Monetary Transmission in a HANK Model with Housing and Rental Sectors*

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May 28, 2026

Abstract

This paper develops a Heterogeneous Agent New Keynesian (HANK) model with housing and individual landlords to examine how monetary policy affects housing and rental markets. Using new UK evidence we document that contractionary monetary policy generates a large, hump-shaped, decline in house prices, while rental prices remain flat. We match the model to micro and macro data, showing that behavioural frictions combined with departures from a RANK framework are key for generating these price dynamics. The results reveal that landlords largely fail to pass through higher interest rates to rents. However, this incomplete pass-through reduces the output-inflation trade-off facing inflation-targeting central banks.

Keywords: Monetary policy, Housing, Heterogeneous agents
JEL Codes: E52, R21, D31, E21

*We are grateful to Klaus Adam, Bence Bardóczy, Lukasz Rachel, Morten Ravn, Ricardo Reis, Sanjay R Singh, Vincent Sterk and fellow BoE researchers for useful comments and suggestions. We are also grateful for excellent research assistance and technical contributions from William Du during his PhD Internship. The views expressed in this paper are those of the authors and do not necessarily represent those of the Bank of England or any of its committees. A previous version of this paper was circulated under the title of "Monetary Transmission Through the Housing Sector".

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1 Introduction

The rise in interest rates and housing rental prices across several countries in the 2020s drew renewed scrutiny both to the role of monetary policy in shaping housing market outcomes, and to the housing and rental markets' role in monetary transmission. Housing can matter for understanding the aggregate and distributional implications of monetary policy since housing tenure is correlated with, or determines, households marginal propensities to consume (MPC) and ability to borrow. Renters in particular tend to hold less liquid wealth and be more financially constrained, making rental price dynamics and rental market adjustment a potentially important concern for monetary policy.

To study this we develop a rich Heterogeneous Agent New Keynesian (HANK) model with housing and individual landlords. We emphasise three ingredients as important for the modelling and understanding of the transmission of monetary policy through the housing and rental sector: a HANK model with discrete housing tenure choice; behavioural expectations; and the endogenous supply of rental units by individual landlords. In our baseline model, heterogeneity combined with discrete housing choice supports real rental prices after a monetary policy shock; behavioural expectations imply that the peak fall in house prices is not on impact; and individual landlords that are credit-constrained and have sluggish expectations partially absorb the monetary tightening rather than pass on higher interest rates to rental prices. This incomplete pass-through has a first-order policy implication: relative to a counterfactual in which rental prices are set by an unconstrained commercial sector with rational expectations, this approximately halves the output sacrifice needed to stabilise inflation, and reduces the distributional consequences by narrowing the gap in consumption responses between renters and other households.

The paper makes three main contributions. First, we extend the empirical evidence on monetary transmission to the UK where individual landlords dominate private rental markets. We estimate a Proxy Structural Vector Autoregression (SVAR) with high frequency identification on UK data, documenting hump-shaped house price dynamics and a delayed rental response. Second, we build a HANK model with private individual landlords, discrete tenure choice, long term mortgages with realistic LTV and LTI constraints binding at origination, partial segmentation between owner-occupied and rental markets, and behavioural expectations, calibrated to match the relevant microeconomic and macroeconomic evidence. Third, we use a set of counterfactual exercises to isolate the contribution of each ingredient to both the model's empirical fit as well as its implications for monetary policy.

The empirical results show that aggregate nominal house prices react strongly to monetary policy, but rents do not. Following a 1 p.p. rise in interest rates, nominal house prices fall by 6% after 16 months in a hump-shaped profile. In contrast, rental prices are stable for 1.5 to 2 years and then start falling. Importantly, these patterns are replicated across regions, dwelling types, and sample periods, suggesting a robust macroeconomic response of prices that is consistent across the housing distribution. We also find that activity in the housing market declines sharply, with sales falling by more than 20% after 6 months, and the stock of unsold houses for sale up by almost 20%.

Next, our model combines the basic New Keynesian features present in HANK frameworks (e.g., Oh and Reis, 2012; McKay et al., 2016; McKay and Reis, 2016; Kaplan et al., 2018) with a detailed model of housing and rental markets within a heterogenous agents setting as in Kaplan et al. (2020), and deviations from full-information rational expectations as in Auclert et al. (2020). Moreover, we also model individual landlords. To the best of our knowledge, this is the first framework to combine all these features in a HANK model. We calibrate our model to the UK economy, and also estimate selected dynamic parameters to match the IRFs of monetary policy shocks. Methodologically, we both extend the sequence-space Jacobian framework of Auclert et al. (2021) to combine sticky and extrapolative expectations, and adapt the discrete choice endogenous gridpoint method of Iskhakov et al. (2017) to handle tenure transitions, building on Bardóczy and Guerreiro (2025).

Three features of the model standout as important in matching the qualitative and quantitive properties of the data. First, building on Kohlhas and Walther (2021) we combine sticky and extrapolative expectations – agents adjust their expectations infrequently and, when they do, simultaneously extrapolate from recent realisations – and show that this combination delivers the closest fit to the data, in particular, the joint movement of rental and house prices. This deviation from rational expectations attenuates household responses to expected future capital gains and losses, which steepens the demand and supply elasticities of the housing market with respect to current house prices. As a result, smaller movements in house prices suffice to clear the market following a rise in interest rates. This delays the peak fall in house prices, which is on impact under rational expectations. This delayed response in turn helps push up on rental prices through expected capital losses and higher rental demand, though by less than if the hump was fully internalised.

Second, the modelling of housing tenure as a discrete choice, which necessitates the introduction of some form of heterogeneity, allows (but does not guarantee) real rental prices to increase following a contractionary monetary policy shock. As we show in section 4.3, in the simplest RANK model real rental prices fall after an increase in interest rates (since the marginal utility of non-housing consumption increases by more than that of housing consumption), which is not in line with the empirical evidence we present.[1]

Third, modelling the supply side of the rental markets as individual landlords with behavioural expectations, instead of a deep-pocketed commercial rental sector with rational expectations, delivers the flat response of nominal rental prices and increase in real rental prices that we observe in the data. Two mechanisms are key for this: (i) behavioural expectations imply that landlords do not fully internalise the expected capital gain losses they are due to make in investment properties, which means they fail to put enough upward pressure on rents to make up for it; (ii) even the financial losses they do anticipate are not fully acted upon due to real and financial frictions in engaging in property transactions. Under alternative specifications,

[1] We do not claim that moving all the way to a HANK setting is necessary to achieve this, but we choose to do so because: the existing quantitative tools allow it; it is the frontier framework for the analysis of the transmission channels of monetary policy; and it allows for endogenous switching between housing tenure types.

rental prices increase by too much relative to the data.

The main takeaway of our analysis for monetary policy is the importance of the interaction between the housing sector and heterogeneity. Endogenous housing tenure choices give rise to a large dispersion in MPCs: landlords and outright owners respond the least to transitory income shocks, followed by mortgagors which are in line with the average MPC in the economy. Renters have low liquid and illiquid wealth and little borrowing capacity, thus they respond the most. This emphasises the importance of rental prices as determinants of movements in consumption, indeed, movements in house prices and rents jointly account for roughly a quarter of the peak consumption response in general equilibrium. Moreover, even though landlords have a low MPC, their consumption response to a monetary policy shock is larger than that of outright owners and in line with those of mortgagors and renters. This is because their disposable income reacts heavily to interest rate movements, since their mortgage rates increase but they don't pass this through to higher rents. Therefore, even though landlords are wealthier than outright owners and have low MPCs, strikingly, they are relative losers after an increase in interest rates.

We also highlight optimal monetary policy implications under our setting. In a counterfactual scenario with a commercial rental sector where rents increase, the resulting fall in consumption by renters (amplified by their higher MPC) approximately doubles the sacrifice ratio between output and inflation compared to our baseline. This occurs somewhat mechanically when considering a CPI index including rental prices but also occurs when considering a CPI index that excludes rents. Thus, individual landlords absorb the increase in interest rates. This lowers the implied output sacrifice ratio, which has optimal monetary policy implications; and dampens the distributional impact, by reducing the heterogeneity in consumption responses following the rise in interest rates.

Finally, we also discuss several extensions emphasised by the housing literature: endogenous housing supply through housing investment; a segmented rental market; mortgages with sticky rates; and a simple search and matching friction that makes finding a buyer uncertain. All these extensions push up on house prices relative to the baseline, and these higher prices spill over into excess demand in the rental market and higher rental prices. Under rational expectations, introducing sticky mortgage rates or endogenous housing supply is enough to raise rental prices following an interest rate rise. However, the peak fall on house prices continues to be on impact.

1.1 Related literature

There are a number of empirical studies that mostly find that house prices fall by a large magnitude following an increase in interest rates.[2] However, evidence for the response of rents to a monetary policy shock is more scarce and mixed. Dias and Duarte (2019), Albuquerque et al. (2024), and Abramson et al. (2025) find that housing rents (nominal and real) increase in the US, and Corsetti et al. (2022) finds the same for European countries. However, Koeniger et al. (2022) finds mixed effects in housing markets in Germany, Italy and Switzerland. Cloyne

[2]See Duca et al. (2021) and Ehrenbergerova et al. (2023) for comprehensive reviews.

et al. (2020) study the response of households in the UK and US and find households reported rises in rental payments following interest rate cuts. With respect to housing tenure, most studies find that a contractionary monetary policy shock increases the share of renters and/or decreases the homeownership rate (Dias and Duarte, 2019; Corsetti et al., 2022; Koeniger et al., 2022; Albuquerque et al., 2024). We complement this body of literature with comprehensive results on prices and quantities in the housing and rental market for the United Kingdom, its sub-regions, and different house types.[3]

The papers most closely related to ours are those that include a housing sector in a macroeconomic model with heterogeneity. Kaplan et al. (2020) highlight the importance of households' beliefs about housing variables in determining outcomes not only in the housing sector, but also its spillovers into overall consumption. While we do not explore exogenous changes in beliefs, we show that expectations are key for understanding the behaviour of house prices and rents, and that deviations from full-information rational expectations (FIRE) are necessary to match the data. We review the literature on the theory and evidence on departures from rational expectations for housing and non-housing variables in more detail in Section 3.3. Kaplan et al. (2020), Dias and Duarte (2022), and Greenwald and Guren (2025) all highlight the importance of modelling homeowner and rental markets jointly, since having the option of selling housing and becoming a renter can mitigate the effect of shocks to housing variables. We allow for partially segmented housing markets and explore an extension with full segmentation where our model predicts similar effects to Dias and Duarte (2022). Our model is also similar to Sommer et al. (2013), who analyse the joint determination of housing and rental prices in a model with individual landlords and heterogeneity,[4] and highlight the importance of endogenous rental supply in determining housing market responses. However, while they study the evolution over longer time spans in response to changing fundamentals like down payment requirements or steady state interest rates, we focus on short-run monetary policy effects.

Furthermore, Eichenbaum et al. (2022), Hedlund et al. (2025), and Kinnerud (2025) highlight the importance of long-term and flexible-rate mortgages for monetary policy transmission. We also model long-term mortgages, albeit with variable rates, in which borrowing constraints only bind on origination. Relative to those papers, our model is embedded in a more general HANK framework where we study in more detail the general equilibrium channels, including through the rental market.

Heterogeneous agent models are now regularly embedded into the New Keynesian framework, e.g., Kaplan et al. (2018) and Auclert et al. (2020). Our contribution is to embed this rich modelling of housing, individual landlords and rental markets into a HANK framework to study monetary transmission. This is important as, empirically, Slacalek et al. (2020) find housing to be a large channel of monetary policy. Even though some HANK models feature illiquid assets that include housing in their motivation, nearly all do not explicitly model housing or

[3]We find a smaller degree of variation in sub-markets in the UK than, e.g., Aastveit and Anundsen (2022) do for the US. However, it is important to notice that they find that this is related to local supply elasticities only in the case of expansionary monetary policy shocks.

[4]Castellanos et al. (2024) also model private individual landlords, to analyse the impact of credit shocks on the housing and rental markets.

the large gross secured debt positions associated with housing. Moreover, even HANK models that include housing or an illiquid asset usually do not feature, or do not try to match, the response of house prices and rents to monetary policy.

Finally, an empirical literature has found support for the channels and outcomes highlighted by our model, but which are not present in most HANK models. We find that outright owners are those that respond the least to a monetary policy shock, in line with Cloyne et al. (2020). More broadly, household balance sheet heterogeneity in the UK marginal propensity to consume is documented in survey data by Albuquerque and Green (2023). The mortgage cash-flow channel is consistent with US evidence in Di Maggio et al. (2017), while Cloyne and Surico (2017) find similar patterns across fiscal shocks.

2 Empirical evidence

This section summarises our empirical evidence on the impact of monetary policy on the housing sector. We estimate a proxy SVAR model in the vein of Mertens and Ravn (2013) and Stock and Watson (2018). The baseline VAR contains seven variables: (i) Bank Rate, (ii) seasonally adjusted Consumer Price Index (CPI) core excluding rents, (iii) seasonally adjusted monthly GDP, (iv) the seasonally adjusted House Price Index for the United Kingdom (UK) from the Office for National Statistics (ONS), (v) a seasonally adjusted measure for rents which we detail below, (vi) the real level of the FTSE 100, and (vii) the spread between the rate on 75% LTV mortgages and the 2 year yield. Our measure of aggregate housing rents is based on the Index of Private Housing Rental Prices from the ONS. We choose this index even though it covers England, not the whole of the UK, due to its longer sample. Still, it is only available post 2005 thus we splice it with the Owner Occupiers' Housing Costs (OOH) component of the UK CPI Index.[5] In the results throughout the paper, we always add extra variables one at a time to the original SVAR with seven variables to get the response of new variables (e.g., the SVAR that includes the sales volume has eight variables).

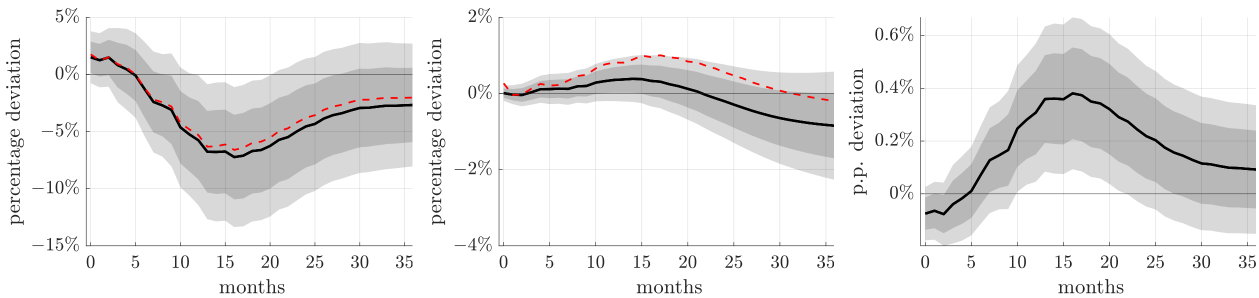
The variables included are standard for VARs for the UK (e.g., Cesa-Bianchi et al., 2020; Braun et al., 2024), with two deviations. First, we include the mortgage spread instead of a corporate spread given our focus on the housing market. Second, the model developed in the next section features non-housing consumption and housing consumption separately. For a better match between the model and data, we then construct a measure of CPI core inflation clean of all housing expenditures by excluding the "Actual Rents for Housing" component. The monthly VAR is estimated over the 1997-2023 period, with 12 lags. Because our sample includes the Covid pandemic, we include dummies to deal with it (Cascaldi-Garcia, 2022).

[5]Both indices take into account all rental contracts, not just new ones. Figure A.2 shows that the baseline results hold for the post 2005 sample and Figure A.3 shows that the IRF of CPI OOH estimated from 2005-2023 is similar to that of the ONS Index of Private Housing Rental Prices (shown in Panel (D) of Figure A.2) in the period that both series overlap. CPI OOH is a good proxy because it uses private rents to impute housing costs for home owners. There is another component of CPI in the UK that corresponds to "Actual Rents for Housing", which we exclude from CPI core in the baseline VAR, but this component includes social housing as well as private rents, so we choose CPI OOH instead.

With a relatively conservative approach, we include dummies for each month of the duration of the Coronavirus Job Retention Scheme in the United Kingdom, covering March 2020 to July 2021. Finally, to identify the impact of monetary policy we use the target factor estimated for the UK by Braun et al. (2024), which moves the short end of the yield curve.

Our main results for house prices and rents are shown in Figure 1, while in Figure A.1 we show the results for all the variables. In Appendix B we report the results for different combinations of variables and instruments, and show that the main results in Figure 1 are robust to different specifications. We also show that our main results are robust across different time samples, including pre-Covid, in Figure A.2. Overall, Figure A.1 reports that after a 100 basis point innovation to the policy rate we observe the expected effects: the CPI displays a prolonged fall, and GDP exhibits a hump-shaped response with a peak fall around 18 months.

2.1 House prices and rents



(A) House prices (B) Housing rents (C) Rent-to-price ratio

Figure 1: House prices, rents, and their ratio: response to a 1p.p. Bank Rate shock

Notes: this figure shows the response of the ONS House Price Index in the UK to a transitory monetary policy shock in Panel (A); and of the ONS Index of Private Housing Rental Prices for England, spliced with UK CPI's "Owner Occupied Housing" component, in Panel (B). Panel (C) shows the response of the rent-to-price ratio, where we substitute the rent variable in the main VAR with this ratio. The rent-to-price ratio was normalised by its average of 5.03% from 2015 to 2023 (see footnote 7 for details). Solid black lines show the response of nominal indices, while dashed red lines are real variables (i.e., the response of the nominal variable minus that of CPI core ex-rents). Grey shaded areas indicate 68 and 90% confidence intervals. Confidence intervals are calculated using a residual-based moving block bootstrap. First stage F-Statistic: 46.6

We now turn to our main variables of interest, the response of house prices and rents to a transitory monetary policy shock, shown in Figure 1. Nominal house prices exhibit a hump-shaped response, falling gradually to around -6% after one year and then reverting to its pre-shock level. The response of rents contrasts to that of house prices. Instead of falling, nominal rents are either stable or slightly above their original level for about two years, before falling. When we look at the response of relative (real) prices the contrast is even starker: relative house prices still clearly fall, but relative rental prices are higher for the duration of the response. Therefore, our results suggest that the relative price of buying a house falls after a monetary policy shock, but the price of renting one rises in relative terms.

