50 basis point increase in the rent-to-price ratio in the first year. This increase is explained by a 10% increase in rents and a 0.5% drop in average house prices upon impact, after which they go back quickly to the initial steady state. This stylised experiment highlights how shocks to monetary policy may have undesired effects, with an interest rate hike increasing rental inflation substantially in the short run.

5.3. Interaction with credit standards

It is well established that borrower based macroprudential limits are effective in controlling house price growth, and we have showed that they can also lead to an acceleration in rental price growth. However, they also have an impact on house price volatility and on the response of house prices to shocks. In Appendix C.3 we show that the fall in average house prices as a result of an increase in the interest rate is stronger when credit limits are more lenient, highlighting the role of macroprudential policy in moderating the house price cycle.

6. Robustness and extensions

In this section we verify whether our modeling assumptions about the nature of the housing good and the movements in house prices qualitatively impact our key result: rental prices increasing as a result of a credit tightening. First, we study the simplest case in which there is just a single housing quality or type, i.e. there are no differences between rental and owner-occupied units. Then, we move on to the opposite case in which housing and rental properties are two completely different goods. These two extreme cases allow us to compare our results to those in Greenwald and Guren (2025) as together with our baseline they capture different degrees of segmentation. Finally, we conclude this section by studying the role of conversion costs, as they impact the response of house prices and consequently can also affect the rental price response.

6.1. A single housing quality implies fixed house prices, but rents still rise

Assuming that all house types are identical, $\tilde{h}_j = \tilde{h}$, implies that the aggregate housing stock H and the house price $p(\tilde{h}) = p_h$ do not move as a result of a credit crunch. The intuition is that, in this version of the model, every household must always be living in a house of size $\tilde{h}$, so credit (or other) shocks have no impact on the aggregate demand for housing.[18]

However, credit shocks still impact who owns these homogeneous houses. As described in Section 2.4, after the macroprudential policy intervention *rents increase* because rental supply is upward sloping and the credit shock increases rental demand by households who can no longer obtain a mortgage to buy their desired property. Quantitatively, the combination of these two effects lead to an increase of 2.6% in the rent-to-income ratio, similar to the one obtained in the benchmark. The top block of Table 7 also shows that other predictions of our baseline model, such as the fall in the homeownership rate or the increase in housing wealth concentration, are still present in this stripped down version of the model.

[18] This can be easily seen by simply inspecting the steady state per-unit house price $p_h = \frac{1}{1-\alpha_L}\left(\frac{1}{A_h}\right)^{\frac{1}{1-\alpha_L}}\left(\frac{(\delta_h+1/J)H}{\bar{L}}\right)^{\frac{\alpha_L}{1-\alpha_L}}$, which is simply a function of fixed parameters and the housing stock. As the latter does not change with a single quality the composition effect that impacted house prices in the baseline is shut down.

TABLE 7. The role of segmentation in a credit crunch

	Pre-Reform	**Post-Reform**	**Percentage Change**
Single quality housing			
Rent-to-Price	4.47 %	4.59 %	2.60 %
Average house price to income	5.12	5.12	0 %
Rent to Income	0.229	0.235	2.60 %
Homeownership rate	76.75 %	74.07 %	-2.68 p.p.
Share of households with 3 properties	6.82 %	7.15%	0.33 p.p.
Two different housing supply curves			
Rent-to-Price	4.58 %	4.73 %	3.42 %
Average house price to income	4.76	4.68	-1.68 %
Owner-occupied house price to income	4.93	4.85	-1.67 %
Buy-to-let house price to income	4.04	4.08	0.98 %
Rent to Income	0.218	0.222	1.68 %
Homeownership rate	81.56 %	78.83 %	-2.73 p.p.
Share of households with 3 properties	5.28 %	5.50%	0.22 p.p.

NOTE. This table shows the equilibrium prices and quantities for the pre-reform and post-reform economies in two different versions of the model: single housing quality (top block) and separate owner and rental-occupied housing markets (bottom block).

6.2. Two goods, two prices: separate markets for rental and owner-occupied houses

Alternatively, one can assume that owner-occupied and buy-to-let units are two completely separate goods, each produced by a different construction firm, and that, once produced, cannot be converted. For example, one could think of this model as one in which rental units are flats that cannot be bought as a primary residence and owner-occupied units are houses that cannot be rented out. In this example, it is also not possible to convert houses into flats or vice versa. A model like this one would also encompass the case in which there are areas of a city which are exclusively dedicated to owner-occupation and other areas which are exclusively dedicated to rentals.

We incorporate this idea by splitting the production of housing between two firms that only differ in their efficiency in production, A_h^j. This generates two different prices for each type of unit $\{p_h^{oo}, p_h^{btl}\}$. Through a suitable calibration we make sure that the average house price to income and the ratio of these two prices ($p_h^{oo}/p_h^{btl} = 1.21$) are in line with the data.

As shown in the bottom block of Table 7, rental prices rise in response to a contraction in credit through the same mechanism we have described. Interestingly, the raise in rental demand, which is responsible for the rise in rental prices, also increases the demand for buy-to-let units, leading to a 1% increase in their price in this version of the model. On the other hand, the demand for owner-occupied units decreases, which drives down their price by 1.7%, partially compensating the effect of the policy for potential first-time owners. This effect keeps the raise in rental demand more contained than in other versions of the model, and implies that rents only need to increase by 1.7% in terms of income. The rise in the average rent to price ratio in the economy is larger in this version because the reduction in the demand for owner-occupied units drives down their price by 1.7%, which in turn lowers the average house price in the post-reform economy.

6.3. The role of market segmentation in our results

Throughout the paper, we have emphasised the importance of our endogenous landlords in generating an upward sloping rental supply curve. Another important source of friction in accommodating shifts in rental demand is, of course, segmentation. This is shown, for example, in Greenwald and Guren (2025) and Kaplan, Mitman, and Violante (2020). Our simple model with only one housing good is an example of a model with no segmentation (see Section 6.1). All houses are identical and there is no primal reason why houses cannot frictionlessly move between the two markets. In this case, it is only our constrained landlords who are unable to frictionlessly accommodate the increase in renters that causes rents to rise. On the other hand, the extension discussed in Section 6.2 where rental and owner-occupied houses are two separate goods with distinct prices is a case of full segmentation. Therefore, there is no sense in which houses can move between markets. Our baseline results correspond to an intermediate case where the housing stock is divided into tiers serving different segments but housing can be converted across types. [19]

By comparing these three cases, we find that the degree of segmentation matters for how much of the change in the rent-to-price ratio goes through rents vs. house prices. Notably, in our no-segmentation case, all of the change goes through rents, while in the other cases there is a larger role for falls in house prices. Importantly, in all of the cases we consider, rents rise, which highlights that our key mechanism does not hinge on assumptions regarding the segmentation between housing and rental markets. It is more general. Additionally, under our parameterisation the effects on rents is much larger than on house prices, and generates stronger welfare effects (see Section 4.3.2).