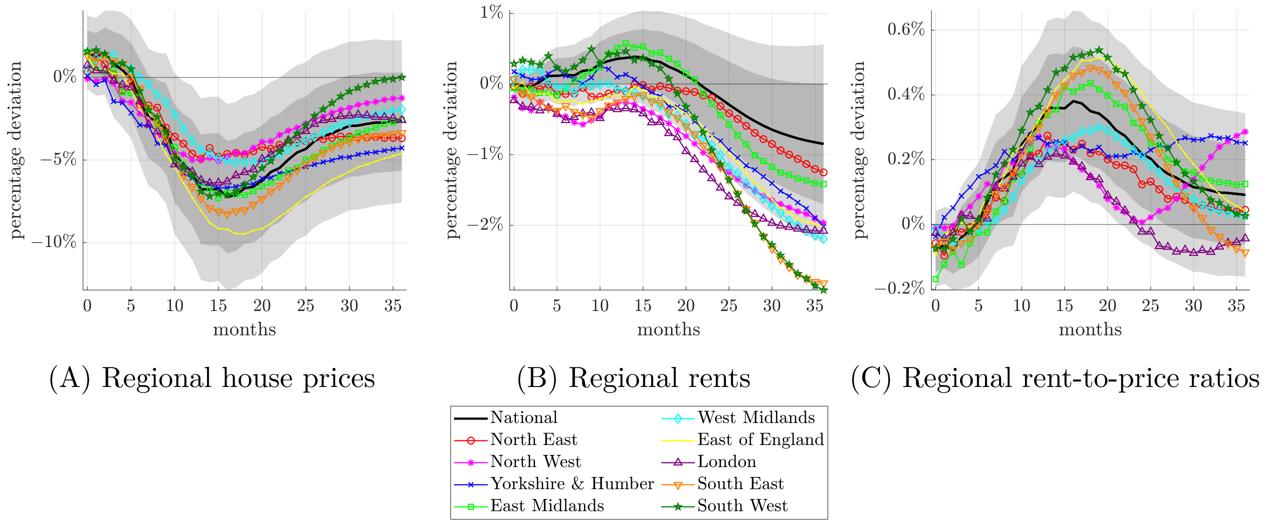
As mentioned in the previous section, the finding of falling house prices, both in nominal and in real terms, is in line with the majority of the literature (e.g., see the review in Ehrenbergerova et al., 2023). However, the few papers that look at the effect on rental prices either find evidence that they increase for the US (Corsetti et al., 2022; Albuquerque et al., 2024), or mixed evidence for European countries (Koeniger et al., 2022). In Section 4.4 we extend the model to replace the marginal supplier of a rental unit from an individual private landlord with a commercial private sector and find that in this case rental prices increase significantly after a positive monetary policy shock. Given that the commercial rental sector, relative to that of individual private landlords, is much larger in the US than in the UK, this may reconcile our findings.[6]

We also analyse the response of rent-to-price ratios. This is an important variable because it is the dividend yield on owning a house for a landlord, i.e., not taking into account the expectation of capital gains. Thus, it should influence the supply of rental housing. As Figure 1 shows, house prices fall while rents are broadly flat initially. Thus, the rent-to-price ratio increases, as shown in Panel (C). After five months the rent-to-price ratio starts to increase, and peaks at around 0.39 p.p. after four quarters.[7] If one thinks about housing as an investment, it is important to compare it with the return of outside options like fixed income. Because the Bank Rate jumps on impact (see Figure A.1A) while the rent-to-price ratio displays a more gradual response, the dividend yield on being a landlord relative to outside options falls, and only becomes positive again after 15 months, once Bank Rate is close to its pre-shock value but house prices are still low. Thus, while house prices show a marked negative response to a monetary policy shock, it does not seem to sufficiently reduce the cost of buying a new house and then renting it so as to attract new landlords purely with rental income.

Finally, we investigate whether our results are robust across sub-regions of the UK, and for different dwelling types. In the regional cases, we substitute the national price and rent indexes with a regional one, while the other variables in the SVAR are at the national level. Because there is no regional measure of CPI OOH, our sample is from 2005-2023 when looking at rents. Figure 2 displays the results for the nine regions in England, overlaid with the national responses in Figure 1. It shows that the qualitative aspects of the national response are replicated in the regional analysis and that, although there is some regional variation, most of it falls within the 68% confidence interval around the national response. We see that all house prices have a trough around 15 months, while rents remain around zero for 15 months as well and then start falling. The regional responses for rents are slightly below the national average, but that is partly explained by their different sample horizons – Figure A.2D shows a similar aggregate

[6]In the UK 94% of landlords are individuals, while in the United States 70.2% of rental properties are owned by private individuals. Data for the UK comes from the 2018 English Private Landlord Survey (Ministry of Housing, Communities and Local Government, 2019), while for the US comes from the 2021 Rental Housing Finance Survey (Congressional Research Service, 2022).

[7]The average gross rent-to-price ratio from 2015 to 2023 was equal to 5.03% in England, according to price data from the House Price Index and rent data from the Price Index of Private Rents, both from the ONS. We do not have data for the actual rent-to-price for the whole sample, only indices, thus we choose to scale the response of the rent-to-price ratio based on indices by 5.03%. Jordà et al. (2019) report that the net rent-to-price ratio for the UK was higher for 1997-2020 (2.9%) than for 2015-2020 (2.3%). Thus, if anything, we are probably underestimating the average gross rent-to-price ratio for the whole sample.



(A) Regional house prices (B) Regional rents (C) Regional rent-to-price ratios

Figure 2: Robustness - regional and dwelling types

Notes: this figure shows the response of the regional ONS House Price Index in Panel (A), regional ONS Index of Private Housing Rental Prices in Panel (B), and the rent-to-price ratio implied by these indices in Panel (C). All specifications use UK measures for the other variables of the SVAR, but uses regional house prices and rents for a given region in the same SVAR. For house prices, the SVAR is estimated from 1997-2023, but for rents and the rent-to-price ratio we have a sample from 2005-2023. The rent-to-price ratio were normalised to 5.03% (see footnote 7 for details), and are displayed as percentage point deviations from this average. The solid black line and the grey shaded areas are the point estimate and the confidence intervals from the national response in Panels (A) and (D) of Figure 1. Grey shaded areas indicate 68 and 90% confidence intervals. Confidence intervals are calculated using a residual-based moving block bootstrap.

response for the same sample of the regional results. Moreover, Figure A.4 shows that different dwelling types also have broadly similar qualitative responses to a monetary policy shock, with a trough around 15 months.

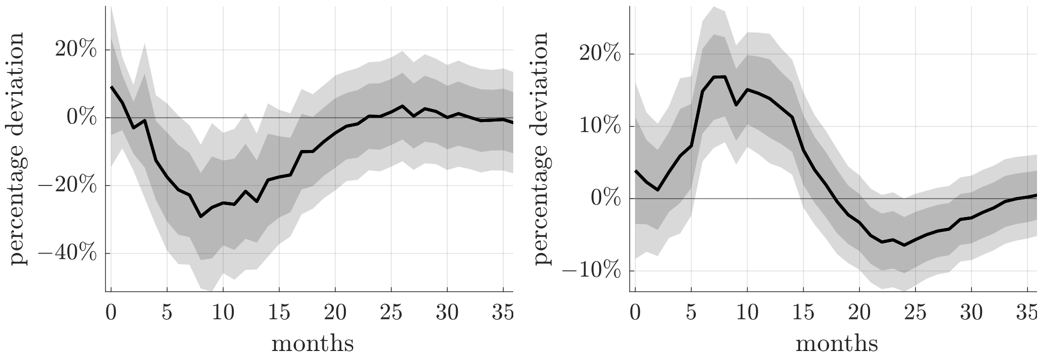
Our main takeaway from Figures 2 and A.4 is that, even though average house prices across regions and dwelling types can differ, they seem to respond in a similar way to a monetary policy shock. This will be an important feature of the model developed in the next section, which features houses with two different sizes but a single price per unit (i.e., price per m^2).

2.2 Sales volume and share of renters

To further investigate the mechanisms that lead to different responses of house prices and rents to a monetary policy shock we look into measures of activity in both the housing and rental markets. These measures can give us important insights on how the real side of the housing market needs to react to be consistent with the price changes that we documented above.

Figure 3 displays the IRFs of the sales volume of houses in Panel (A), and of the average level of stock of unsold houses per surveyor according to the UK Residential Market Survey of the Royal Institute of Chartered Surveyors (RICS).[8] The responses display the same gradual

[8]The UK Residential Market Survey by RICS is a monthly survey of Chartered Surveyors in the UK. In 2023, it had a sample size between 406 and 615 branches in each month.



(A) Sales volume of houses (B) Stock of unsold houses per surveyor

Figure 3: Sales and stocks of houses

Notes: shows the IRF of sales volume of houses in England in Panel (A), and of the average stock per surveyor for England and Wales from the UK Residential Market Survey by RICS in Panel (B). In both instances they were added as an extra variable to the six variable baseline SVAR. The sample for both panels is 1997-2023, with 76121.4 average monthly sales in England, and 62.0 average houses in stock per surveyor. The grey shaded areas are 68 and 90% confidence intervals. Confidence intervals are calculated using a residual-based moving block bootstrap.

adjustment that we found for house prices and rents. Sales volume declines for about a year to around -20%, and rebound after that. Although the stock of housing for sale is not only a function of sales but also of the volume of new houses coming into the market, it is reassuring that the response of stocks is consistent with the response of sales. As sales fall, stocks increase for about eight to ten months. After sales pick up, stocks decrease and return to their original value.

The response of sales is especially interesting considering the dynamics of prices. Even though house prices fall, sales fall as well and stocks rise, which could be indicative that prices do not fall fast enough in the beginning to incentivise renters to become homeowners. The same seems to happen for landlords, since the response of the rent-to-price ratio in Figure 1C does not increase fast enough at the start to compensate for the higher Bank Rate. Thus, it is only after 10 to 12 months, slightly before house prices reach their trough, that sales start to increase again.

Consistent with reduced housing market activity, we also find that young households are more likely to delay their transition from renting to owning. See Appendix A.6 for details.

3 Model

The evidence presented in the section above suggests that after a monetary policy shock both prices and real variables in the housing market are slow to adjust. Moreover, house prices follow a hump-shaped response and, while the level of activity in the housing market falls, the share of renters increases among certain population groups, suggesting an increase in demand even though nominal rental prices are not falling.

In this section we present a DSGE HANK model to help us rationalise the facts above and explore the underlying drivers of the response of the private rental and housing market to interest rate movements. The departure point for the model is a single asset HANK model in the spirit of the models developed in Kaplan et al. (2018) and Auclert et al. (2024) and the related literature. We augment the model by introducing a housing and rental market with fixed housing supply, where prices must clear the housing and rental market in each period. One key contribution is to introduce a household choice over tenure type: renter, owner occupier and landlord. Thus, the share of renters in the economy can increase or decrease endogenously, as households move between homeownership and renting, or between homeownership and being a landlord. We also model sticky rental prices at the level of the household and include several features of the housing market that have been highlighted by the previous literature as being important for the dynamics of housing variables, such as: partially segmented housing markets, LTV and LTI borrowing constraints, and long-term mortgages.

3.1 Households

Households are of measure 1, ex-ante identical, and infinitely lived. In each period households make decisions over consumption and housing tenure subject to their budget constraint, while supplying labour services to a labour union which negotiates their wage. Households earn income through labour services, interest on risk free deposits and, when a landlord, from rental payments. Households may borrow to buy housing up to Loan-To-Value (LTV) and Loan-To-Income (LTI) constraints, whichever binds first. Finally, households are subject to transitory and persistent idiosyncratic shocks to their labour productivity, and random taste shocks with regard to preference over housing tenure.

The households' state space is defined by $(\chi, h, z, a, p_{r,i})$, where χ is the aggregate state of the economy, h is a housing transition, z is labour productivity, a is the net financial asset position and $p_{r,i}$ is a household-specific rental payment. Note that h is the housing transition and not housing tenure. Given budget and borrowing constraints are specific to each transition, it is more convenient to track the transition than the housing tenure. For example, households can move from a 'rent-rent' state in the prior period to 'rent-own' in the current period, as opposed to transitioning from a 'rent' to 'own' state.

It is useful to break the households' problem at each period into two stages

Stage 1 At the beginning of this stage the aggregate state χ and idiosyncratic labour productivity $z = (z_1, z_2)$ are realized, where (z_1, z_2) are persistent and transitory components. When a renter or a landlord, the household also learns whether it will be constrained to stay as a renter/landlord at their previous nominal rental price $\frac{p_{r,i,t-1}}{1+\pi_t}$ or, with probability θ_r, free to move (or not) at the new rental market spot price $p^*_{r,t}$. Households also learn the taste shock $\epsilon(h)$, which is an idiosyncratic additive shock for each transition choice. Thus, households choose h' such that:

$$V^{(1)}(\chi, h', z, a, p_{r,i}) = \max_{\tilde{h}} \left[V^{(2)}(\chi, \tilde{h}, z, a, p_{r,i}) + \epsilon(\tilde{h}) - \eta(\tilde{h}) \right] \tag{1}$$

where $V^{(1)}$ denotes the household's utility at the end of the first stage, and $V^{(2)}$ at the end of the second stage.

We introduce idiosyncratic shocks $\epsilon(h)$ that are re-drawn every period, and fixed costs $\eta(h)$ of engaging in certain transitions that are common to all households.[9] Both costs exist to help match the transition rates between housing tenures to the data, and the taste shock also helps to smooth the transition over discrete states (Iskhakov et al., 2017). Moreover, because we assume that the preference shocks $\epsilon(h)$ follow a Gumbel distribution with scale parameter α_z, the solution to the problem in Equation (1) implies that the ex-ante probability of a specific housing transition in the next period is

$$Prob(\chi, h'|h, z, a, p_{r,i}) = \frac{\exp\left(\frac{V^{(2)}(\chi,h',z,a,p_{r,i})-\eta(h')}{\alpha_z}\right)}{\sum_{h'|h}\exp\left(\frac{V^{(2)}(\chi,h',z,a,p_{r,i})-\eta(h')}{\alpha_z}\right)} \tag{2}$$

The equation above makes it clear why it is useful to split the households' problem into two stages: this way it is possible to write the probabilities of each house transition as a function of end of Stage 2 value function $V^{(2)}$.

Finally, individual productivity shocks z_i are modelled as a mix of two AR(1) processes, one capturing persistent shocks and the other temporary:

$$z_{i,t} = z_{1,i,t} + z_{2,i,t}$$

$$z_{j,i,t} = \rho_{j,z} z_{j,i,t-1} + \epsilon_{j,z,t}, \quad \epsilon_{j,z} \sim N(0, \sigma^2_{j,z,t}), j = 1, 2$$

Stage 2 Having chosen their housing tenure transition, households consume and save based on the budget and borrowing constraints dictated by that transition. They do so by maximising the following value function with discount rate β on future periods:

$$V^{(2)}(\chi, h', a, z, p_{r,i}) = \max_{a'} u(c, h', l) + \beta\mathbb{E}[V^{(1)}(\chi'|\chi, h', z'|z, a', p'_{r,i})]$$

subject to budget and borrowing constraints:

$$a' + c + C_h(p_h, p_{r,i}, h') = (1 + r + \mathbb{1}_{a<0}\bar{r})a + zwl(1 - \tau) + \Pi(z),$$
$$a' \geqslant \bar{a}(h', p_h, z, w, l, a)$$

where households receive interest rate r on their liquid asset holdings; pay a higher interest rate $r + \bar{r}$ on negative balances; earn labour income $y(z) = zwl(1 - \tau)$ subject to their idiosyncratic productivity z, aggregate wage w, hours worked l and tax rate τ; receive dividends income Π from firms (which is paid out proportionally to labour productivity); and pay/receive housing costs C_h that depend on the housing transition h, house price p_h, and agreed rental price. Renters pay (landlords receive) current or lagged market-determined rental costs $p_{r,i}$

[9]It can be motivated, for example, by a distaste for moving or ending tenancies. We also set this cost to infinity to rule out certain impossible or prohibited transitions.

each period:

$$p_{r,i,t} = \begin{cases} p^*_{r,t} & \text{with probability } \theta_r \\ \frac{p_{r,i,t-1}}{1+\pi_t} & \text{with probability } 1-\theta_r \end{cases}$$

Households can engage in secured borrowing against property which is a function of the value of the property and their disposable income. Finally, the interest rate $(1+r+\mathbb{1}_{a<0}\bar{r})$ that households receive (pay) on their savings (debt) is a function of the ex-post real rate given by $(1+r_t) = (1+i_{t-1})/(1+\pi_t)$. Thus, promises are made in nominal terms.

We assume there are two housing types: flats H_1 and houses H_2, with $H_2 > H_1$. Having more than one size is important because households must live somewhere, thus there can only be an increase/decrease in demand for housing if households want to upgrade/downgrade the home they live in. Furthermore, we assume that only flats can be rented, and that owner-occupiers can live in a flat or a house, but landlords only live in houses.

Households have the option to buy a house or flat at a proportional price p_h, subject to some fixed transaction costs F, and borrowing constraints based on LTV and LTI ratios, whichever binds first. These borrowing constraints only apply at origination. In this sense, mortgages in the model are long term mortgages with households allowed to violate their borrowing constraints when not adjusting their housing assets. Current owners have the option to sell their home and become renters or buy a further flat to rent out. Landlords can also choose to purchase a second flat to rent out. We detail the costs and borrowing constraints associated with each transition in our baseline model in Table 1.

Given Equation (2) the expected value function for Stage 1 on the following period will be given by

$$\mathbb{E}\left[V^{(1)}(\chi'|\chi, h', z'|z, a', p'_{r,i})\right] = \sum_{h''|h'} Prob(\chi'|\chi, h''|h', z'|z, a', p'_{r,i})\left(V^{(2)}(\chi', h'', z', a', p'_{r,i}) - \eta(h'')\right)$$

We specify the utility function as:

$$u(c,h,l) = \frac{(c^{1-\phi_h}x(h)^{\phi_h})^{1-\sigma_c}}{1-\sigma_c} - \phi_l\frac{l^{1+\psi_l}}{1+\psi_l} \ , x(h) = H(h)(1+\omega_{oo}\mathbb{1}_{oo})$$

with a Cobb-Douglas aggregator over consumption of housing services $x(h)$ and consumption of non durable goods c. Housing services $x(h)$ depend on house size $H(h)$ and an extra utility w_{oo} from being an owner-occupier ($\mathbb{1}_{oo} = 1$) versus a renter in the same house.

Finally, we allow owners and landlords to default on their properties subject to a large utility cost $v_{default}$[10]. Default occurs when households choose to sell their house but the proceeds are insufficient to pay off their debt. The government finances these defaults through taxes, revenues received on the borrowing wedge $\bar{r}$, and revenues from the housing association, to be described below.

[10]Default is not a focus of this study but is necessary to always give homeowners and landlords a viable transition to ensure positive consumption. In steady state the share defaulting is negligible.

Table 1: Budget and borrowing constraints for each housing transition

Transition	$-C_h$	$\bar{a}$
Own H - Own H	$-\delta_h H_2$	$\min(a, \max(-\kappa_h p_h H_2, -\kappa_y y(z)))$
Own H - Own F	$-p_h(H_1 - H_2) - 2F - \delta_h H_1$	$\max(-\kappa_h p_h H_1, -\kappa_y y(z))$
Own H - Rent	$p_h H_2 - F - p_r^*$	0
Own H - LL	$-p_h H_1 - F + p_r^* - \delta_h(H_1 + H_2)$	$\max(-\kappa_h p_h(H_1 + H_2), -\kappa_y y(z) - \kappa_h H_1 p_h)$
Own F - Own F	$-\delta_h H_1$	$\min(a, \max(-\kappa_h p_h H_1, -\kappa_y y(z)))$
Own F - Own H	$-p_h(H_2 - H_1) - 2F - \delta_h H_2$	$\max(-\kappa_h p_h H_2, -\kappa_y y(z))$
Own F - Rent	$p_h H_1 - F - p_r^*$	0
Rent - Own F	$-p_h H_1 - F - \delta_h H_1$	$\max(-\kappa_h p_h H_1, -\kappa_y y(z)))$
Rent - Rent	$-p_{r,i}$	0
LL - Own H	$H_1 p_h - F - \delta_h H_2$	$\min(a + p_h H_1 - F, \max(-\kappa_h p_h H_2, -\kappa_y y(z)))$
LL - LL	$p_{r,i} - \delta_h(H_2 + H_1)$	$\min(a, \max(-\kappa_h p_h(H_1 + H_2), -\kappa_h p_h H_1 - \kappa_y y(z))$
LL - LL x2	$-H_1 p_h + 2p_r^* - F - \delta_h(H_2 + 2H_1)$	$\max(-\kappa_h p_h(2H_1 + H_2), -\kappa_h 2 p_h H_1 - \kappa_y y(z))$
LL x2 - LL x2	$2p_{r,i} - \delta_h(H_2 + 2H_1)$	$\min(a, \max(-\kappa_h p_h(2H_1 + H_2), -\kappa_h 2 p_h H_1 - \kappa_y y(z)))$
LL x2 - LL	$H_1 p_h + p_r^* - F - \delta_h(H_2 + H_1)$	$\min(a + H_1 p_h - F, \max(-\kappa_h p_h(H_1 + H_2), -\kappa_h p_h H_1 - \kappa_y y(z)))$

Notes: "Rent" denotes a renter, "Own F" denotes an owner-occupier that lives in a Flat, "Own H" denotes an owner-occupier that lives in a house, "LL" denotes a landlord with a single flat to let, and "LLx2" denotes a landlord with two flats to let. The rent price $p_{r,i}$ of each renter/landlord is equal to $p_{r,t}^*$ if they were hit by a readjustment shock in the current transition, and equal to $\frac{p_{r,i,t-1}}{1+\pi_t}$ otherwise.

3.2 Housing market

We consider the case of a fixed supply of housing, an assumption based on a quarterly business cycle analysis and the established long lags of monetary policy transmission in the UK and other countries. In each period, demand for housing has to match supply $\overline{H}$. House prices p_h adjust such that equilibrium in the housing market holds

$$\overline{H} = H_1(s_{r,t} + s_{ooF,t}) + H_2(s_{ooH,t} + s_{ll,t}) \tag{3}$$

where $\{s_{r,t}, s_{ooF,t}, s_{ooH,t}, s_{ll,t}\}$ are the shares of renters, flat owners, house owners and landlords in each period.[11] Alongside the housing market, the rental market must also be cleared, i.e., in each period any marginal change in renters has to be matched by a change in the share of private landlords and the number of homes each landlord owns

$$H_1 s_{r,t} = H_1 s_{ll1,t} + 2H_1 s_{ll2,t} + \overline{HA}, \tag{4}$$

where $s_{ll1,t}, s_{ll2,t}$, are the measure of landlords with one or two flats. We allow for a fixed share of rental housing $\overline{HA}$ to be provided by a passive housing association with fixed supply of flats that takes the price as given and passes on its revenues to the government. This allows us to better calibrate the share of tenure types in steady state without having to match the skewed distribution of number of properties owned per landlord. Crucially, because $\overline{HA}$ remains fixed in each period, it is private landlords that act as the marginal provider of rental housing after a monetary policy shock.

[11] Notice that Equation (3) combined with the restriction $s_{r,t} + s_{ooF,t} + s_{ooH,t} + s_{ll,t} = 1$ implies that the share of households that live either in a flat or in a house is fixed over time. For example, the mass of households living in a house is given by $s_{ooH,t} + s_{ll,t} = (\overline{H} - H_1)/(H_2 - H_1)$.

3.3 Household expectations

In order to match the macro and micro data more closely we allow for deviations from Full Information Rational Expectations (FIRE). Specifically, we allow for the possibility that households may simultaneously overreact to current economic conditions while under reacting to news about future economic conditions. This is the key insight of Kohlhas and Walther (2021) who provide extensive empirical evidence of this phenomena across agent types and surveys, microfounding their results through asymmetric attention whereby agents pay different levels of attention to different signals about variables or components of variables relevant to their decision making. Our expectations process therefore embeds both extrapolation and sticky information. Households forecast an input x in their decision problem k periods ahead as follows:

$$\bar{f}_t x_{t+k} = x_{ss} + \frac{1}{1+\delta_x}\left(\delta_x \bar{f}_{t-1} dx_{t+k} + \mathbb{E}_t^*[dx_{t+k}] - \gamma_x dx_t\right) \tag{5}$$

where $\bar{f}_t x_{t+k}$ is the k period ahead forecast, $\mathbb{E}_t^*[x_{t+k}]$ is the unbiased perfect foresight forecast of $dx_{t+k} = x_{t+k} - x_{ss}$. The parameter δ determines the under ($\delta_x > 0$) or over ($\delta_x < 0$) reaction to news about the future and γ_x determines the extent to which household over ($\gamma_x < 0$) or under ($\gamma_x > 0$) extrapolate from today into the future. The case ($\gamma_x = 0, \delta_x = 0$) is perfect foresight. We assume all households have the same expectations process. We further assume δ_x and γ_x are fixed across household inputs (e.g., wages or the interest rate) as in Auclert et al. (2020), but we do allow for separate values for house prices. A key result from Kaplan et al. (2020) is the importance of house price expectations in the determination of house prices and aggregate consumption. Households may be more attentive to house prices as a commonly discussed price in wider society and the media and an important investment or, alternatively, households may have particularly sticky beliefs around house prices anchored around their own purchases history and previous capital gains.[12]

The case ($\gamma_x = 0, \delta_x > 0$) is exactly sticky expectations as modelled by Auclert et al. (2020). Sticky expectations have a long history in the macro literature (Mankiw and Reis, 2002; Carroll, 2003). More recently, studies have incorporated it into HANK models to emphasise its importance for both matching the movement of aggregate variables after a monetary policy shock, and also being consistent with evidence from micro data on individual consumption responses (Auclert et al., 2020; Carroll et al., 2020). In this case, in any period with probability $\frac{1}{1+\delta_x}$ households update their expectations of future prices, but with probability $1 - \frac{1}{1+\delta_x}$ households maintain their forecast from the previous period. There is also a large literature in asset pricing (e.g., Adam and Nagel, 2023), including for house prices (Case et al., 2012; Armona et al., 2019; Adam et al., 2024), that focuses on over- and under-reactions of expectations. Given this literature and the evidence Kohlhas and Walther (2021) we allow for the possibility that households may over or under extrapolate from past price behaviour when making their forecasts.

The mapping of the forecasting in Equation (5) into the sequence space is outlined in Ap-

[12] In appendix C.2.2 we show results where δ_x and γ_x are the same for all variables, including house prices.

pendix C.2 where we follow the procedure and assumptions of Bardóczy and Guerreiro (2025), who show how one can map rational expectations sequence space Jacobians J to generalised Jacobians $\hat{J}$. The combination of stickiness and extrapolation allows us to match both the large and hump shaped responses of ouput and house prices in response to a rise in the interest rate, while simultaneously matching the flat rental price reaction.

3.4 Rest of the model

The rest of the model closely follows the recent HANK literature. This includes New Keynesian Philips curves for prices and wages, a Taylor rule for monetary policy, and a fiscal authority that adjusts taxes to stabilise debt in the long run.

Supply A continuum of intermediate goods firms produce output subject to a production function that combines labour services n with the current level of aggregate technology $\theta_{A,t}$

$$y_{j,t} = \theta_{A,t} n_{j,t} \tag{6}$$

Under monopolistic competition each firm enjoys some pricing power and is able to charge a markup μ^*. Alongside quadratic adjustment costs Ψ_t this yields the familiar linearised price Philips Curve that describes the evolution of prices around the competitive symmetric zero steady state inflation equilibrium

$$\log(1+\pi_t) = \kappa_p \left(\frac{w_t}{\theta_{A,t}} - \frac{1}{\mu^*} \right) + \beta \mathbb{E}_t \left[\log(1+\pi_{t+1}) \right] \tag{7}$$

Profits $\Pi_t = Y_t - w_t N_t - \Psi_t$ from these firms are distributed as dividends out to households in proportion to their labour income.

Moreover, a labour union negotiates hours and wages on behalf of households. Unions set the wage based on average marginal utilities of households subject to adjustment costs.[13] In the symmetric equilibrium aggregate wage inflation is determined by a linearised wage Philips Curve:

$$\log(1+\pi_{w,t}) = \kappa_w \left(\phi_l L_t^{\psi_l} - w_t(1-\tau_t) \int_i z_{i,t} u_c(c_{i,t}, h_{i,t}) di \right) + \beta \mathbb{E}_t \left[\log(1+\pi_{w,t+1}) \right] \tag{8}$$

Fiscal and Monetary Policy The Central Bank is assumed to react to deviations of inflation and output from their steady state by setting the short term safe nominal interest rate i_t using a smoothed Taylor rule

$$i_t = \rho_m i_{t-1} + (1-\rho_m) \left(r_{ss} + \phi_\pi (\pi_{t,cpi} - \pi_{ss,cpi}) + \phi_y \left(\frac{Y_t - Y_{ss}}{Y_{ss}} \right) \right) + \epsilon_{m,t} \tag{9}$$

where ρ_m is the smoothing parameter, and $\varepsilon_{m,t}$ is the monetary policy shock. Note that the inflation measure in the Taylor Rule is the total CPI which is a weighted average between rental

[13]We integrate over all households, meaning heterogeneity affects labour supply.

price inflation and goods price inflation with weights based on the steady state share of rental expenditure.[14]

Fiscal policy reacts to deviations in public debt B from it's steady state by adjusting the labour tax τ in line with a rule that targets adjustment towards a desired debt to GDP ratio as in Auclert et al. (2020).

$$\tau_t = \tau_{ss} + \gamma_{tax} \left(\frac{B_{t-1} - B_{ss}}{Y_{ss}} \right) \tag{10}$$

Public debt then evolves according to the government budget constraint:

$$B_t = (1 + r_t)B_{t-1} + G + A_{def,t} - w_t N_t \tau_t - \overline{r} A_{<0,t-1} - (\overline{p}_{r,t} - \delta_H)\overline{HA} - FTR_t \tag{11}$$

with government expenditures including a fixed amount of government purchases G, interest payments on the previous periods debt, and the cost of household defaults $A_{def,t}$. Government receives income from the labour tax, interest payments on mortgages over and above the safe rate, and revenue from its stock of rental housing $\overline{HA}$, where $\overline{p}_t$ is the average rental price in the economy. Finally, we rebate housing transaction costs FTR_t back to the government so they do not have output implications.

Market Clearing and Equilibrium Given specified stochastic processes for shocks, an initial debt level B_{-1}, price level P_{-1}, nominal wage W_{-1}, interest rate i_{-1} and distribution of agents D_{-1} over $\{h, z, a, p_{r,i}\}$, a competitive equilibrium is: a sequence of prices $\{\pi_t,\ \pi_{w,t},\ i_t,\ r_t,\ p^*_{r,t},\ p_{h,t},\ \tau_t\}$; aggregate quantities $\{Y_t,\ C_t,\ N_t,\ L_t,\ B_t,\ s_{r,t},\ s_{oo,t},\ s_{ll,t},\ A_{def,t},\ A_{0<,t},\ \Pi_t\}$; individual policy rules $\{c_t(h_t, z_t, a_{t-1}, p_{r,i})\ ,\ a_t(h_t, z_t, a_{t-1}, p_{r,i}),\ h_t(h_{t-1}, z_t, a_{t-1}, p_{r,i})\}$; and household distribution $D_t(h, z, a, p_{r,i})$; such that households, firms, and the labour unions optimise, policymakers follow their rules, housing markets clear, and goods and asset markets clear:

$$Y_t = C_t + G_t + \delta_h \overline{H} \tag{12}$$

$$B_t = \int_i a_t(h_t, z_t, a_{t-1}) di \tag{13}$$

3.5 Calibration and solution method

Parameters are divided into those that are internally estimated to match steady-state moments (Table 2), externally calibrated (Table 3), and estimated through IRF matching (Table 5). Using parameters and sources noted in Table 2 we target ten key moments in the UK data for the model's steady state. For the labour income parameters, we use the analysis in Bell et al. (2022) and match the idiosyncratic income process to reproduce the 90-10 ratio for labour income observed in the UK data, the variance in income, and variance in the changes in income over one and five year periods. We also target a level of saving consistent with liquid savings held by UK households as reported in ONS's national balance sheets, averaged

[14] $\pi_{t,cpi} = \omega_{rent}\pi_{t,rent} + (1 - \omega_{rent})\pi_t$ where $\omega_{rent} = \frac{p_{r,ss}H_1 s_{r,ss}}{p_{r,ss}H_1 s_{r,ss} + C_{ss}}$.

Table 2: Internally estimated parameters

Moment	Data	Model	Parameter	Source
Cross sectional labour income std. dev	0.66	0.73	$\rho_{z,1}, \rho_{z,2}, \sigma^2_{z,1}, \sigma^2_{z,2}$	Bell et al. (2022)
One year earnings change std. dev	0.19	0.22	$\rho_{z,1}, \rho_{z,2}, \sigma^2_{z,1}, \sigma^2_{z,2}$	Bell et al. (2022)
Five year earnings change std. dev	0.78	0.50	$\rho_{z,1}, \rho_{z,2}, \sigma^2_{z,1}, \sigma^2_{z,2}$	Bell et al. (2022)
90-10 income ratio	4.66	4.66	$\rho_{z,1}, \rho_{z,2}, \sigma^2_{z,1}, \sigma^2_{z,2}$	Bell et al. (2022)
Ann. debt to GDP	0.63	0.63	β	ONS (97-23)
Share of renters	0.33	0.33	ϕ_h	EHS (97-23)
Share of flat owners	0.10	0.10	ω_{oo}	EHS (97-23)
Share of landlords	0.06	0.06	$p_{r,ss}$	WAS (08-20)
Ann. prob of owner → renter	0.012	0.011	η_m	EHS (97-23)
Ann. prob landlord portfolio reduction	0.10	0.07	η_{ll}	EPLS (2018)

Notes: Bell et al. (2022) calculate their moments using labour income collected in the Annual Survey of Hours and Earnings. We consider labour income only in this calibration. Balance sheet data for the UK is from the Office for National Statistics (ONS), EHS is the English Housing Survey, and WAS is the Wealth and Assets Survey. In the calibrated model $\beta = 0.9852$, $\phi_h = 0.35$, $\omega_{oo} = 1.1$, $\eta_{ll} = 0.008$ and $\eta_m = 0.06$. For the income process $\rho_{z,1} = 0.99$,$\rho_{z,2} = 0.08$, $\sigma_{z,1} = 0.10$ and $\sigma^2_{z,2} = 0.01$.

over the 1997-2023 period. The share of renters and of flat owners is matched to the averages over 1997-2023 reported in the English Housing Survey and English Private Landlord Survey. The share of landlords is calibrated using the Wealth and Assets Survey between 2008 and 2020. From these surveys we are also able to back out the annual average probability of a household transitioning from owning to renting. To assist us with this calibration we have two tenure/transaction specific utility costs. Transitions that involve buying or selling a property incur a utility cost η_m. We also include a constant utility cost of being a landlord (η_{ll}) to help target the landlord share, which can be rationalised as extra labour disutility from managing their property portfolio. The other steady-state parameters are calibrated to values typically used in the literature as shown in Table 3.

Table 4 compares several untargeted moments in the model and the data. The model matches well the overall amount of housing wealth to financial net worth relative to what we see in the Wealth and Assets Survey. The model also matches the share of homeowners with a mortgage and average rent to disposable income. Wealth inequality is substantial, but not quite to the extent implied in the data. The model also produces average annualised MPC of 0.34, consistent with survey data (see Panel (c) in Figure 6).