[19] We discuss the issue of conversion costs below.

6.4. Conversion costs

Our main results have assumed that construction companies can costlessly convert between housing types when demand for different qualities change. This assumption matters solely for the transition, given that in the steady states the distribution of households over housing types is constant. In Appendix D.2, we explore the case in which conversion costs are set at a level such that the cost of converting is equivalent to half the cost of building a new small house from scratch. There, we show that while the presence of conversion costs raises the theoretically interesting possibility of divergence in the unit-price of each housing type, the overall effects on house prices is small, even if these costs are very high.

7. Conclusion

In this paper, we build an equilibrium model of the housing and rental markets in which households differ in their age, income and wealth as well as in their housing tenure status (renters, homeowners, or landlords). Endogenous landlord formation and lumpy housing allow us to generate an upward sloping rental supply curve, with empirically plausible elasticities, which is crucial to understand the effect of credit conditions on house and rental prices.

We show that contractionary credit shocks, such as the introduction of LTI and LTV limits or increases in the real interest rate, reduce house prices, increase rental rates and decrease homeownership rates. Price and rental changes are stronger in the short run, in which rental and housing supply are more inelastic. These changes negatively impact renters, who are typically younger and poorer, because they have to pay higher rents, slowing down their ability to build a deposit to apply for a mortgage in a market with already tighter limits. Landlords, who are less constrained, benefit because they can get cheaper houses and receive higher cash flows from their real estate businesses. These dynamics potentially exacerbated structural factors that have decreased the homeownership rates of the young (Paz-Pardo 2024).

Our paper highlights that rental markets are key to understand the equilibrium impacts and welfare effects of credit shocks, and provides a theoretical and quantitative framework to analyze shocks in which both house prices and rents can react endogenously and in potentially different directions. It also provides a microfoundation for why rental rates might react positively to a tightening in credit conditions such as a contractionary monetary policy shock.

These results open interesting avenues for future research. A broader framework with a rich financial sector could jointly evaluate the benefits of macroprudential policy coming from increased financial stability with the distributional costs imposed on households. Another interesting extension would consider spatial heterogeneity across different urban and rural areas, and the interaction of a credit shock in a context of accelerated urbanization and increased house price and rent inequalities.

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Online Appendix

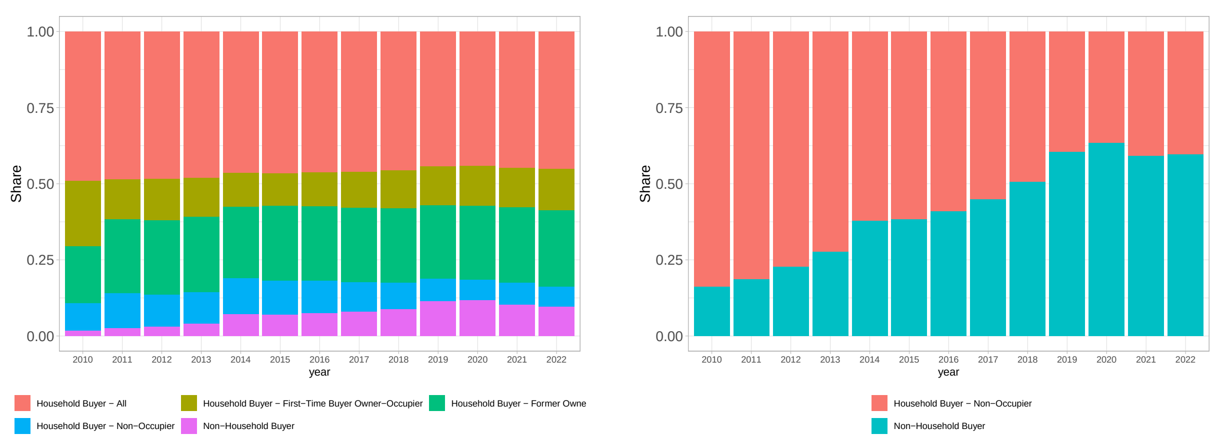
Appendix A. Additional empirical evidence

A.1. Irish rental sector

In our model economy we assume that the rental sector is populated by households that own one or two rental properties. Although, this assumption may seem restrictive, it is consistent with the Irish private rental sector.

In Figure A1, we use data from the Central Statistical Office (CSO) on residential property transactions to show that the vast majority of non-occupier property purchases correspond to household buyers. In fact, in 2015, the year when the macroprudential reform was introduced, around 70% of those transactions correspond to household buyers. Nonetheless, these data also confirms that the role of non-household buyers such as pension funds, private rental firms and Real Estate Investment Trusts (REITs) has increased over the last decade.