Finally, notice that the model also does quite well at generating a large share of landlords who maintain negative liquid asset positions, though not quite to the extent we see in the data. This large share, of 57% in the data and 49% in the model, suggests that many landlords can behave as wealthy HTM (Kaplan and Violante, 2014) due to their low liquid savings, which will be an important feature of the model.[15] Applying the Kaplan and Violante (2014) hand to mouth (HtM) classification to the Wealth and Assets Survey (2018-2022), we find

[15]Kaplan and Violante (2014) classify mortgages as negative illiquid assets, but in Table 4 mortgages are classified as negative liquid assets, because in the model they are liquid as well. Given the lower fixation periods of 2 to 5 years of mortgages in the UK compared to 25 to 30 years in the US, they are more liquid in the former. We also include financial assets such as stocks in the calculation.

Table 3: Externally calibrated parameters

Parameter	Value	Source
Frisch	0.5	Auclert et al. (2020)
EIS	0.5	Crump et al. (2022)
Steady State Markup	1.06	Auclert et al. (2020)
Steady State $r(ann)$	0.02	Average over 1997-2019
Borrowing wedge $\bar{r}(ann)$	0.0125	Average over 1997-2019
Transaction Cost	$0.02p_{h,ss}$	Halifax Build Society
$\frac{p_{h,ss}}{\bar{y}}$	6.3	Average over 1997-2023 (ONS)
Loan to value max κ_h	0.90	PSD 90 pctile. FTB
Loan to income max κ_y	4.5	PSD 90 pctile. FTB
Rental price adj. prob θ_r	0.25	1 year contract
Housing Maintenance δ_h	0.021	ONS CPI-H share
Taste shock scaler α_z	0.2	Iskhakov et al. (2017)

Notes: LTV/LTI data comes from the Product Sales Database (PSD) for First Time Buyers (FTB); mortgage yields and spreads comes from Datastream and refer to mortgages with 2 year fixation period and 75% LTV, and the spread is over 2y government bond yields; other UK data comes from the Office of National Statistics (ONS).

Table 4: Untargeted Moments

Moment	Model	Data	Source
Housing Wealth to Financial Net Worth	8.1	7.0	Wealth & Assets Survey (08-20)
Top 10 pct. Total Wealth Share	0.31	0.48	Wealth & Assets Survey (08-20)
Share of Homeowners with Mortgage	0.54	0.53	English Housing Survey (97-23)
Share of Landlords with Liquid Assets < 0	0.49	0.57	Wealth & Assets Survey (08-20)
Avg Rent to Renter Disposable Income	0.28	0.33	English Housing Survey (97-23)

37% of landlords are classified as HtM.[16] Further details on the model's steady state and its computation are provided in Appendix C.

To study the dynamics of the model we solve the model using the first order sequence space method developed by Auclert et al. (2021). In order to accommodate the discrete choices in our model we follow Iskhakov et al. (2017) by augmenting the endogenous grid point method (EGM) procedure of Carroll (2006) with a further step that calculates an upper envelope of the value functions over the endogenous grid. This upper envelope allows us to use the EGM procedure in stage 2, where the discrete choices can induce multiple solutions for the savings policy function.

3.6 IRF Matching

We start out by calibrating the model as closely as possible to the dynamics described in Section 2. We do so by adjusting the parameters in Table 5 using a minimum distance estimator that minimises the squared distance between the model IRFs $Y(\theta_{IRF})$ to a monetary policy shock to their empirical counterparts $\dot{Y}$. We include 12 quarters of IRFs for the interest rate, output, prices, house prices and rents, weighting with the inverse variances of the empirical IRF's:

[16] We adopt a relatively conservative threshold for the credit limit to classify a household as HtM (12 months of income), reflecting shorter mortgage fixation periods in the UK. A less conservative threshold (fewer months of income) increases the share of HtM households. See Appendix C for further details.

Table 5: IRF Matched Parameters

Parameter	Symbol	IRF matched value
Slope of price Philips Curve	κ_p	0.012
Slope of wage Philips Curve	κ_w	0.003
Debt stab. in fiscal rule	γ_{tax}	0.12
Taylor rule coefficients	$(\phi_\pi, \phi_y, \rho_m)$	(1.11, 0.00, 0.87)
Price update prob.	$\frac{1}{1+\delta_x}$	0.12
House price update prob.	$\frac{1}{1+\delta_{p_h}}$	0.37
Price extrapolation	γ_x	-0.41
House price extrapolation	γ_{p_h}	0.09

$$\min_{\theta_{IRF}} (Y(\theta_{IRF}) - \dot{Y})^T W (Y(\theta_{IRF}) - \dot{Y}) \tag{14}$$

We perform the same exercise for the three possible sets of expectation processes we consider: (i) rational; (ii) sticky; and (iii) sticky and extrapolative. The one that is able to best match the response overall is (iii). Figure 4 shows the resulting IRFs in the model compared to the data, and Appendix Figure C.3 compares the IRFs under all expectation settings, including a version where the house price behavioural parameter is the same as for other prices. As discussed in Auclert et al. (2020), rational expectations solutions tend to fail to recover the humps we see in the empirical data. Households update their information set on impact, and this leads to large peak impacts at time zero. For pure sticky expectations we found that they recover somewhat the hump shaped response of GDP and house prices. However, the dampening of the expectations channels also dampens the overall fall in GDP and the relative house price. Sticky and extrapolative expectations generate the necessary delayed responses and amplification, and separating house price and other price expectations allows us to get much closer to the joint response of GDP, house prices and crucially housing rents (see Figure C.3). Consistent with the data, the model also produces a prolonged fall in housing sales and a temporary increase of the rental share (see Figure D.1).

Table 5 shows that the model requires a high degree of stickiness and extrapolation for non-house price variables in order to match the data. The low probability of update of 0.12 for prices other than the house price is in line with the estimates of 0.065 from Auclert et al. (2020), who carry out a similar IRF matching exercise. Coibion and Gorodnichenko (2012) estimate a value of around 0.2 for households. The extrapolation coefficient is quite a bit beyond the point estimates of Kohlhas and Walther (2021), who estimate a value of around -0.14 in survey data. However, we find it key to matching the large hump shaped responses of the empirical IRFs, in particular the GDP response. For house prices we find a higher update probability and no extrapolation is required. As Kohlhas and Walther (2021) do not estimate their regressions on house prices expectations we provide empirical evidence for these parameters based on household data in appendix Table C.3. We find that our model estimates lie within the 90 percent confidence interval of our reduced form estimates. The other parameter estimates relating to the Philips curves, monetary and fiscal policy are in line with parameters

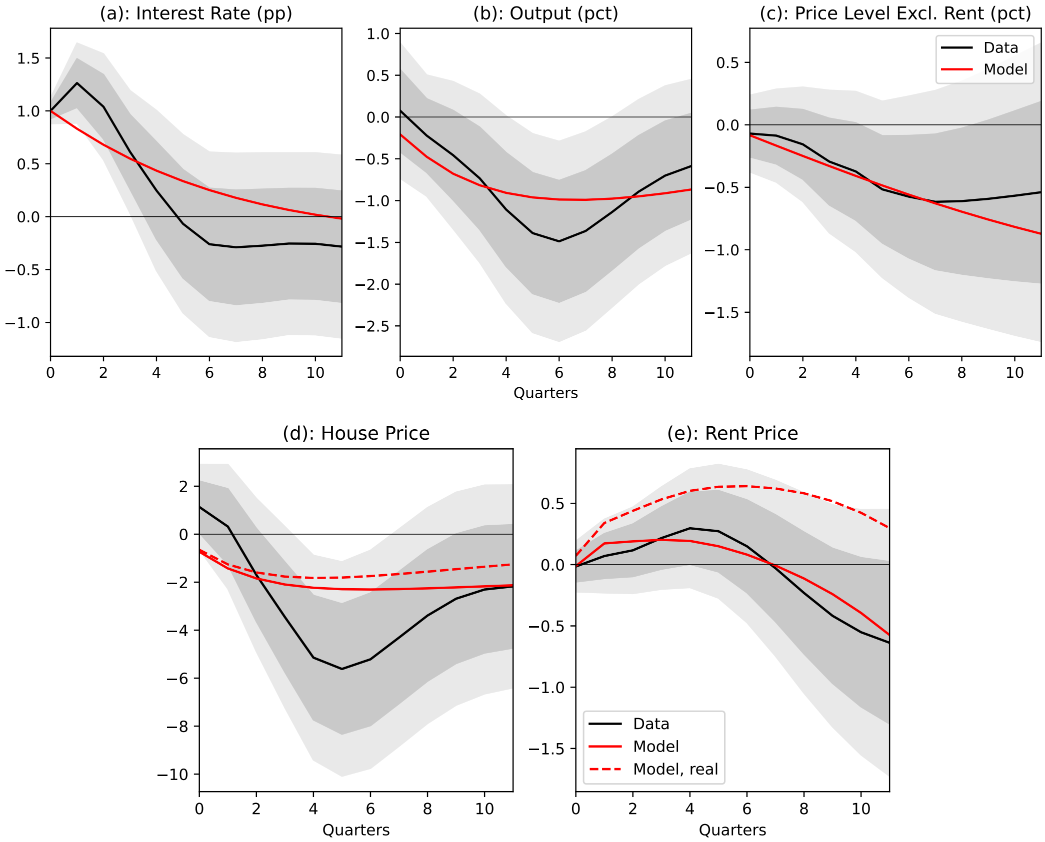


Figure 4: IRF Matching

Notes: this figure reports the impulse response to a 1pp unanticipated monetary policy shock. The black line and shaded areas are the paths from the SVAR estimated in Section 2 (see figure A.1) averaged to a quarterly frequency. The shaded areas represent the 68% and 90% confidence intervals for the empirical responses. The red lines are the paths for the equivalent variables in the model laid out in Section 3.

typically calibrated to in the literature, e.g., Auclert et al. (2020).

4 Model results and extensions

In this section we examine the response of the model laid out in Section 3 to innovations in monetary policy. First, we analyse the impact of monetary policy in the housing market, and how the latter shapes the monetary transmission mechanism. Second, we analyse each set of assumptions in our model in turn to better understand their impact: behavioural expectations, HANK setting, and individual private landlords. We also highlight the implications of these assumptions for monetary policy. Finally, we consider several extensions to the model.

4.1 Rental and Housing Market ⇄ Monetary Policy

4.1.1 Housing market clearing

The novel feature of our HANK model is that both supply and demand in housing markets are determined wholly in the household block. For there to be a new renter, there must be

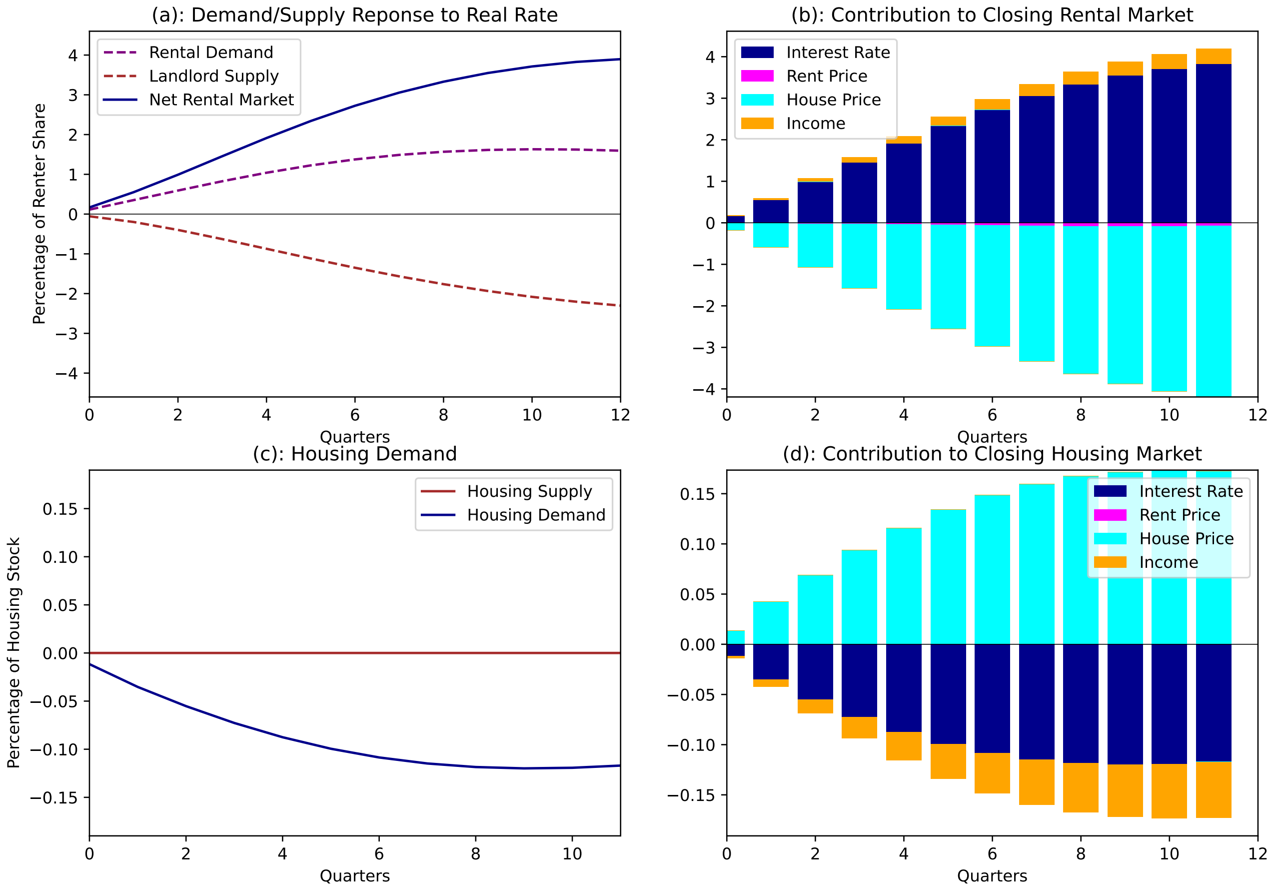


Figure 5: Housing Market Response to Higher Interest Rate

Notes: this figure reports the impulse response in the model to a real interest rate shock that mimics the path for real rates after a 1p.p. monetary policy shock in Figure 4. Panel (a) plots the partial equilibrium response of the rental share and landlord share to the interest rate path. Panel (b) decomposes the general equilibrium response into the contribution from each price to closing the rental market. The bars sum to zero in each period. Similarly, Panel (c) plots the partial equilibrium response of total housing demand (RHS of Eq. (3)) and Panel (d) the contribution of each price to closing the housing market. Notice that the underlying price responses are not displayed, only their effect on the rental and housing market. For example, the house price movements in Panels (b) and (d) is the same, and is the one displayed in the House Price panel of Figure 4.

more rental property investment by another household. The exercise we consider in this section shows what happens under this setting to the housing sector after a partial equilibrium real interest rate shock, and what are the ensuing movements in other prices in general equilibrium to direct the housing sectors into equilibrium. The real interest rate shocks considered in this section are matched to the real rate implied by the paths of nominal interest rate and inflation in Figure 4.

Figure 5 shows the partial equilibrium response to an interest rate shock on demand and supply in the rental market in Panel (a), and in the housing market in Panel (c).[17] Panel (a) shows that the rise in interest rates pushes up on rental demand and down on landlord supply, therefore creating excess demand (blue line). This is because, all else equal, higher interest

[17]This is calculated by combining the household Jacobian with respect to the relevant price in the sequence space with the general equilibrium price response.

payments dissuade homeowners and landlords from borrowing to buy a house, while at the same time increasing the relative return on liquid savings (the house price is kept fixed in this partial equilibrium exercise). The same effects apply in Panel (c), decreasing the demand on housing, while the supply is fixed by assumption.[18]

The responses in Panels (a) and (c) are only possible in partial equilibrium: there is positive net demand for rental units, and negative net demand for housing units. Thus, prices must move so that demand equals supply. Panels (b) and (d) show the effects on the housing and rental markets from price changes in general equilibrium following the real interest rate shock, such that Equations (3) and (4) hold and the rental and housing markets are back in equilibrium. The dark blue bars in Panels (b) and (d) trace out the gaps induced by the interest rate illustrated by the dark blue lines in Panels (a) and (c). The other prices in the model then adjust to close these gaps such that the bars sum to zero in each period in both Panels (b) and (d). The main takeaway is that despite the potential role for all prices to contribute to closing the housing markets, house prices (light blue) explain almost all of the offsetting pricing effects in the housing and rental market: they are responsible for reducing the net rental demand by 4p.p. after 12 quarters, and increasing the net housing demand by slightly more than 0.15 p.p. Moreover, the effect of monetary policy on the housing market through a decline in other income sources is quite small. The rental price also has a negligible effect, which largely follows from the fact we have matched the model to the small general equilibrium rental price movements in the data. House price effects dominate because housing is an asset with a high price relative to average incomes, and because it is a lumpy investment. Thus, investing in a house is a longer and more expensive financial commitment, and movements in prices are more consequential. Based on Panels (b) and (d) we can conclude that it is largely the effect of house prices and interest rates that determine the rental price adjustment needed to clean up any residual excess demand or supply in the rental market.

4.1.2 Rental and Housing Market → Monetary Policy

In the section above we saw how interest rate changes can have significant implications on the housing and rental markets. We now focus on the role that these markets play in shaping monetary transmission and its distributional implications. To do so, Figure 6 shows consumption IRFs and intertemporal Marginal Propensities to Consume (iMPCs) for the aggregate, and split by housing tenure.[19]

A distinct advantage of HANK models is their ability to deliver more realistic narratives for the transmission of macroeconomic shocks owing to their richer modelling and calibration of key micro moments (Kaplan et al., 2018). Panel (a) of Figure 6 decomposes the consumption response in the model to a rise in interest rates into several different channels. Consistent with

[18]Note that switching from owning a flat to renting does not change the size of house the agent demands, solely how they pay for it, therefore, it does not affect overall housing demand. However, the lower endogenous demand for housing comes exactly from households wanting to downsize (or not upsize).

[19]We calculate annual iMPCs as the sum of the consumption response to a one-time income shock over the quarters in that year. For example, the iMPC for year 1 is the sum over the quarters 1 to 4. This follows Kaplan et al. (2018) and Kaplan and Violante (2022).