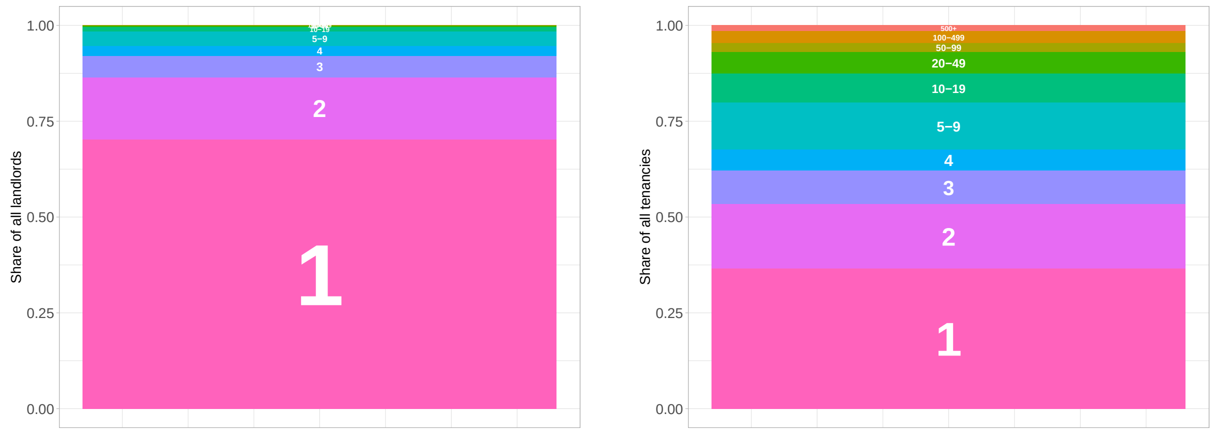
In Figure A2, we dig deeper into the ownership structure in the rental sector and use data from the Residential Tenancies Board (RTB) using RTB registrations as a proxy for ownership. Panel A shows the share of landlords by number of tenancies. Note that a tenancy is not fully analogous to a property as there may be some instances where



A. All properties B. All properties bought by non-owner-occupiers

FIGURE A1. Share of property transactions, by type of buyer and year

NOTE: This figure shows the share of all house sales by type of buyer and year in panel A. Panel B focus the attention in non-occupier buyers which are split into two categories: household buyers and non-household buyers. Data is available at the CSO.



A. Share of landlords by number of tenancies B. Share of all tenancies owned by landlords

FIGURE A2. Irish rental sector structure

NOTE: This figure shows the share of landlords by number of registered tenancies (panel A) as well as the share of tenancies owned by landlords with different number of registered tenancies (panel B). Data is from the RTB.

there are multiple tenancies in one property (e.g. a flat with multiple rented rooms). Nonetheless, the vast majority of tenancies are individual properties. With that in mind, the evidence on the RTB data points to a lesser role of large scale professional landlords as only 4.6% of tenancies are held by landlords with more than 100 units. On the other hand, the vast majority of landlords register a single rental property (70%) or at most two (86%). One gets a similar picture, if looks at the share of tenancies by landlords – panel B. In fact, landlords with one or two properties registered more than 50% of all tenancies.

Figure A1 and A2 are consistent with each other as the rise of institutional investors in Ireland is mostly concentrated in newly constructed, high quality and well located units, but not so relevant at the aggregate level (Ireland's Department of Finance 2019).

A.2. Macroprudential limits, house & rental prices

In this section, we describe the data used in our regression analysis, provide additional non-parametric evidence on the opposite response of house and rental prices to the introduction of macroprudential limits, and run some robustness test that verify such relationships.

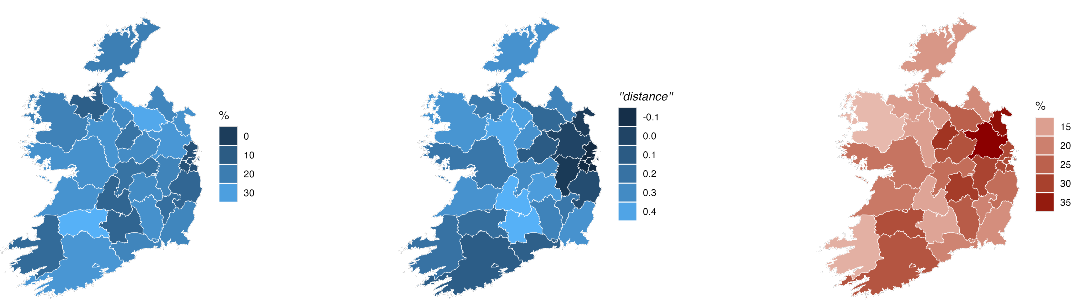
A.2.1. Data sources

The core of our final data set is the result of combining the distance measure with county-level selling and rental house prices. In our main specifications, we borrow the distance measure from Acharya et al. (2022). They construct this measure using loan-level information on residential mortgages. In particular, they "calculate what would have been the distance from the limits for each borrower in the year before the policy, assuming that the limits were in place during that period" (p. 12, Acharya et al., 2022). For confidential reasons, we got this information aggregated to the county level.

Data on house and rental prices comes from Daft.ie. We borrow these data from Lyons (2018) since in his website he has the aggregated time series for each Irish county of both selling and rental prices.

A.2.2. Non-parametric evidence

Figure A3 shows the variation in house price growth (panel A), the distance measure (panel B) and rental price growth (panel C) across all Irish counties. In low-distance counties, such as those areas around Dublin, house price growth was slower and close to zero, while rental prices were growing faster at a pace around 30-35%. This observation suggests that the distance measure is positively correlated with house price growth while it is negatively correlated with rental price growth. This statement was formally verified in our regression analysis in Section 4.2.



A. House price growth B. Distance measure C. Rental price growth

FIGURE A3. Counties, lending limits, house & rental price growth

NOTE. This figure shows the county-level distance from the limits (panel A), house price (panel B) and rental price (panel C) growth between the third quarter of 2014 and the fourth quarter of 2016. Data on prices comes from Daft.ie while the distance measure was provided by Mateo Crosignani and corresponds to the one in their paper: Acharya et al. (2022). Darker colors indicate less distant counties, lower house price growth and higher rental price growth.

Appendix B. Further model details

B.1. Solution method

The steady state solutions of the model consist of two main loops: an inner loop that solves the household problem given structural parameters and prices, and an outer loop that recovers the equilibrium distribution and prices. A description of the algorithms used for the approximation of the steady state equilibria can be found in Appendix B.1.1 and B.1.2. In addition to steady state equilibria, welfare comparisons also require to solve the transition from one steady state to another. The computational approach used to solve for such transition is described in Appendix B.1.3.