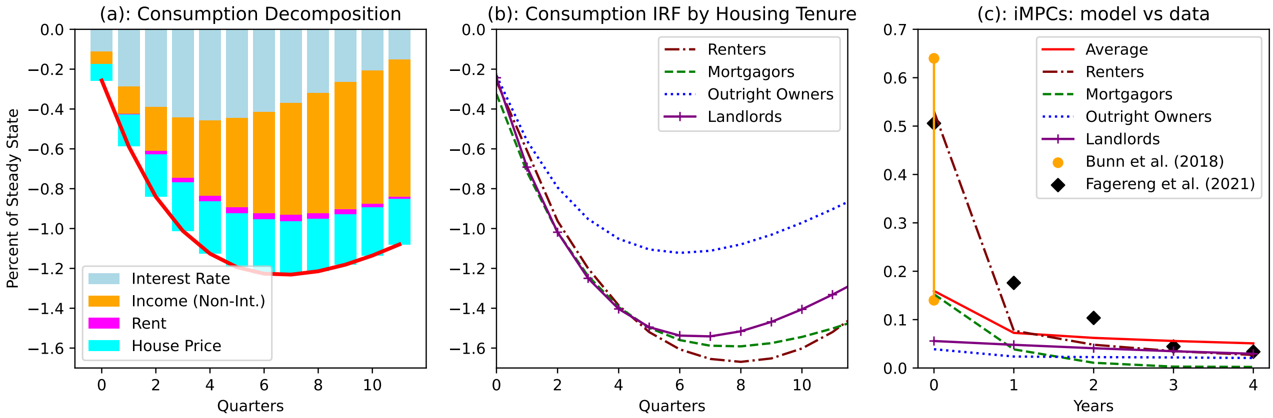


Figure 6: Consumption Decomposition, iMPCs, and Heterogeneity

Notes: Panel (a) decomposes the consumption response into different channels. The interest rate channel is the effect from current period interest rates (cash-flow channel) and inter-temporal substitution effects. The disposable income channel is the joint effect of wages, hours, taxes and dividends. The rent and house price channel is the partial equilibrium effect of real rental and house prices. Panel (b) shows the consumption response broken down by housing tenure. Panel (c) shows the average intertemporal Marginal Propensity to Consume (iMPC) in the model in response to an unexpected and transitory lump-sum transfer, and also broken down by housing tenure. This is compared to empirical estimates from Bunn et al. (2018) for the UK and Fagereng et al. (2021) for Norway. The lower and higher end for the UK estimates refer to positive and negative transfers, respectively. 'Outright Owners' denotes those homeowners that do not have any mortgage debt remaining.

the main messages from the HANK literature the decomposition highlights a significant role for general equilibrium channels that affect households' disposable income (e.g., wages and taxes), and a relatively smaller role relative to RANK models for the direct interest rate channel.[20] Panel (c) shows that the consumption response in Panel (a) is backed by an average untargeted MPC that is in line with evidence for the UK, especially for those coming from positive income shocks, although slightly below international counterparts.

Importantly, the model incorporates housing, which plays a consequential role in consumption responses (Slacalek et al., 2020) but is usually absent from HANK models. Panel (a) highlights that indirect effects coming through changes in rents and house prices, which incorporates both wealth and collateral constraint effects, play a large role in lowering consumption. At the peak consumption response, housing channels account for around one quarter of the impact of monetary policy.

Panels (b) and (c) unpack the same outcomes across different housing tenures and reveal that monetary policy interacts, and is shaped by, considerable cross-sectional heterogeneity. First, Panel (c) reveals the ordering of MPC magnitude that one would expect. Landlords and outright owners have very low MPCs, since they are better able to insure themselves against transitory income shocks, due to higher levels of wealth and more borrowing capacity due to lower debt. Next, mortgagors have MPCs in line with the economy average, since they are best thought of as 'wealthy hand-to-mouth' types (Kaplan and Violante, 2014). Finally, renters

[20] As shown by Kaplan et al., 2018 the direct interest channel wholly explains the consumption response in a RANK model.

have much larger MPCs since they have little to no liquid, or illiquid, wealth.

However, Panel (b) shows that the ordering of MPC magnitudes does not translate one-to-one to consumption responses to interest rate changes. After a contractionary monetary policy shock several prices move, affecting both consumption prices and income. Still, consistent with evidence from Cloyne et al. (2020), outright owners stand out from the other tenure types by responding the least to the interest rate rise. Renters' consumption responds more since they are poorer, but they are not as impacted by house price movements or changes to the mortgage rate. Mortgagors' consumption also respond more because they are heavily indebted and the hike in mortgage rates have a big impact on their disposable income.

Strikingly, landlords have a stronger response than outright owners (and similar to renters and mortgagors). Several elements contribute to this. First, landlords have mortgages on their rental properties while outright owners do not, thus they suffer from increased borrowing costs. Second, landlords are not able to pass on the increase in their costs to renters (as further discussed in section 4.4), and nominal rents are basically flat. In the end, the return on their investment properties has fallen sharply. Finally, even though landlords are on average wealthier than outright owners, the latter have no investment properties and, other than their own home, invest only in government bonds, which see their return increase. This highlights how monetary policy can have distributional implications through the housing market, sometimes in unexpected ways.

4.2 Behavioural Frictions

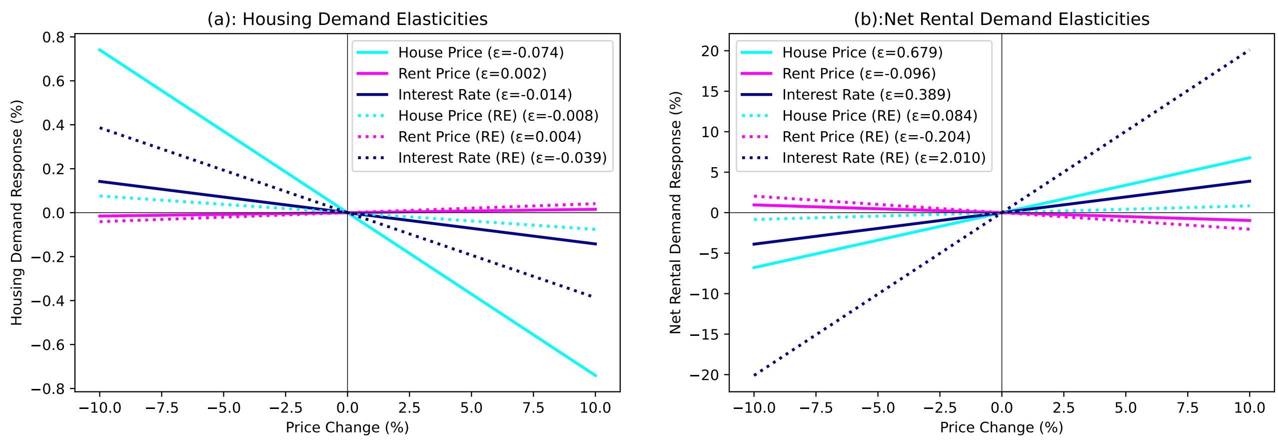


Figure 7: Housing Market Elasticities

Notes: This figure reports the elasticities of aggregate housing demand and net rental demand with respect to near-permanent changes in house prices, rental prices, and interest rates. Elasticities are computed by summing the first row of the Jacobian matrices for household net demand responses to each price change. The "RE" (rational expectations) case is shown with dotted lines. Net rental demand incorporates endogenous landlord supply responses. The elasticities are constant because we approximate the model dynamics using a first-order perturbation method.

Section 3.6 established that incorporating behavioural expectations seemed essential for aligning the model's macroeconomic dynamics with empirical evidence. This section examines more deeply how deviations from rational expectations affect the transmission of monetary policy to housing markets.

Figure 7 presents the elasticities of net demand in the housing and rental markets with respect to three key prices. Specifically, we compute the immediate demand response to a quasi-permanent increase in each price.[21] The figure compares elasticities under our baseline behavioural specification (solid lines) with those under rational expectations (dotted lines), isolating the effects of departing from the rational expectations benchmark.

Consider each price in turn. The interest rate (dark blue) generates substantial elasticities under both specifications, with the primary effect of behavioural expectations being to dampen responses in both markets. The elasticities to rental price change (pink) are relatively small in both markets. In the housing market, this modest effect reflects limited tenure segmentation: when households can substitute between owning and renting, the rental price has little impact on aggregate housing demand. Even in the rental market itself, the elasticity to rents is small compared to other prices. This follows from the relative magnitudes involved – a 10% rent increase represents a small cost compared to a 1% house price change or compared to the substantial real and financial frictions associated with tenure transitions.

The house price generates the largest effects in both markets and, unlike for the interest rate and rental price, behavioural expectations substantially amplify its response. This amplification stems from households' insufficient updating of house price forecasts. When house prices fall persistently, households fail to fully internalize that prices will remain low or decline further tomorrow. This makes households climbing the housing ladder more eager to purchase today (before perceived future price increases), while those descending the ladder become less willing to sell (expecting better future prices). Both forces increase current housing demand beyond the rational expectations benchmark. In the rental market, lower house prices today exert stronger effects when renters and prospective landlords react more to current prices without fully anticipating persistently low future prices. The net result is that behavioural frictions attenuate the house price decline needed to clear the housing market following an interest rate increase, implying higher initial house prices relative to the rational expectations baseline. These elevated house prices generate higher demand (or reduced excess supply) in the rental market, necessitating higher rental prices to restore equilibrium.

4.3 HANK vs RANK

In the section above we highlighted how behavioural frictions alter the transmission of monetary policy. In this section we analyse whether similar results could have been achieved with a simpler representative agent model.

To do so we develop a RANK model in Appendix D.3 that shares the same calibration with our HANK model. In this model, housing is also fixed in supply, and the output structure of the economy is the same. The representative households chooses both how much housing to own h_t and housing services to consume $h_{l,t}$. Since there is no heterogeneity, in equilibrium

[21] We define quasi-permanent as a 400-quarter horizon.

we have $h_t = h_{l,t}$. Moreover, this lack of heterogeneity both amongst renters and amongst landlords implies that there is a single rental price, which is fully flexible. As we argue below, this is not a key assumption.

Figure 8 compares the IRFs of output, real house prices, and real rental prices for our baseline HANK model with behavioural frictions, and the analogous RANK model. We also include the rational expectations versions of both HANK and RANK models for completeness. Panel (a) reveals that the fall in output in the HANK behavioural version is more persistent than in the RANK one. As we discussed above, in our HANK model house prices matter for monetary policy transmission, while in a RANK model all the transmission comes from direct interest rate channels. Thus, this depressed output can in partly be explained by Panel (b), which shows real house prices falling more in the HANK version as well. In turn, the lower output in the HANK setting will also push house prices lower, highlighting the important interaction of housing and non-housing sectors in a HANK setting.

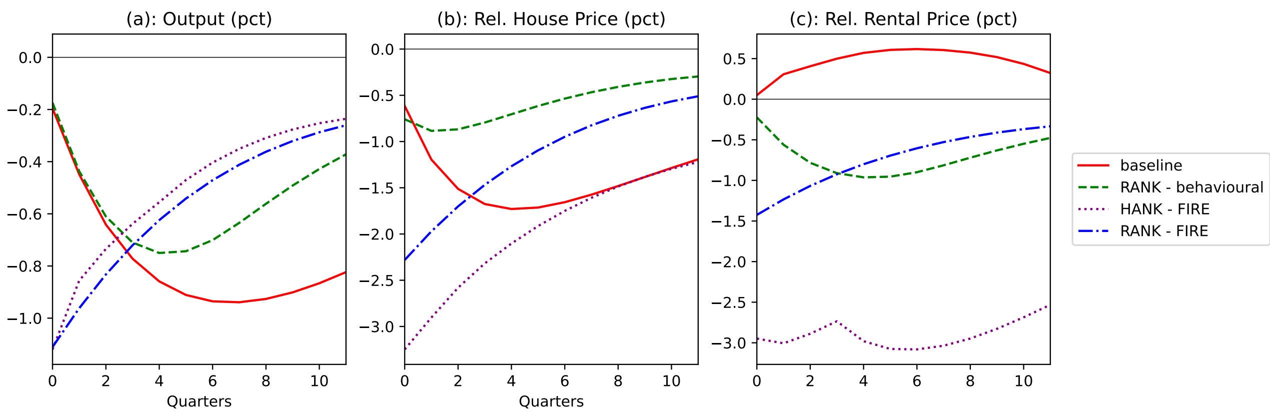


Figure 8: Comparison with Frictionless Benchmark

Notes: this figure displays IRFs for the baseline model (solid line), the baseline model under rational expectations (dotted line), a RANK version with behavioural expectations (dashed line), and a RANK version with rational expectations (dashed-dotted line).

However, the biggest difference between the RANK and the HANK model is visible in Panel (c): rental prices increase in the baseline model, but fall under the behavioural RANK. This is because in the RANK model rental prices equal the ratio of marginal utilities of housing and consumption:

$$p_{r,t} = u_{h,t}/u_{c,t}. \tag{15}$$

With fixed housing supply but falling consumption (i.e., increasing marginal utility), real rental prices must fall after an increase in interest rates, which is not in line with the data.[22] Finally, notice that real rental prices must fall in RANK model, regardless of its stickiness.

Moving on to the two FIRE models, the IRFs in Panels (a) and (b) of Figure 8 are as expected: the peak response of output and real house prices is on impact. However, Panel

[22]With time-varying housing investment it would be possible for housing consumption to fall as well. However, it does not seem plausible that housing consumption would fall more than non-housing consumption, since the latter is a jump variable.

(c) shows that the HANK with FIRE also sees a fall in real rental prices. This highlights the importance of the interaction between deviations from rational expectations and the HANK setting present in our baseline model to deliver an increase in real rental prices. The reasoning is as follows: first, with the frictions allowed by the introduction of heterogeneity there is no more intra-temporal decision between consumption and renting that gives rise to an optimality condition of the type in Equation (15). The rental decision is now a discrete one across time periods, breaking this direct link. Second, behavioural frictions determine what are the expected capital gains by prospective buyers, sellers, and investors, as explained in the section above. With our deviation from FIRE, a smaller fall in house prices is needed to clear the housing market at first since households do not understand that prices will remain low in the future. This pushes up on housing demand, which spills over to the rental market, pushing up on prices. Thus, moving away from a RANK setting combined with deviations from rational expectations, allows our model to match the shape of the house price response, and the relative increase in rental prices.

4.4 Individual Landlords vs Commercial Rental Sector

A distinctive feature of housing markets in many countries is the prevalence of private households acting as landlords. This institutional setting is particularly salient in the UK, where 94% of landlords are individuals, but also in the United States, where 70.2% of rental properties are owned by private individuals (see Ministry of Housing, Communities and Local Government, 2019; Congressional Research Service, 2022). In our baseline model, these private landlords constitute the marginal suppliers of rental housing.

To assess the importance of this modelling choice, we now examine an alternative specification where the marginal supplier is a deep-pocketed commercial sector – a common assumption in macroeconomic models (e.g., Iacoviello, 2005; Kaplan et al., 2020). This sector is composed of rental firms that can enter the market, buy flats, and rent them to households. Commercial properties are subject to the same stickiness θ_r in rental price contracts. Thus, their expected profits upon entry, when the rental price of new contracts is $p^*_{r,t}$, are given by:

$$\Pi^E_{cm,t} = p^*_{r,t} - \delta_h H_1 - F_{cm} - H_1 p_{h,t} + \theta_r \frac{\mathbb{E}_t[p_{h,t+1} H_1]}{1 + r_{t+1}} + \mathbb{E}_t\left[\sum_{s=1}^{\infty}\left\{(1-\theta_r)^s\left(\frac{p^*_{r,t}}{\prod_{\tau=1}^{s}(1+i_{t+\tau})} - \frac{(\delta_h H_1 + F_{cm})}{\prod_{\tau=1}^{s}(1+r_{t+\tau})}\right) + (1-\theta_r)^s\theta_r \frac{p_{h,t+s+1} H_1}{\prod_{\tau=1}^{s+1}(1+r_{t+\tau})}\right\}\right] \tag{16}$$

where F_{cm} is a per-period cost of operating the commercial rental firm to ensure commercial landlords charge the same rental price as private landlords in the steady state of the baseline model. Notice that all variables above are in real terms as usual, and that rental prices are discounted using the nominal interest rate because rental contracts are sticky in nominal terms.

To maintain comparability with the baseline steady state we assume this commercial sector is perfectly competitive with free entry, such that expected profits upon entry $\Pi^E_{cm,t}$ are equal to zero in equilibrium.[23] These assumptions allow us to set a zero measure of private landlords in steady-state, but they might enter the market after a monetary policy shock.

Defining auxiliary variables:

$$
\begin{aligned}
v_{1,t} =& 1 + \frac{(1-\theta_r)}{1+i_{t+1}}\mathbb{E}_t[v_{1,t+1}] \\
v_{2,t} =& 1 + \frac{(1-\theta_r)}{1+r_{t+1}}\mathbb{E}_t[v_{2,t+1}] \\
v_{3,t} =& \frac{\theta_r p_{h,t+1} H_1}{1+r_{t+1}} + \frac{(1-\theta_r)}{1+r_{t+1}}\mathbb{E}_t[v_{3,t+1}]
\end{aligned}
$$

we can now re-write the free-entry condition $\Pi^E_{cm,t} = 0$ using Equation (16) as:

$$0 = p^*_{r,t} v_{1,t} - (\delta_h H_1 + F_{cm}) v_{2,t} - p_{h,t} H_1 + v_{3,t} \tag{17}$$

In the equation above, when $\theta_r = 1$ (contracts reset every period) there are no continuation values and we have $v_{1,t+1} = v_{2,t+1} = 0$, but now the commercial landlords will sell back their property next period with certainty ($v_{3,t+1} = \mathbb{E}_t[p_{h,t+1}H_1/(1+r_{t+1})]$). Thus, Equation (17) reduces to the usual no arbitrage pricing equation:

$$p_{h,t} H_1 = p^*_{r,t} - (\delta_h H_1 + F_{cm}) + \mathbb{E}_t\left[\frac{p_{h,t+1}H_1}{1+r_{t+1}}\right] \tag{18}$$

Notice that the Equation (17) imposes a direct relationship between the net present value of the spot rental price, the net present value of providing the rental unit while the rental price is fixed, and the expected capital gains. While private landlords also take these into consideration, they do so under borrowing constraints and more relevant housing indivisibility and transaction costs. In our baseline model they do so under biased expectations as well, but in this section we also analyse a model in which landlords have rational expectations.

Figure 9 compares what happens under this new commercial rental sector setting (dashed green) against the baseline model (solid red) and the model with landlords with rational expectations (dash-dot blue), holding the real interest rate path constant. The most striking difference between the baseline and commercial specifications appears in rental price dynamics: rents respond substantially more when commercial landlords are the marginal suppliers.[24]

This amplified rental response reflects the fact that commercial landlords are modelled as rational, forward-looking, and financially unconstrained. To illustrate that, we calculate total return on rental units, defined as four quarters of rental income at price $p_{r,t}$ (since rental

[23] Total profits from the commercial sector are given by $\Pi_{cm,t} = \mu_{cm,t}(r_t - \delta_h H_1 - F_{cm}) - (\mu_{cm,t} - \mu_{cm,t-1})p_{h,t}H_1$, where $\mu_{cm,t}$ is the mass of commercial sector firms. All profits are rebated to households as dividends, alongside those from the production sector.

[24] Corsetti et al. (2022) provide tentative evidence that commercial landlords in Germany raise rents sharply following interest rate increases, while individual landlords do not. Moreover, the larger commercial rental sector in the United States (Congressional Research Service, 2022) may explain why some studies find nominal rental price increases following U.S. monetary tightening (Dias and Duarte, 2019; Albuquerque et al., 2024), while we find flat nominal rents in the UK.

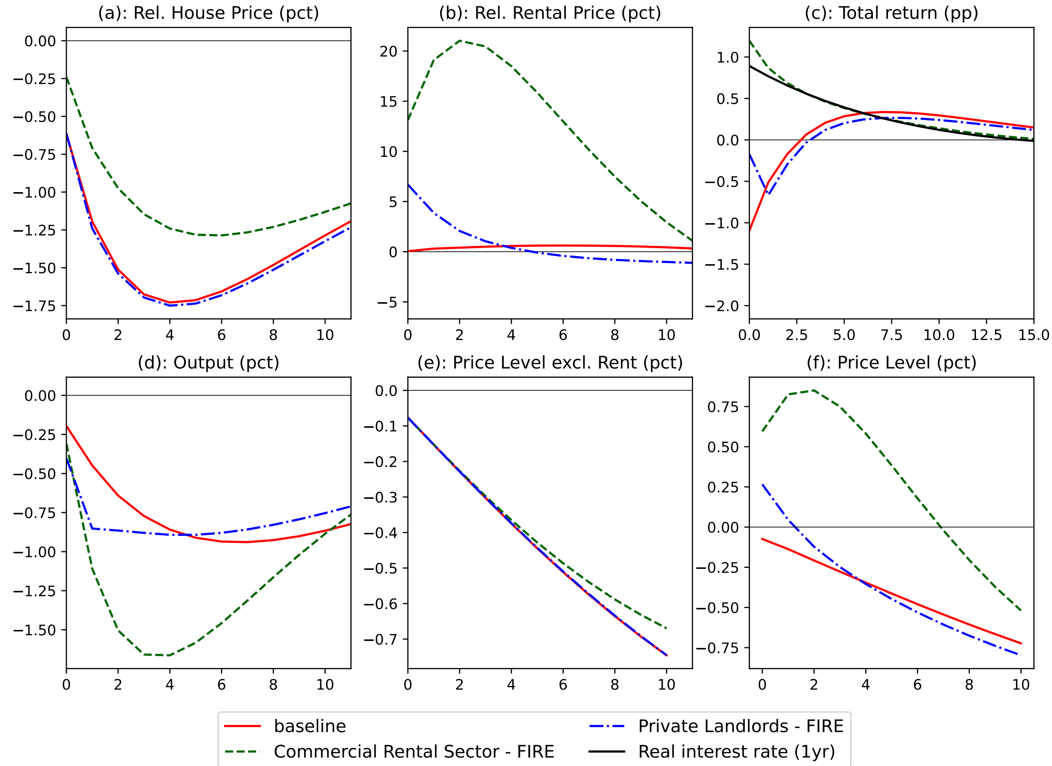


Figure 9: Role of Individual Landlords

Notes: This figure displays impulse responses to a 1 percentage point monetary policy shock for three model specifications: the baseline IRF-matched model (solid line), the model with a marginal commercial landlord sector (dashed line), and the baseline model in which landlords have ration expectations (dashed-dotted line). The monetary policy shocks are calibrated to generate identical real interest rate paths across specifications. Panels (a) and (b) show house prices and rents, respectively, relative to non-housing goods prices. Panel (c) displays the real interest rate path (black) and the total one-year return on housing, defined as rental yield plus capital gains: $\frac{(4p_{r,t}+p_{h,t+4}-F)}{p_{h,t}+F} - 1$. Panel (e) shows the price level calculated by excluding rental prices from the CPI basket.

contracts have an average duration of four quarters) plus realised capital gains. Panel (c) reveals that commercial investors price rental contracts close to the opportunity cost of investing in government bonds. In this scenario, they demand higher rental yields consistent with Equation (17), since the discount rate is increasing and house prices are expected to fall.

In contrast, under our baseline behavioural specification private landlords update expectations too slowly and fail to require the increase in the return of being a landlord in line with the increase in the opportunity cost. In this sense, private landlords are the losers from the interest rate increase, both in the data (Figure 1) and in the model, which helps explain their consumption response in Figure 6.

Given that rental yields comprise both rental income and capital gains, why do the specifications under private vs commercial landlords differ primarily in rental price dynamics rather than house prices? Figure 7 provides the answer: the elasticity of house prices with respect to rental prices is very small. Consequently, introducing a commercial rental sector leaves the overall house price path largely unchanged, as it remains determined by private households with sluggish expectation formation. With limited feedback from the rental market to house prices, the adjustment in rental yields operates almost entirely through rental prices rather than capital gains.

Figure 9 also makes it clear that the difference between the baseline and commercial rental sector exercises is not soley due to the assumption on expectations. In the IRFs for the model in which private landlords have rational expectations (while the other households continue to have the same behavioural expectations) we can see that the results are more in line with the baseline model. It is true that real rental prices jump on impact – which is not in line with the data – but the responses after four quarters of house and rental prices are very similar. With rational expectations, private landlords also want to price their rental properties such that their return is near the correct expected path for bond returns. However, without deep pockets and with transaction constraints, they are not able to do so. Moreover, it is also the case that different specifications for landlords have a bigger impact on rental than housing markets.

Finally, the bottom row Figure 9 shows that modelling assumptions on landlord behaviour have important implications for optimal policy. Output falls significantly more under the commercial landlord specification, as sharply higher rental prices reduces non-housing consumption among renters, who have higher marginal propensities to consume. The overall CPI (including rents) even rises initially in this specification.

To quantify the stabilization trade-off, we compute sacrifice ratios defined as the average annual output loss over three years required to achieve a 1 percentage point average disinflation over the same horizon. The sacrifice ratio under the commercial rental sector specification (21.5) is approximately twice that of the baseline model (11.4), and that is also true (19.6 versus 11.2) when considering core CPI excluding rents.[25] This occurs even for the CPI ex-rents due to a labour supply effect whereby a large rise in rents pushes down considerably on renters consumption. This causes a large increase in labour supply from renters which mitigates the deflationary consequences of the large fall in output by driving a wedge between the marginal cost gap in the Philips curve and the output gap. Thus, correct modelling of the rental sector – commercial vs individual landlords, rational vs behavioural expectations – appears important for understanding the trade-off faced by policymakers.

4.5 Extensions

To investigate and clarify the importance of further assumptions in our baseline model, we now extend it in several different directions. In all cases, except the one with additional selling frictions, the steady-state of the model is exactly the same. Thus, we do not re-estimate parameters to clearly display solely the impact of the change in question. The equations with the detail of the modifications under each extension are in Appendix E.

Figure 10 shows the IRFs of output, real house prices and real rental prices under each extension and below we discuss what happens in each of those cases under our baseline assumption of behavioural frictions for expectations. In all of these cases these added frictions

[25] The sacrifice ratio is calculated as average annualized output loss divided by average year-over-year (Q4/Q4) inflation change.

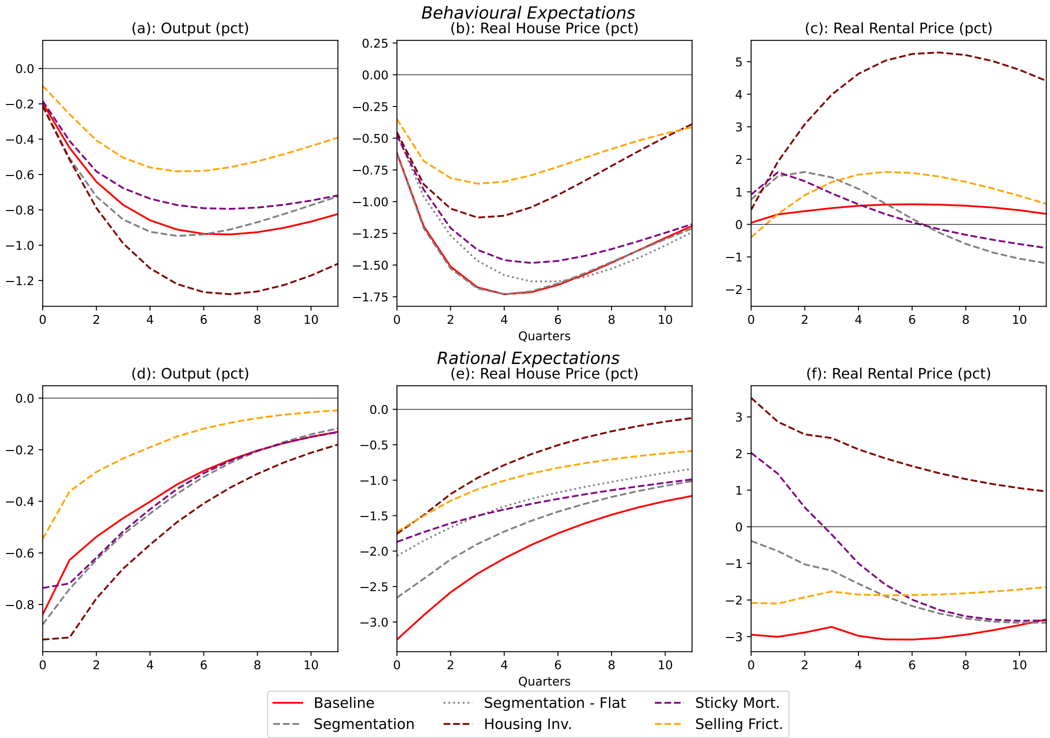


Figure 10: Extensions

Notes: this figure shows the responses of different variables to a 1p.p. monetary policy shock under the baseline model and the four extensions considered in this section: (1) additional market segmentation, (2) endogenous housing supply, (3) sticky mortgage rates, and (4) selling frictions. Under extension (2) flats and houses have different prices, thus there are two different responses of prices. The bottom row plots the responses under rational expectations.

dampen the fall in house prices, which then pushes up on the response on rental prices relative to our baseline model. Figure 10 also displays the responses of those variables under Rational Expectations to investigate whether these extensions could deliver the delayed response of house prices and the increase in real rents that we observe in the data, without the need for the behavioural frictions we emphasized. While some extensions are able to deliver an increase in real rents under Rational Expectations, none of them are able to delay the peak fall on house prices on their own – house prices fall the most on impact in every case. This result further emphasizes the need for behavioural frictions to match the response of housing market variables to monetary policy shocks.

4.5.1 Additional Market Segmentation

Several papers in the literature have emphasized that the degree of segmentation between the rental and housing markets can be important for aggregate outcomes (Kaplan et al., 2020; Dias and Duarte, 2022; Greenwald and Guren, 2025). In our baseline model there is partial segmentation between those markets, since flats can be both rented and bought by homeowners, but houses cannot be rented. Thus, the share of renters can fluctuate over time. However, studies like Greenwald and Guren (2025) have argued for substantial segmentation. In order to investigate what would happen under those conditions we change our assumption on the supply of housing, such that now there is a fixed supply of rental flats $\overline{H}_F$ with its own price $p_{h,F}$. Owner-occupied housing, which is still composed of both houses and flats, also has a fixed supply $\overline{H}$, with its own price p_h. With this increased segmentation the price of flat and houses can move in different ways, and owner-occupied housing cannot be converted into rental units. Therefore, the share of households that are renters is now fixed.

Figure 10 shows that in this case the rental price increases more on impact. This happens because the increase in the demand for flats relative to houses after an increase in interest (and mortgage) rates cannot be partially met by landlords converting owner-occupied housing into rental units any more. With the supply of rental flats fixed, rents increase by more. As in the baseline case, this development in the rental market has little effect on the price of the much larger housing market, and the response of the price of owner-occupied housing p_h is the same as in the baseline case. However, the price of rental flats $p_{h,F}$ falls by less, since they are the only type of housing that can be used to supply the increased demand for rental units.

4.5.2 Endogenous Housing Supply

Given our analysis has a short to medium term horizon and that it can take several years between a company starting a housing project and putting it into market, we assume in our baseline model that housing supply is fixed. However, it could be that housing investment falls abruptly after an increase in interest rates, which could keep house prices elevated. To investigate this issue we follow Kaplan et al. (2020) and introduce endogenous housing supply through a housing investment firm that combines final goods with land permits purchased from the government to build houses, and sell them to households. Given our assumptions, the elasticity of housing investment to real house prices will be equal to $\alpha_i/(1-\alpha_i)$, where α_i is the share of final goods in the production function for housing goods (and $1-\alpha_i$ is the share of land). We set $\alpha_i = 0.2$ so that the response of housing investment is in line with our estimated response of construction sector activity in the UK, as shown in Figure E.1.

Figure 10 shows that the endogenous decline in housing supply is such that both rents increase more on impact and house prices fall by less. Both make sense, since the reduced investment in the housing market causes a fall in housing supply, both for owner-occupiers and for renters. In the Rational Expectations case this fall is enough to cause an increase in rental prices, but the response of house prices still falls the most on impact. Interestingly, Figure E.1 shows that housing investment displays a hump-shaped response in line with the data in the case with behavioural frictions, but not in the case of Rational Expectations.

4.5.3 Sticky Mortgage Rates

In our baseline model the mortgage rate is variable, even though mortgage contracts are long-term since LTV and LTI constraints only bind on origination. We used this simplifying assumption because keeping track of individual fixed mortgage rates for each household would be computationally costly since it would add another individual state variable. Furthermore, this assumption is also less stark in the UK than in the US, since in the former mortgage fixation periods are between 2 and 5 years, with most households opting for either 2 or 3 year fixations.

However, in our model part of the reason why house prices go down but rent prices do not is that mortgage rates go up. Thus, to investigate the sensitivity of our results to this assumption without adding an unfeasible computational burden we extend the model to assume that all households pay the same sticky mortgage rate that mimics a 3-year fixation period. This mortgage rate is priced from the 3-year nominal rate and its value is an average of its last period value and the spot mortgage rate, each with weights of (11/12) and (1/12), respectively, to match the 12 quarters average fixation period. Figure 10 shows that in this scenario house prices fall by less and rents increase by more, since mortgage rates go up by less as well.

4.5.4 Selling Frictions

Prior research has highlighted the relevance of search and matching frictions in the housing market, arguing that transactions are not instantaneous but require time and effort for buyers and sellers to find suitable matches (Wheaton, 1990; Piazzesi and Schneider, 2009; Diaz and Jerez, 2013). In the baseline setting, even though there are fixed transaction costs F and utility costs of moving η_m, there is no doubt whether a sale will be made – in the centralised market house prices adjust such that every willing buying and seller find a match.

We introduce selling frictions in the housing market following Garriga and Hedlund (2020). In this setting sellers need to match with a broker to be able to sell their house, but the market between brokers and house buyers is centralised and frictionless. We then reinterpret the fixed cost F of selling a house in our baseline model as the fee that must be paid to brokers in order to sell the house. With a free-entry condition for brokers, a fixed transaction cost implies a fixed selling probability for sellers, as we detail in Appendix E.[26] If a sale fails the household still pays the utility cost for trying to sell it.

Figure 10 shows that moving from a centralised market to one with search-and-matching frictions magnifies the increase in rental prices and reduces the fall in house prices as it is now more costly to sell your house, and this reduces the downward pressure on house prices. Again, these relatively higher house prices spillover into greater demand pressure in the rental market. However, as with the other extensions above, the frictional market for houses on its own is not able to revert the steep fall of house prices on impact, nor the decrease in rents in this case, under Rational Expectations.

5 Conclusion

This paper has studied how monetary policy transmits through, and is shaped by, housing and rental markets, combining new UK evidence with a quantitative HANK model. Using a high-frequency-identified proxy SVAR, we document that a contractionary shock produces a large fall in nominal house prices that does not peak on impact, while nominal rents stay flat and

[26] In Garriga and Hedlund (2020) and Hedlund et al. (2025) this fee is endogenous, generating endogenous selling probabilities. Incorporating this is beyond the scope of our model.

real rents rise. We rationalise these facts in a HANK model with discrete tenure choice, long-term mortgages, behavioural expectations, and a rental sector supplied by individual landlords. Three ingredients prove essential: sticky and extrapolative expectations delay and amplify the house price decline; heterogeneity and discrete tenure choice allow real rents to rise after a tightening; and credit-constrained landlords with sluggish expectations fail to pass higher required yields through to tenants. This incomplete pass-through is first-order for policy: relative to a counterfactual with rational commercial landlords, it roughly halves the output cost of disinflation, while leaving landlords themselves as relative losers from the tightening.

Several extensions seem promising. The framework could be used to study optimal monetary policy in response to a wider set of shocks along the lines of the exercise in Appendix D.2, and to evaluate rental-market and macroprudential interventions whose effects operate through the tenure-choice and landlord-supply margins we model. Our methodological contribution of embedding jointly sticky and extrapolative expectations within the sequence-space Jacobian framework also provides a portable toolkit for introducing disciplined departures from rational expectations into other heterogeneous-agent models.