B.1.1. Household problem

As shown in Section 2.1, the household state variables are age, j, income, y, the housing state, $s = (h, \tilde{h})$, and net financial wealth, a. Consequently, the first step is to discretize the continuous state variables. Financial wealth lie on a non-linearly spaced grid with 150 points that includes 50 negative values and 100 positive ones, while the stochastic component of income is discretized using the approach in De Nardi, Fella, and Paz-Pardo (2020) that accounts for non-linearities and age-dependence. In particular, we allow for 7 points for the stochastic component of income whose values vary with the working age of the household.[20] The remaining state variables are already discrete. The model period is one year, households live up to 71 years, and the housing state can take 7 different values: *(i)* $s = (0, \tilde{h}_1)$ if renter, *(ii)* $s = (1, \tilde{h}_2)$ if small owner, *(iii)* $s = (1, \tilde{h}_3)$ if mid owner, *(iv)* $s = (1, \tilde{h}_4)$ if big owner, *(v)* $s = (2, \{\tilde{h}_1, \tilde{h}_3\})$ if mid landlord with one rented house, *(vi)* $s = (2, \{\tilde{h}_1, \tilde{h}_4\})$ if big landlord with one rented house or *(vi)* $s = (3, \{2 \times \tilde{h}_1, \tilde{h}_4\})$ if big landlord with two rented houses.

Since households die with certainty at age J, we know their optimal policy in their terminal period, so we can proceed by backward induction and compute the remaining age-dependent policy functions. Note that households make the standard consumption-savings choice, a', as well as decide on the next period housing tenure, s', at each age. Given that the housing choice is discrete, the solution of the household problem requires using computational techniques employed to solve discrete-continuous dynamic choice models. We follow closely the recipe from Fella (2014) and Iskhakov et al. (2017) to use

[20] The transition matrix that controls the evolution of household's income over time is also age-dependent and hence it is of dimension $7 \times 7 \times 41$ where 41 is the retirement age J^{ret}.

the endogenous grid method (EGM) together with taste shocks to solve for these discrete-choice specific policy and value functions. In a nutshell, for each $j < J$ we first compute the expected marginal utility to then invert the Euler equation and get the endogenous consumption-asset policy in a normal EGM step. After that, we apply the general EGM procedure to verify the global optimality of these choices in the non-concave region and discard those that are not. Finally, we use the obtained s'-dependent value and policy functions to compute the probability of the discrete choice using the Logit probability formula and the expected value function using the log-sum formula. These are stored and used in the next step of the backward induction. Once the backward induction is finished, the final outcomes of the algorithm are s'-dependent consumption-savings policy functions, a discrete choice probability and a value function.

B.1.2. General equilibrium

To compute the equilibrium in the housing and rental markets we proceed as follows:

1. Make a guess for the rental price, p_r^g, and the per unit house price p_h^g.

2. Use the per unit house price guess to analytically recover the quantity of housing produced in the construction sector using equilibrium relationship (12). Then, use the steady state version of the housing law of motion, equation (15), to obtain the level of housing stock implied by the construction firm's optimal choices given the per unit house price guess: H_s^g.

3. The implied price of land p_L can at this point also be recovered as it is an exponential function of the per-unit housing price p_h. Note that after substituting the housing investment function (12) into the first order condition with respect to land, one would get:

$$p_{L,t} = \alpha_L(1 - \alpha_L)^{\frac{1-\alpha_L}{\alpha_L}} \left(p_{h,t}A_h\right)^{\frac{1}{\alpha_L}}$$

4. Given rental and per-unit house price guesses $\left\{p_r^g, p_h^g\right\}$, compute the transacted house prices for each quality, $p^g(\tilde{h}_n) = h_n p_h$. Then, use the algorithm described in Appendix B.1.1 to get the value and policy functions that solve the household problem.

5. Using the household's consumption-saving policy and the discrete choice probability, recover the stationary distribution of households $\mathcal{D}(a, s, y, j)$ as it contains all the information needed for evaluating if the rental and housing market clear.

   a. Rental demand equals the share of households that choose to be renters:

$$R^d = \sum_{i_a=1}^{n_a} \sum_{i_y=1}^{n_y} \sum_{j=1}^{J} \mathcal{D}(a_{i_a}, s_1, y_{i_y}, j)$$

   b. Rental supply is given by the sum of landlords with one rented out property plus two times the share of landlords with two rented out properties:

$$R^s = \sum_{i_a=1}^{n_a} \sum_{i_s=5}^{6} \sum_{i_y=1}^{n_y} \sum_{j=1}^{J} \Big(\mathcal{D}(a_{i_a}, s_{i_s}, y_{i_y}, j)\Big) + 2 \times \sum_{i_a=1}^{n_a} \sum_{i_y=1}^{n_y} \sum_{j=1}^{J} \mathcal{D}(a_{i_a}, s_7, y_{i_y}, j)$$

   c. The aggregate housing stock from the demand side is a quality weighted (row vector) sum of the share of households who live in each type of home (column vector):

$$H_d^g = \begin{bmatrix} \tilde{h}_1 & \tilde{h}_2 & \tilde{h}_3 & \tilde{h}_4 & \tilde{h}_3 & \tilde{h}_4 & \tilde{h}_4 \end{bmatrix}_{1\times 7} \times \left[\sum_{i_a=1}^{n_a} \sum_{i_y=1}^{n_y} \sum_{j=1}^{J} \mathcal{D}(a_{i_a}, :, y_{i_y}, j) \right]_{7\times 1}$$

6. If $|R^d - R^s| < \varepsilon_r$ and $|H_s^g - H_d^s| < \varepsilon_h$, then we are done. Otherwise, we need to update the guesses and go back to step 2.

The final outcomes of this algorithm are: an equilibrium rental price, an equilibrium per-unit and average house price, an implied land price, the stationary distribution of households over their state space and optimal policy and value functions.

B.1.3. Transition dynamics

To compute the transition paths shown in Figures 6 and 8, we resort to the traditional approach that assumes that at time $t = 0$ the economy is initially in a steady state. Then, at $t = 1$ the policy reform is introduced as a surprise for households and maintained forever. Recall that in the macroprudential experiment the policy reform consists in introducing tighter LTV and LTI limits, so that λ_{LTV} and λ_{LTI} change while everything else remains untouched; while for the interest rate experiment, it is only the return on financial assets r_s and the mortgage rate r_b that increase in the new steady state. Note that for the transitory shock this new steady state is identical to the initial steady state, while the exogenous path of interest rates changes. In either case, the key idea is to assume that after T periods the transition from the old to the new steady state is completed. As a result, one can safely assume that policy and value functions at time $t = T$ are those from the new steady state. So that $c_T = c_{ss}^{new}$, $a_T = a_{ss}^{new}$ and $\mathbb{P}_T(s) = \mathbb{P}_{ss}^{new}(s)$.

For a given sequence of prices $\left\{ p_t^r,\ p_t(\tilde{h}_n) \right\}_{t=1}^{T}$, the previous insight allow us to solve the household problem backwards and obtain their policy functions at each point in time $\left\{c_t, a_t, \mathbb{P}_t(s)\right\}_{t=1}^{T}$. Knowing that $\mathcal{D}_0 = \mathcal{D}_1$, these are useful to iterate the distribution forward: $\mathcal{D}_{t+1} = \Gamma_t\left(\mathcal{D}_t\right)$ where Γ_t is the mapping obtained from the policy functions. Finally, using the sequence of household distributions over their state space $\{\mathcal{D}_t\}_{t=0}^{T}$ one can check if rental and housing markets clear at each point in time. If they do not, then the given sequence of prices needs to be updated until they do.

Thus, the most difficult aspect of the transition is to find suitable paths for rental and house prices. We approach this problem by first guessing different rental and housing price paths and evaluating ex-post which ones are closer to form an equilibrium sequence in housing and rental markets. These guesses are constructed parametrically by imposing an initial jump and a degree of curvature in its reversal to the new steady state level. Once we have a sense on how these equilibrium paths should look like, we follow a similar approach to that described in point 6 of the general equilibrium algorithm with the caveat that we now update the guesses based on the gaps between supply and demand along the entire path and not just based on one point in time.

B.2. LTI and LTV implementation in Ireland

As stated in Section 2.1, the borrower must satisfy two constraints. First, a loan-to-income (LTI) requirement that limits household's borrowing to a multiple, λ_{LTI}, of its current (annual) income. And second, a maximum loan-to-value (LTV) limit, which imposes that the size of the mortgage has to be smaller than a fraction of the value of the house.

When Central Banks establish these limits, they often include some exemptions based on the type of borrower or the type of property households purchase. For example, the Irish reform of 2015 imposed a LTI limit of 3.5 that only applied to First Time Buyers (FTBs). In the model, we identify FTBs with households that transition from renting into owning as there are very few (or even zero) households that after selling their primary residence become homeowners for a second time during their life-cycle. For all other borrowers, we let the pre-reform limit to apply as this was the LTI implicitly imposed by banks in absence of the Bank of Ireland macroprudential framework. Hence, formally, the LTI in the *post-reform* economy is

$$a' \geq -\lambda_{LTI}^{post}\; y \qquad \text{if} \quad h' = 1 > h \tag{A1}$$

$$a' \geq -\lambda_{LTI}^{pre}\; y \qquad \text{otherwise} \tag{A2}$$

Moreover, the reform also included some exceptions for the LTV limit based on the type of purchase. For example, buy-to-let buyers faced a more stringent 70% loan-to-value limit. We include this feature in the model by distinguishing between owner-occupied and buy to let purchases for which we let $\lambda_{LTV}^{oo} = 0.8$ and $\lambda_{LTV}^{btl} = 0.7$ to apply. In the model, it is easy to identify this purchases as households that own more than one property always lease it out. Hence, in the *post-reform* economy the LTV limit is given by

$$a' \geq -\lambda_{LTV}^{oo}\; p(\tilde{h}'_n) \qquad \text{if} \quad h' = 1, h = 0 \tag{A3}$$

$$a' \geq -\left(\lambda_{LTV}^{oo}\; p(\tilde{h}'_n) + \lambda_{LTV}^{btl}\; p(\tilde{h}'_1)\left(h' - 1\right)\right) \quad \text{if} \quad h' > 1 \geq h. \tag{A4}$$

B.3. Computing lifetime consumption equivalent variations

We evaluate the distributional effects of the reform through the traditional lifetime consumption equivalent variation (CEV) measure. This metric informs us about how much consumption (in percentage) needs to change in the pre-reform economy such that the households are indifferent between living in the pre-reform steady state and living through the transition induced by the policy reform. Formally, for a given set of state variables $x = (a, y, h, j)$, we compute the consumption equivalent variation $g(x)$ as

$$V_0(x; g) \equiv (1+g)^{1-\gamma} V_0(x) = V_1(x) \qquad \Rightarrow \qquad g(x) = \left[\frac{V_1(x)}{V_0(x)}\right]^{\frac{1}{1-\gamma}} - 1 \tag{A5}$$

where we are using the fact that the utility function is CRRA. From (A5) it is easy to realize that a negative value of $g(x)$ is associated with agents being worse-off by the introduction of the reform.

B.4. Estimation of the earnings process

Our earnings process is based on De Nardi, Fella, and Paz-Pardo (2020). Namely, we extract out the persistent and the transitory component of earnings using the procedure described in Arellano, Blundell, and Bonhomme (2017), and then incorporate the dynamics for the persistent component in a nonparametric way. Applying this procedure allows us to estimate earnings dynamics under flexible assumptions, and in particular incorporating potential age-dependence, non-normalities and non-linearities in earnings dynamics. The first element is of particular relevance for our question. Most households become homeowners when they are relatively young, still changing jobs and potentially subject to large fluctuations to their labour market income. A standard earnings process in which earnings are a random walk is a poor representation of the earnings risk faced by households at this particular age. Middle-aged households with stable jobs, instead, have much higher persistence, but significant negative skewness risk (e.g., through job loss). For a detailed description of the method and the economic implications of flexible earnings dynamics, see De Nardi, Fella, and Paz-Pardo (2020).

We use data from the Household Finance and Consumption Survey (HFCS) to extract the average age-earnings profile in the Irish economy after taking into account year effects. However, the triennial nature of the HFCS does not allow us to estimate an annual earnings process. Hence, for the stochastic component of the earnings process we use household earnings data for the United Kingdom from De Nardi, Fella, and Paz-Pardo (2024), who extract them from the BHPS/Understanding Society survey, and assume that the stochastic properties of household earnings are similar across both countries.