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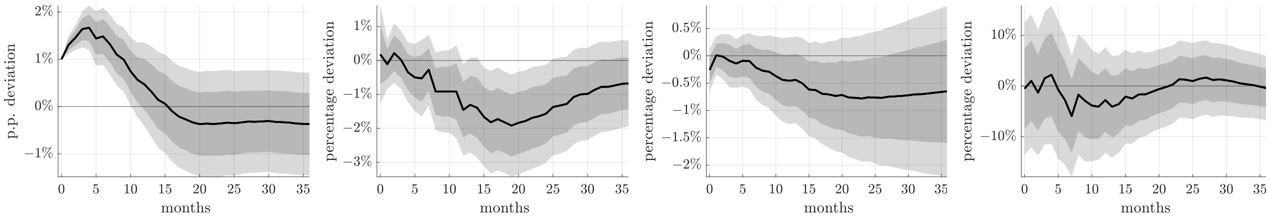
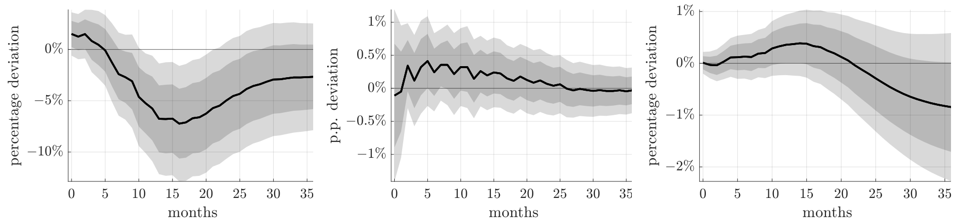
A Additional figures and tables



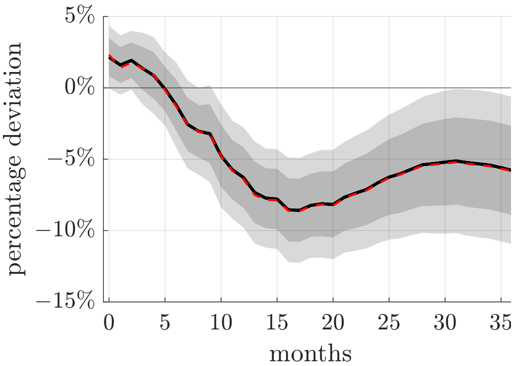
(A) Bank Rate (B) GDP (C) CPI core, ex-rent (D) FTSE



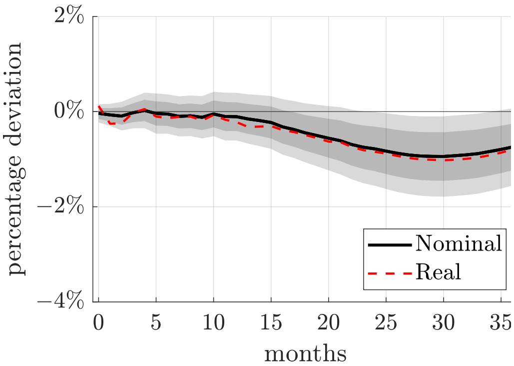
(E) House Prices (F) Mortgage Spread (G) Rents

Figure A.1: Baseline VAR, IRFs to 1p.p. Bank Rate shock

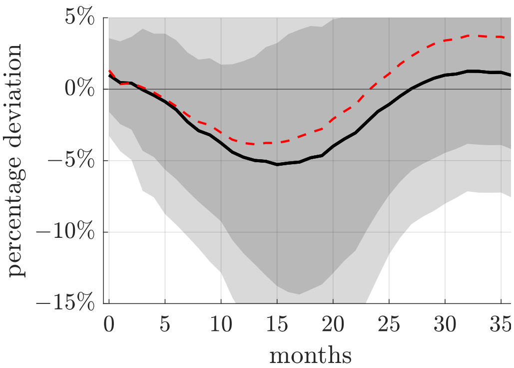
Notes: this figure shows the response to a 1p.p. Bank Rate shock of all the seven variables included in our baseline VAR, where Bank Rate is instrumented with the target factor as explained in Section 2. The variables included are: (A) Bank rate, (B) seasonally adjusted Consumer Price Index (CPI) core excluding rents, (C) seasonally adjusted monthly GDP, (D) seasonally adjusted UK House Price Index from the Office for National Statistics (ONS), (E) the real level of the FTSE 100, (F) the spread between the rate on 75% LTV mortgages and the 2 year yield, and (G) the ONS Index of Private Housing Rental Prices for England, spliced with UK CPI's "Owner Occupied Housing" component. The shaded areas represent 68 and 90% confidence intervals. Confidence intervals are calculated using a residual-based moving block bootstrap.



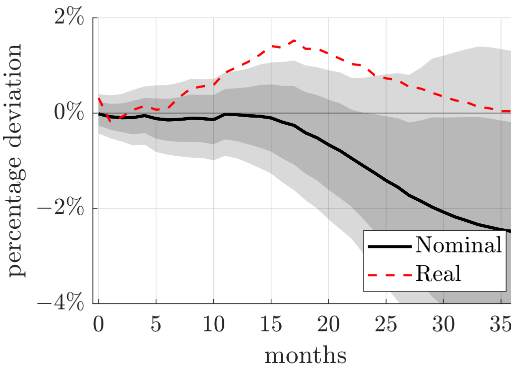
(A) House prices (1997-2019)



(B) Housing rents (1997-2019)



(C) House prices (2005-2023)



(D) Housing rents (2005-2023)

Figure A.2: House prices and housing rents: response to a 1p.p. Bank Rate shock

Notes: this figure shows the IRFs of the ONS House Price Index and ONS Index of Private Housing Rental Prices for the pre-covid period from 1997 to 2019 in panels (A) and (B); and for the post-2005 period in panels (C) and (D). For the 1997-2019 case the ONS Index of Private Housing Rental Prices is spliced with UK CPI's "Owner Occupied Housing" component. It is the same exercise as in Figure 1, for a different time sample. Solid black lines show the response of nominal indices, while dashed red lines are real variables (i.e., the response of the nominal variable minus that of CPI core ex-rent). Grey shaded areas indicate 68 and 90% confidence intervals. Confidence intervals are calculated using a residual-based moving block bootstrap.

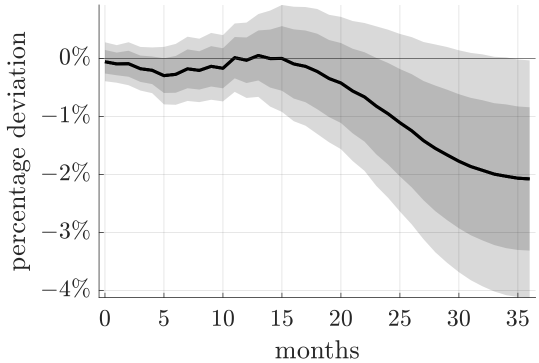


Figure A.3: Response of CPI-OOH, post 2005

Notes: this figure shows the response of the Owner Occupied Housing component of CPI to a 1p.p. monetary policy shock, estimated in the post-2005 period. This is the measure of rents from the pre-2005 period used to splice with our preferred measure of rents, the Index of Private Housing Rental Prices from the ONS. Compared to Figure A.2D, it shows that both variables show a similar response to monetary policy shock in the period they overlap.

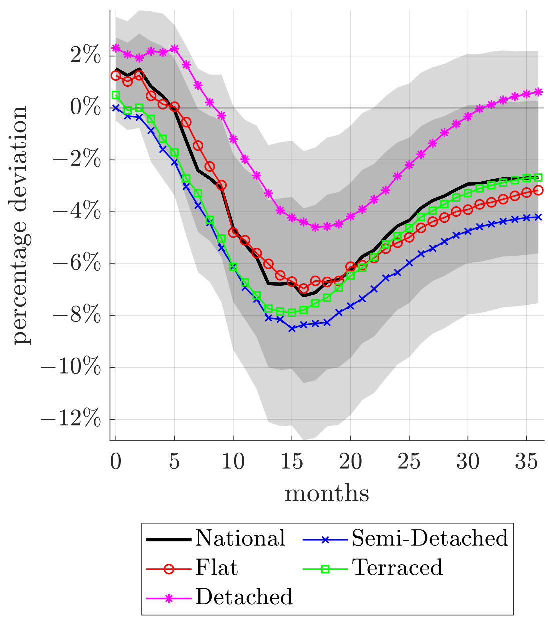


Figure A.4: Response of house prices by dwelling types

Notes: this figure shows the response of the ONS House Price Index by dwelling type in England to a 1p.p. monetary policy shock. In all cases, they house price index in the 7 variable VAR was swapped for the index for the particular dwelling type, and estimated over the same period (1997-2023). The solid black line and the grey shaded areas are the point estimate and the confidence intervals from the national response in Panel (A) of Figure 1. Confidence intervals are calculated using a residual-based moving block bootstrap.

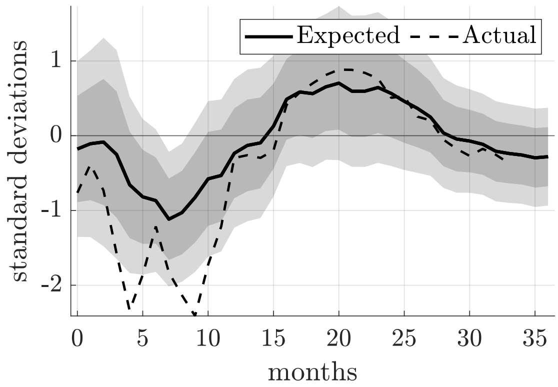
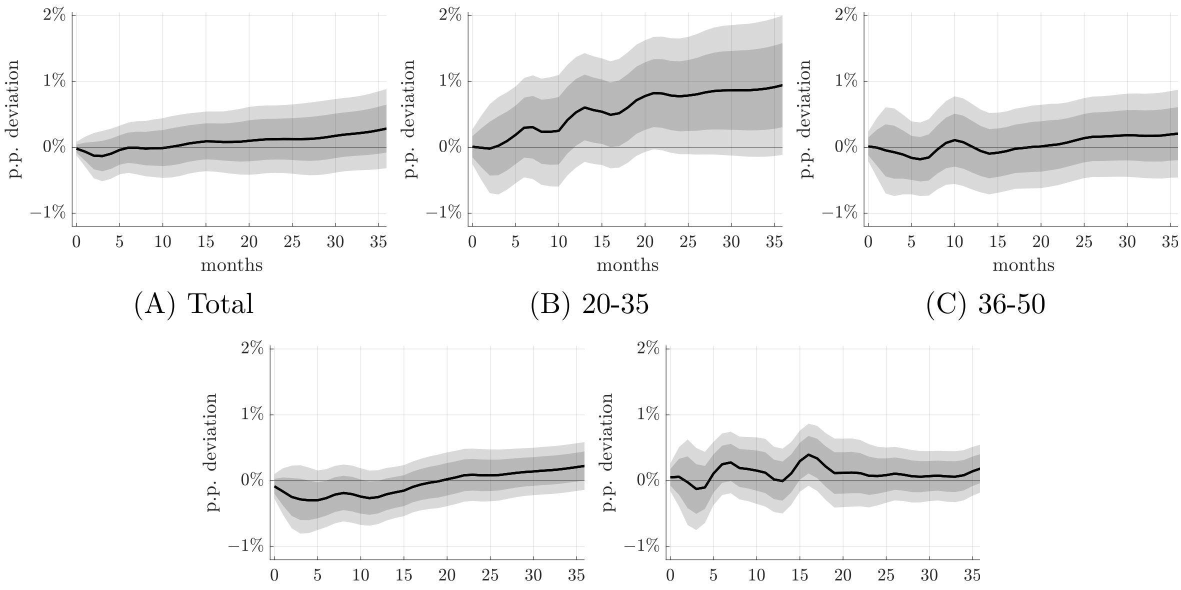


Figure A.5: House price expectations by surveyors, normalised

Notes: this figure shows in the solid black line the response of the mean-variance normalised net balance 3-months house price expectation for England and Wales from RICS. In the dashed line it shows the actual 3-months ahead realised price growth for the UK, consistent with the IRF in Panel (A) of Figure 1. This variable is also normalised, by dividing by the historical standard deviation of 3-months log house price growth. The grey shaded areas are 68 and 90% confidence intervals for the house price expectations point estimate. Confidence intervals are calculated using a residual-based moving block bootstrap. *Source*: RICS, 1998 - 2023.



(A) Total (B) 20-35 (C) 36-50

(D) 51-65 (E) >65

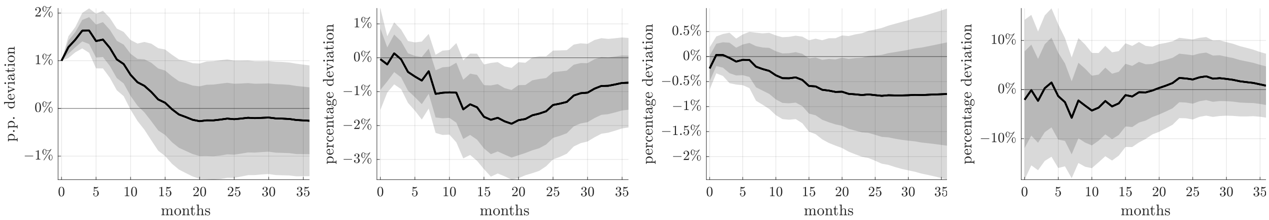
Figure A.6: Share of renters - total and by age

Notes: Panel (A) shows the response of the percentage of households in the UK that declare themselves renters in the LFS. Panels (B) to (E) show the response of the share of renters by age of the head of household. The average share of renters from 1997 to 2019 for the total population is equal to 29.0%. For Panels (B) to (E) these averages are: 44.3, 26.7, 20.0 and 23.8%. The sample stops at 2019 due to declining response rates in the LFS after Covid. The grey shaded areas are 68 and 90% confidence intervals. Confidence intervals are calculated using a residual-based moving block bootstrap.

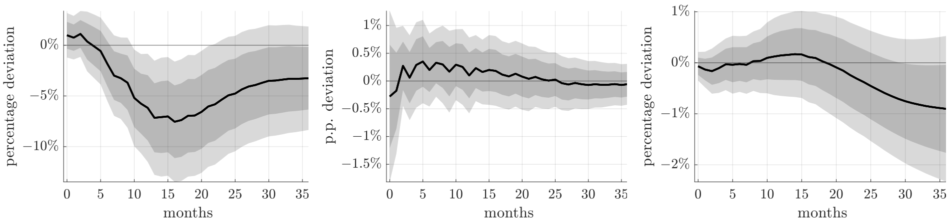
B Empirical results with different instruments

In this section we report our main empirical results using instruments other than the target factor of the main text. In all cases, we estimate the VAR with 7 variables that includes rents.

In general, we have found that the path factor has a very low first-stage F-statistic and so do not include results here using it as an instrument for the one year yield or for the mortgage itself. The only case with a F-statistic higher than a rule of thumb threshold of 10 is in Figure B.4, in which it is an instrument for the mortgage spread. We do not report results instrumenting Bank Rate with the path factor, as by design the loading of the path factor on the shortest end of the yield curve is near zero.



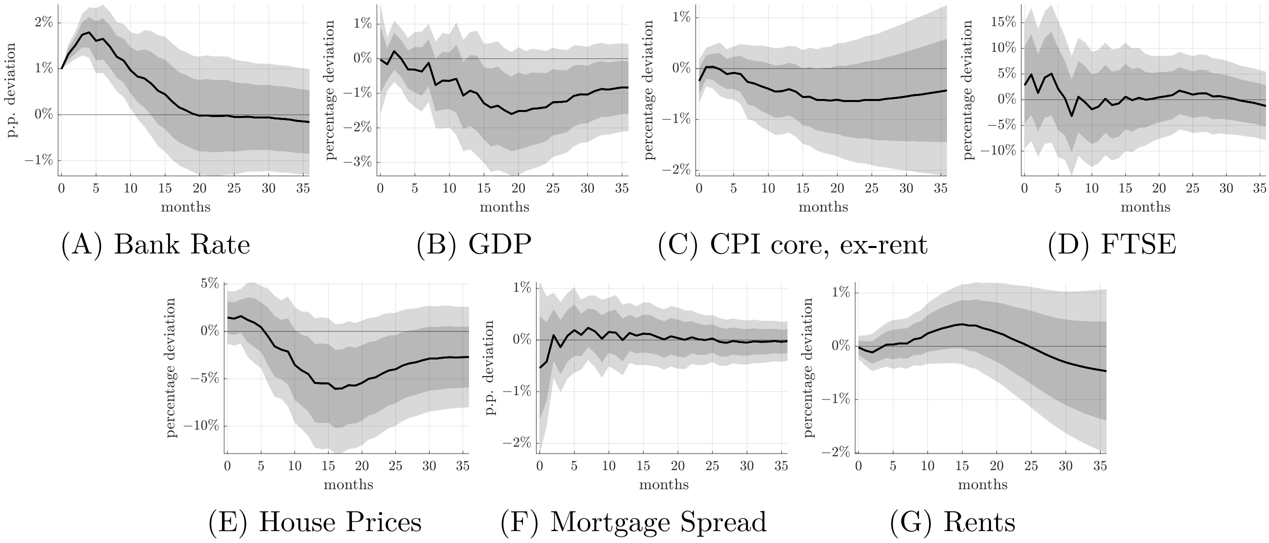
(A) Bank Rate (B) GDP (C) CPI core, ex-rent (D) FTSE



(E) House Prices (F) Mortgage Spread (G) Rents

Figure B.1: Bank rate instrumented with the sign-restricted target factor

Notes: this replicates Figure A.1, with the sign-restricted target factor as the instrument for Bank Rate. The sign restriction is implemented as the "poor-man's restriction" as in Jarociński and Karadi (2020), setting the shock equal to zero if the high-frequency responses of the FTSE and the target factor had the same sign. Grey shaded areas indicate 68 and 90% confidence intervals. Confidence intervals are calculated using a residual-based moving block bootstrap.