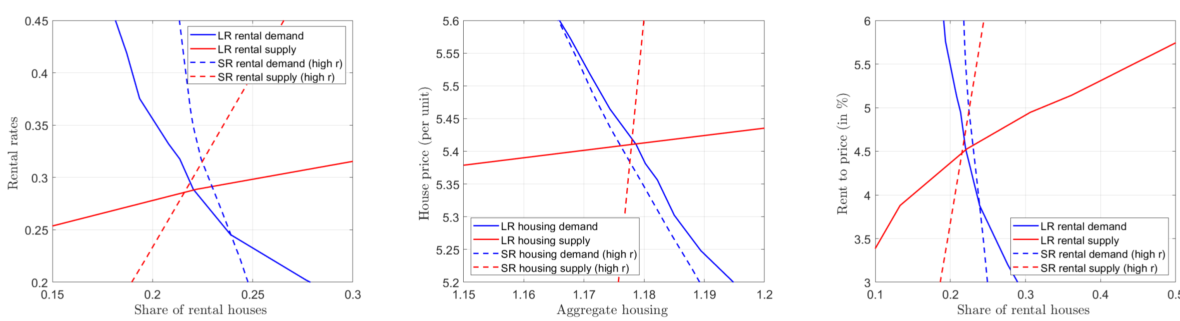
We have also estimated an annual earnings process for Ireland based on EU-SILC data (European Union Statistics on Income and Living Conditions), which, despite being nationally representative, is targeted to produce statistics on poverty and living conditions and hence might capture the earnings dynamics of the upper part of the income distribution in a more limited way. Our main results with this alternative earnings process are very similar.

Appendix C. Further model results

C.1. Supply-demand illustration over the transition path

The rental and house price responses to a credit tightening differs in the long and the short run as we describe in Sections 4.3 and 5. These differences are explained by a combination of factors that are embedded in the elasticities of rental and housing supply and demand.

Figure A4, as the transition counterpart of Figure 3, plots the supply and demand shifts in the period immediately after a temporary interest rate shock hits the economy. The key intuition from the supply and demand illustration when comparing steady states still holds and we see that as a result of the credit tightening there is an equilibrium in $t = 1$ that features higher rental prices (panel A), lower house prices (panel B) and higher rent-to-price ratio (panel C). However, the slope of the supply and demand curves both for rental and owner-occupied housing differs substantially. In particular, supply curves become much more inelastic in the short run. In the housing market, this is explained by the slow adjustment of the aggregate housing stock, which requires large short-run house price movements to induce the necessary adjustments in housing construction to clear this market (middle panel). In the rental market, it is the presence of fixed costs to become a landlord – arising from housing transaction costs and indivisibilities – which limits the responsiveness of rental supply in the very short run (left panel),



A. Rents B. House prices C. Rent-to-price ratio

FIGURE A4. Supply and demand in the rental and housing markets, baseline model

NOTE. This figures show the main mechanisms of the model through a supply and demand illustration. The demand and supply curves are computed numerically using a suitable parameterization of the model economy, and varying rental prices in the period after the shock hits while keeping house prices at their optimal transition path (panels A and C) and varying house prices after the shock hits (i.e. in $t = 1$) while rents stay at their optimal path (panel B).

relative to the medium run since households need time to adjust their saving decisions to overcome these barriers. As a result, both house prices and rents respond sharply to the credit tightening in the short run.

C.2. Interaction between mortgage credit limits

Loan to Value (LTV) and Loan to Income (LTI) limits are often introduced jointly, as it was the case for Ireland. However, there are some other countries, such as the United Kingdom that have only an LTI limit in place. To understand the contribution of each of them to the overall quantity and price effects of the reform, we compute two counterfactual economies: *(i)* the *Only LTI* economy which imposes the institutional 3.5 LTI limit but leaves the LTV unchanged, and *(ii)* the *Only LTV* economy which imposes the institutional 80% LTV limit but leaves the LTI unaltered.

TABLE A1. Non-linear interactions between credit limits

	Full-Reform	**Only LTI**	**Only LTV**
Δ% Rent-to-Price	+2.45 %	+2.46 %	+0.3 %
Δ% Rent-to-Income	+2.58 %	+2.48 %	+0.56 %
Δ% Price-to-Income	+0.13 %	+0.02 %	+0.23 %
Δ Homeownership rate	-3.18 p.p	-2.83 p.p.	-1.45 p.p.

NOTE. This table shows the effects of the reform on the rent to house price rate and home-ownership rate (first column) and decomposes the role of each limit by imposing one at a time. A tighter LTI (second column) has a larger effect than the tighter LTV (third column) if they are introduced on their own.

Table A1 shows the change relative to the *pre-reform* economy in the rent-to-price ratio as well as the homeownership rate after imposing both (full-reform) or one of these two limits. Results show that the LTI alone had a larger effect than the LTV, with a rise in the rent-to-price ratio similar to the full reform. The fall in the homeownership rate was also more pronounced in the counterfactual economy with only tighter LTI limits. Nonetheless, there are some interactions between LTV and LTI limits which shows here in the form of a larger drop in the homeownership rate for the full reform.[21] It is important to note, however, that these results are specific to our case study. In fact, the LTI introduced in Ireland was quite stringent relative to those introduced in other

[21] Other research has shown how these interactions can also affect the dynamics of house prices and mortgage debt when the economy is hit by a technology or monetary policy shock (Greenwald 2018, Castellanos, Millard, and Varadi 2025).

countries (e.g. in the UK the LTI limit is 4.5). Consequently, it bind for many prospective buyers, leading to strong effects even if it would have been imposed just in isolation.

C.3. Interactions between interest rate shocks and the tightness of credit limits

To understand how borrower based macroprudential limits interact with other shocks, we study the long and short run effects of our interest rate experiment under two credit regimes: *(a)* a *loose credit* regime in which LTV and LTI limits correspond to those prevailing in Ireland before the 2015 reform, and *(b)* a *tight credit* regime in which institutional limits are imposed.

Long run effects. Table A2 shows the long run effects of a 20 basis points permanent increase in the real interest rate before and after having imposed the institutional limits introduced in 2015. It indicates that the fall in the average house price and the homeownership rate is weaker when credit limits are more stringent, while rental rates continue to rise by similar magnitude. The later could be explained because the marginal landlord that drives the rental price response is likely to be unconstrained by those stringer limits, and hence reacts similarly to the real interest rate shock.

TABLE A2. A permanent increase in the real interest rate under two credit regimes

	Loose Credit (Pre-reform)	**Tight Credit (Post-reform)**
Δ Rent-to-Price	+10 bps	+10 bps
Δ%Average house price to income	-0.61 %	-0.4 %
Δ% Rent to Income	+1.44 %	+1.5 %
ΔHomeownership rate	-0.48 p.p	-0.3 p.p.

NOTE. This table shows the long-run effects of a 20 bps permanent increase in the real interest rate for two economies: *(i) loose credit* in which LTV and LTI limits correspond to the pre-reform economy, and *(ii) tight credit* in which institutional LTV and LTI limits are imposed and hence credit conditions are equivalent to those in the post-reform economy.

Short run effects. Figure A5 depicts the response of rental and house prices in deviations from steady state after the pre-reform (loose credit) and post-reform (tight credit) economies are shocked with a 100 basis points transitory shock, modeled as an AR(1) with 0.10 annual persistence. Similarly to the long run effects explained just above, the tighter credit conditions weaken the response of house prices to the shock. However, the two economies display a very similar response in rental prices. This again highlights that the marginal landlord is not effectively impacted by the credit tightness as rental prices need to temporarily rise by a similar amount in both economies.

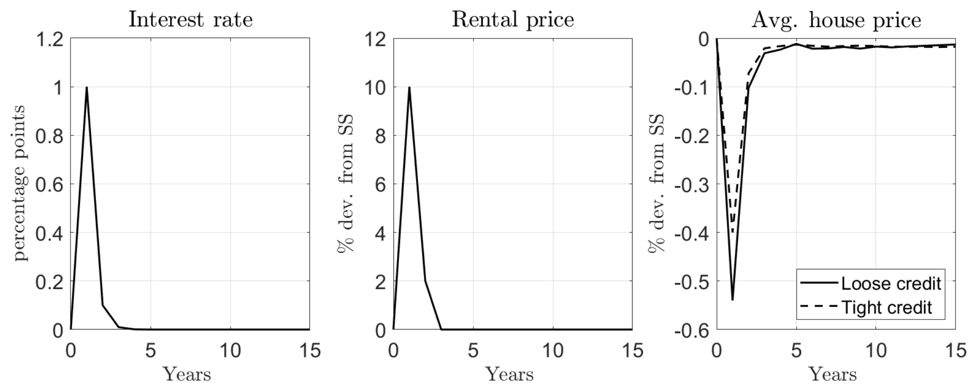


FIGURE A5. A temporary increase in the real interest rate under two credit regimes

NOTE. This figure shows the evolution of the interest rate, the rental price and the average house price after the pre-reform (solid line) and post-reform (dashed line) economies are shocked with a transitory increase in the real interest rate.

Implications. These two exercises highlight that macroprudential policies are effective in moderating house price cycles, consistent with the consensus in policy spheres. Hence, the model is still able to showcase some of the benefits associated to borrower based measures although it lacks its benefits associated to weakening aggregate demand externalities and reducing households' defaults. As a result, we do not investigate further what would be the optimal LTI/LTVs ratios that insure borrowers against the negative impacts of the shock.

Appendix D. A Model with Conversion Costs

The model in the main body of the paper takes costlesss conversion between housing types as its baseline assumption while Section 6.2 takes the opposite extreme by assuming housing types are totally different goods with different production functions and, therefore, no conversion between types. Here, we lay out a simple, micro-founded yet tractable way to introduce conversion costs into the model. We find that, even at relatively large assumed conversion costs, the transition dynamics are broadly similar to those we report in our main experiment.

D.1. Arbitrage and housing conversion with construction input

Suppose the existence of an arbitrageur who is able to buy, convert, and sell different housing types. We suppose an arbitrageur who is able to take advantage of the need to refurbish many houses at once and so, unlike a household, is able to repackage a measure of the housing stock into houses of different quality types. In our economy we have n housing types indexed by $i = 1, \dots, n$, ordered by quality $\tilde{h}_1 > \tilde{h}_2 > \cdots > \tilde{h}_n > 0$, with the price of a whole type-i house is p_i^h. In the frictionless benchmark with perfectly convertible housing types, no-arbitrage equalizes price per unit of quality (we could think of this as price per square meter), i.e.

$$\text{(A6)} \qquad \frac{p_i^h}{\tilde{h}_i} = \frac{p_j^h}{\tilde{h}_j} \quad \text{for all } i, j \qquad \Longleftrightarrow \qquad p_i^h = \frac{\tilde{h}_i}{\tilde{h}_j} p_j^h.$$

We will now consider the possibility of conversion costs. We suppose that to convert a measure of housing x_{ij} from type-i to type-j, the arbitrageur must buy inputs from the construction sector. Specifically, let $\xi_{ij}(x_{ij})$ be the quantity of intermediate input required for the $i \to j$ conversions. The arbitrageur purchases these inputs at the prevailing cost of construction sector output p^h. Let $B_i \geq 0$ be the number of type-i houses *bought*; $S_i \geq 0$ be the number of type-i houses *sold*. Since the arbitrageur is merely repackaging the existing housing stock into different housing types, they face a feasibility constraint given by

$$\text{(A7)} \qquad g_i(S, B, x): \ \tilde{h}_i S_i - \tilde{h}_i B_i + \sum_{j \neq i} \tilde{h}_i x_{ij} - \sum_{j \neq i} \tilde{h}_j x_{ji} \ \leq \ 0, \qquad i = 1, \dots, n.$$

This says that the quality-weighted number of houses of type-i sold is less than or equal to the number of houses of type-i bought less the number of type-i converted into other types plus the number of other types converted into type-i.

Problem. The arbitrageur is risk neutral and solves

$$\text{(A8)} \quad \max_{B,S,x\geq 0} \pi = \sum_{i=1}^{n} p_i^h(S_i - B_i) - p^h \sum_{i \neq j} \xi_{ij}(x_{ij}) \quad \text{s.t.} \quad g_i(S, B, x) \leq 0 \; (i = 1, \dots, n).$$

Let $\mu_i \geq 0$ be the multipliers on (A7).

FOC for trades. The Lagrangian is $\mathcal{L} = \sum_i p_i^h(S_i - B_i) - p^h \sum_{i \neq j} \xi_{ij}(x_{ij}) - \sum_i \mu_i g_i$. FOCs with respect to S_i and B_i give

$$\text{(A9)} \qquad p_i^h - \mu_i \tilde{h}_i = 0 \;\; (\text{if } S_i > 0)$$

$$\text{(A10)} \qquad -p_i^h + \mu_i \tilde{h}_i = 0 \;\; (\text{if } B_i > 0) \;\Rightarrow\; \mu_i = \frac{p_i^h}{\tilde{h}_i} \quad \text{(whenever trades clear balances).}$$

Thus μ_i is the shadow value *per unit of housing* of type i.

FOC for conversion flows. For each $i \neq j$,

$$\text{(A11)} \qquad \partial_{x_{ij}} \mathcal{L} : -p^h \xi'_{ij}(x_{ij}) - \mu_i \tilde{h}_i + \mu_j \tilde{h}_i \begin{cases} = 0 & \text{if } x_{ij} > 0, \\ \leq 0 & \text{if } x_{ij} = 0. \end{cases}$$

Substitute (A9) to obtain the pairwise no-arbitrage condition :

$$\text{(A12)} \qquad p_i^h \geq \frac{\tilde{h}_i}{\tilde{h}_j} p_j^h - p^h \xi'_{ij}(x_{ij}), \qquad \text{with equality if } x_{ij} > 0.$$

Importantly, in spite of potential arbitrage gains (i.e.: when $\Delta_{ij} := \frac{\tilde{h}_i}{\tilde{h}_j} p_j^h - p_i^h \neq 0$), it is possible that the presence of conversion costs may mean there is a region where it is not worth the arbitrageur converting housing types. In this case, the stock of that housing type would essentially be fixed and we would need to search for the price that lead to demand equaling this fixed supply. For this reason, it is useful to restrict ourselves to cases where ξ is smooth and differentiable for all $x_{ij} > 0$ and that $\xi'_{ij}(0) = 0$. This has the spirit of an Inada condition and is present simply to avoid this corner solution. With this condition in hand, we can be sure that the arbitrageurs will always exploit price differences and ensure that a demanded change in composition of the housing stock will be met.

Example: Three Housing Types. With $n = 3$ the six directed links satisfy

$$p_1^h \geq \frac{\tilde{h}_1}{\tilde{h}_2} p_2^h - p^h \xi_{12}'(x_{12}), \qquad p_1^h \geq \frac{\tilde{h}_1}{\tilde{h}_3} p_3^h - p^h \xi_{13}'(x_{13}), \tag{A13}$$

$$p_2^h \geq \frac{\tilde{h}_2}{\tilde{h}_1} p_1^h - p^h \xi_{21}'(x_{21}), \qquad p_2^h \geq \frac{\tilde{h}_2}{\tilde{h}_3} p_3^h - p^h \xi_{23}'(x_{23}), \tag{A14}$$

$$p_3^h \geq \frac{\tilde{h}_3}{\tilde{h}_1} p_1^h - p^h \xi_{31}'(x_{31}), \qquad p_3^h \geq \frac{\tilde{h}_3}{\tilde{h}_2} p_2^h - p^h \xi_{32}'(x_{32}), \tag{A15}$$

with equality on active links. Along an active chain $i \to j \to k$, costs add with the appropriate size scaling via (A12).

Quadratic conversion costs. Suppose the input requirement itself is quadratic, $\xi_{ij}(x) = \frac{1}{2}kx^2$ with $k > 0$. Then conversion cost is $p^h \xi_{ij}(x)$ and the marginal cost entering (A12) is $p^h \xi_{ij}'(x) = p^h kx$. Because $\xi_{ij}'(0) = 0$, any strictly positive wedge Δ_{ij} induces the flow $x_{ij} = \Delta_{ij}/(p^h k)$ and satisfies

$$p_i^h = \frac{\tilde{h}_i}{\tilde{h}_j} p_j^h - p^h k x_{ij}. \tag{A16}$$

The above equations define house price gaps but are silent on the actual level. To close the model, we assume that the flow of new construction can be installed as any of the housing types. As such, the construction company will always sell its output as the most expensive housing type k. Perfect competition in the construction sector will then ensure that the per-unit price of type k will equal the price of construction sector output such that $p_n^h/\tilde{h}_n = p_h$. All other prices are then set relative to this anchor.

D.2. Robustness to Conversion Costs

To illustrate the limited impact conversion costs have in our particular setup, we take a value of conversion costs that is at what we consider to be the upper bound of plausible such that cost of converting big houses into smaller houses is half the cost of building a new small house from scratch. Figure A6 shows the result. The middle panel shows

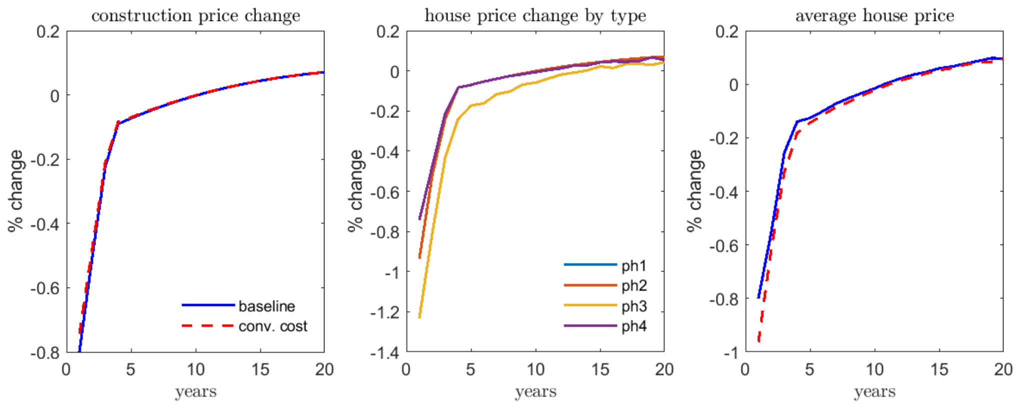


FIGURE A6. Baseline vs. Conversion Costs

NOTE: This figure compares the baseline transition with a version of the model with very high conversion costs.

the theoretical possibility of price dispersion between the houses that are relatively in demand vs those being moved away from. Despite this, the other two panels show that both the unit price is only very slightly higher (reflecting the fac that the construction sector must now support conversions) while the average house price drops by 0.1p.p. more on impact (reflecting the fact that the housing being moved away from drop my more than the unit price, pulling down the average).

The reason for this small impact is that, ultimately, the required number of conversions is low due to the fact that there is a flow of new housing being built and that these can be installed as any of the housing types - namely the ones subject to an increase in demand.