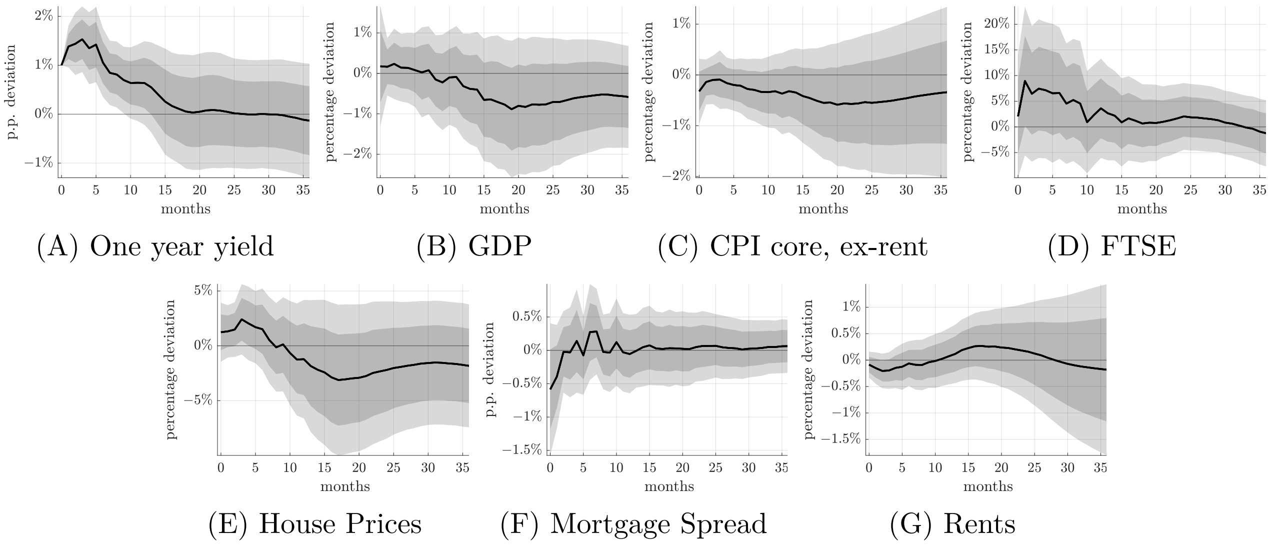


(A) Bank Rate (B) GDP (C) CPI core, ex-rent (D) FTSE

(E) House Prices (F) Mortgage Spread (G) Rents

Figure B.2: Bank Rate instrumented with FSScm2

Notes: this replicates Figure A.1, with FSScm2 as the instrument for Bank Rate. This series is constructed in Cesa-Bianchi et al. (2020) and consists of high frequency movements around MPC events in the second front contract of 3-month Sterling Futures. Grey shaded areas indicate 68 and 90% confidence intervals. Confidence intervals are calculated using a residual-based moving block bootstrap.

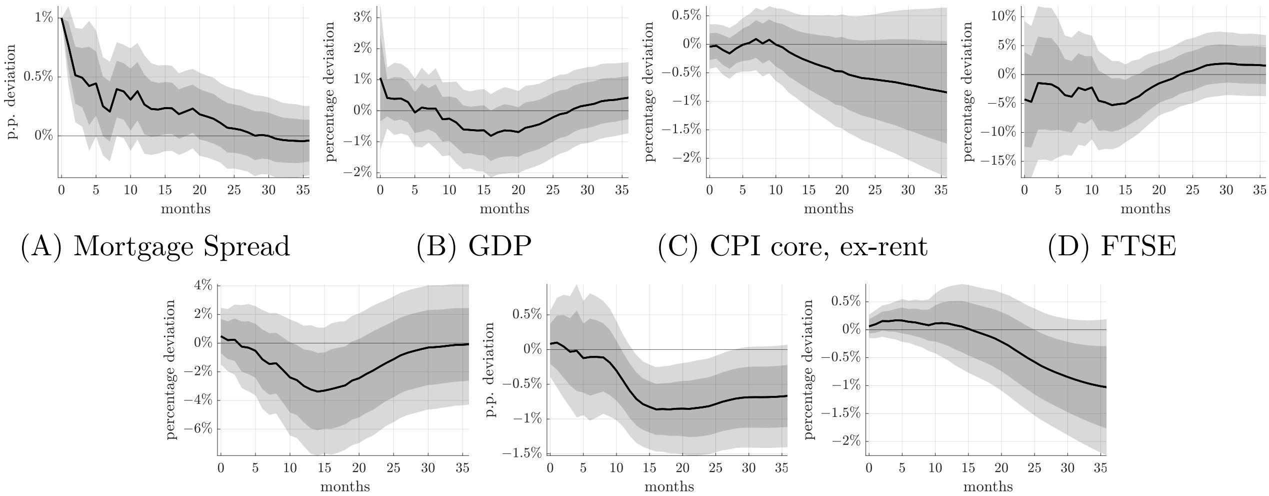


(A) One year yield (B) GDP (C) CPI core, ex-rent (D) FTSE

(E) House Prices (F) Mortgage Spread (G) Rents

Figure B.3: One year yield instrumented with FSScm2

Notes: this replicates Figure A.1, with FSScm2 as the instrument for the one year yield. This series is constructed in Cesa-Bianchi et al. (2020) and consists of high frequency movements around MPC events in the second front contract of 3-month Sterling Futures. Grey shaded areas indicate 68 and 90% confidence intervals. Confidence intervals are calculated using a residual-based moving block bootstrap.



(A) Mortgage Spread (B) GDP (C) CPI core, ex-rent (D) FTSE

(E) House Prices (F) Bank Rate (G) Rents

Figure B.4: Mortgage Spread instrumented with path factor

Notes: this replicates Figure A.1, with the path factor as an instrument for the mortgage spread, to capture long-term funding of mortgages in the UK. Grey shaded areas indicate 68 and 90% confidence intervals. Confidence intervals are calculated using a residual-based moving block bootstrap.

C Model: additional details

C.1 Calibration and Steady State

The model is discretised using 250 grid points along the financial asset grid (a) and 15 grid points along the idiosyncratic productivity grid (z). Within those, 5 points are used for the permanent productivity process and 3 for the transitory, each discretising their respective AR1 processes using the Rouwenhorst (1995) method. The discretisation along the asset grid varies by housing tenure and is outlined in table C.1. The grids are unevenly spaced, with the bottom 60 percent of points evenly spaced, 60th to 95th percentile evenly spaced, and the top 5 percent of points evenly spaced to make up the remaining distance to the max asset value, which is equal to 8x the house price. We also include 3 grid points to track the individual rental price of renters and landlords around the models steady state.

Table C.1: Asset grid discretisation

Initial Tenure	Low point	60th pct	95th pct	Max
Renter	0	4Y	p_h	$8p_h$
Flat Owner	$-H_1 p_h$	0	$H_2 p_h$	$8H_2 p_h$
Owner	$-p_h H_2$	0	$H_2 p_h$	$8H_2 p_h$
Landlord	$-p_h(\kappa_h + \kappa_{h,LL})$	0	p_h	$8p_h$

C.2 Expectations processes

We model three expectations processes that are specific cases of the following generalised expectations process and mapping into the sequence space.

1. Rational Expectations: $\gamma = 0$, $\delta = 0$
2. Sticky Expectations: $\gamma = 0$, $\delta > 0$
3. Sticky and Extrapolative Expectations: $\gamma \neq 0$, $\delta > 0$

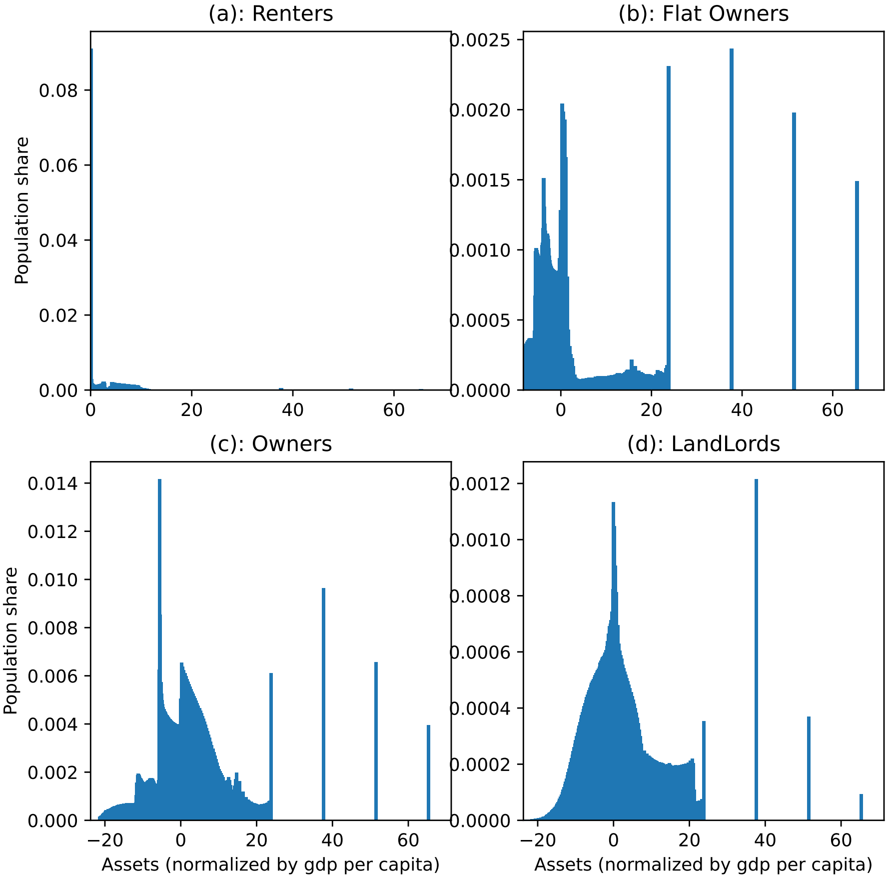
To do so we start from the reduced form regression equations of Kohlhas and Walther (2021) that expresses the forecast errors of agents about an input x, k period ahead, as a function of observations of x today and news about future x, which in their paper[27], is proxied empirically by the average forecast $\bar{f}$ of x in the current and previous period x.

$$x_{t+k} - f_{it} x_{t+k} = \alpha_i + \gamma x_t + \delta(\bar{f}_t x_{t+k} - \bar{f}_{t-1} x_{t+k}) + \varepsilon_{i,t|t+k} \tag{C.1}$$

The parameter γ captures extrapolation from current conditions (the "Extrapolation" effect), while δ captures the reaction to news (the "News" effect). Statistically significant differences from zero of either γ or δ is a rejection of the rational expectations hypothesis.

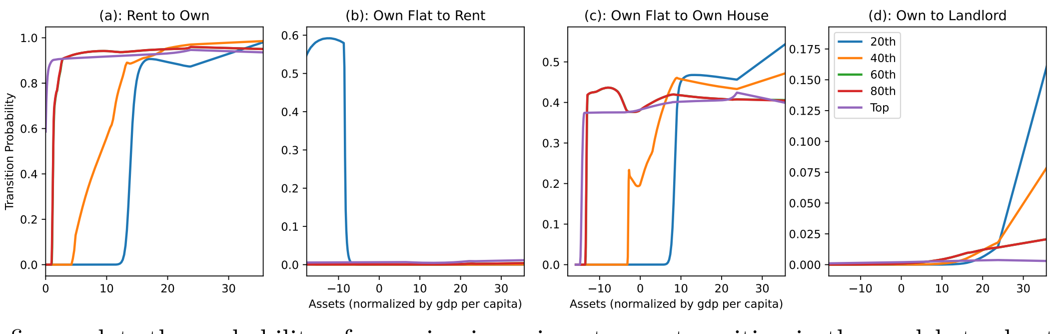
[27]As is typical in this literature

Figure C.1: Asset Distribution by Tenure



Note: this figure plots the share of households at each asset position in the model steady state by tenure. Each bar represents the mass point on the discretised asset grid.

Figure C.2: Transition Probabilities



Note: this figure plots the probability of engaging in a given tenure transition in the model steady state by starting wealth position. Lines are plotted for 5 different points along the labour income distribution.

C.2.1 Implementation in the Sequence Space

Forecasts

The first step in mapping Equation (C.1) into the sequence space is to derive a forecasting equation for x. First we consider taking expectations over Equation (C.1) assuming no correlation of $\epsilon_{i,t|t+k}$ across agents. Doing so and rearranging results in the following expression for the average k period ahead forecast of x:

$$\bar{f}_t x_{t+k} = c + \frac{1}{1+\delta}\left(\delta \bar{f}_{t-1} x_{t+k} + \mathbb{E}_t^*[x_{t+k}] - \gamma x_t\right) \tag{C.2}$$

where we note $\bar{f}_t x_{t+k} = E[f_{it} x_{t+k}]$ and E^* is the perfect foresight (actual outcome) for x. Over and above certainty equivalence we assume: (1) agents have unbiased expectations in the steady state i.e. $c = \frac{\gamma}{1+\delta} x_{ss}$; (2) that for some large T agents expect a return[28] to the steady state x_{ss} and (3) that for agents the law of iterated expectations holds, such that agents do not expect to make forecast errors. These assumptions combine to ensure agents act rationality given their internal beliefs and are internally rational as described by Adam and Marcet (2011).
Starting at the steady state we now consider how the forecast of $x_k = x_{ss} + dx_k$ evolves as we move through time from period 0 to period k. The evolution is as follows:

$$\bar{f}_0 x_k = x_{ss} + \frac{1}{1+\delta} dx_k - \frac{\gamma}{1+\delta} dx_0$$

$$\bar{f}_1 x_k = x_{ss} + \left(\frac{1}{1+\delta} + \frac{\delta}{(1+\delta)^2}\right) dx_k - \frac{\gamma}{1+\delta} dx_1 - \frac{\gamma\delta}{(1+\delta)^2} dx_0$$

$$\bar{f}_t x_k = x_{ss} + \sum_{j=0}^{t} \left(\frac{\delta}{1+\delta}\right)^{t-j} \frac{1}{1+\delta} dx_k - \gamma \sum_{j=0}^{t} \left(\frac{\delta}{1+\delta}\right)^{t-j} \frac{1}{1+\delta} dx_j \tag{C.3}$$

where for the period $t < k$ the first sum represents the news effect which grows over time and converges to perfect foresight for $\delta > 0$. The second sum captures the extrapolation effect, where agents extrapolate from the sequence of realisations of x observed up until period k with greatest weight given to more recent observations. We see that forecasts for x are therefore neatly decomposable as a function of the histories of x and news about x in the future.

General mapping

Bardóczy and Guerreiro (2025) show how generalised expectations processes can be mapped into the sequence space building on the objects derived in Auclert et al. (2021). In the approach of Auclert et al. (2021) the economic model is broken down into a series of decision problems that map block level inputs X to outputs $Y(X)$ in the sequence space. For example household aggregate household consumption C is determined by the real interest rate r, real wage w and distribution of households D in the canonical Aiygari model. Under linear approximation and certainty equivalence deviations in dY can be expressed as a product of dX and a Jacobian

[28]This implies that Equation (5) holds for $k < T$ and that the final model must converge to x_{ss} in general equilibrium.

$J \in R^{T \times T}$ that linearly maps dX to dY. By breaking out Y as a function of realisations of X and forecasts of X^e, $Y(X, X^e)$, Bardóczy and Guerreiro (2025) show how under the assumptions made we can derive a generalised Jacobians $\hat{J}$ as a function of the rational expectation Jacobian J derived in Auclert et al. (2021) and a sequence of forecast for $X^e \in R^{T \times T}$:

$$dY = JdX^{e,0} + \sum_h R_h(dX^{e,h} - dX^{e,h-1}) \tag{C.4}$$

where $R_h = \begin{pmatrix} 0 & 0_h' \\ 0_h & J \end{pmatrix}$ shifts the rational expectations Jacobian diagonally by the horizon h. Equation (C.4) intuitively shows outcomes of Y through the sequence space as depending upon a series of unanticipated shocks to outcomes and expectations of X. For example at time zero a shock hits the economy which might change X today and causes agents to update their expectations of future X^e. The effect of this can be computed with the first row of the rational expectations Jacobian J. If no further shocks happen and there are no revisions to expectations then the we simply continue to apply the rational expectations Jacobian as we move through time (down the rows of J). When further shocks happen or expectations are revised and this is unanticipated (as we've assumed) it is equivalent to another set of unanticipated shocks to which we again can apply the first row of the rational expectations Jacobian J and again move down the rows as we move through time.

Our assumptions and Equation (C.3) tells us forecasts of X only depend upon the the actual realisations X. When this is the case we can define a generalised behavioural expectations Jacobian $\hat{J}$ as a function of those forecasts and the rational expectations Jacobian J. This $\hat{J}$ is independent of any specific path X and conveniently allows us to compute $\hat{J}$ at the block level in partial equilibrium. To do so we we must define forecast matrices $\Lambda_k \in R^{TxT}$ that map the realized (perfect foresight) price path deviations dX into a sequence of forecasts $dX^{e,k}$. With those in hand we can define our behavioural expectations Jacobian $\hat{J}$

$$\hat{J} = J\Lambda_0 + \sum_h R_h(\Lambda_h - \Lambda_{h-1}) \tag{C.5}$$

where $dX^{e,0} = \Lambda_0 dX$ and $dY = \hat{J}dX$.

Forecast mapping

The construction of Λ_k follow from Equation (C.3). Each Λ_k can be subdivided into 4 distict regions. The top left region is the identity matrix I_{k+1} representing the fact agents see inputs today and in history perfectly. Below the identify matrix is A_k which is the extrapolative effect that describes the effect of each observed x (moving along the columns) on forecasts of future X (moving down the rows). The bottom right region is the news effect which is a diagonal matrix B_k.

$$\Lambda_0 = \begin{pmatrix} 1 & 0 & 0 & 0 & \cdots & 0 \\ \frac{-\gamma}{1+\delta} & \frac{1}{1+\delta} & 0 & 0 & \cdots & 0 \\ \frac{-\gamma}{1+\delta} & 0 & \frac{1}{1+\delta} & 0 & \cdots & 0 \\ \frac{-\gamma}{1+\delta} & 0 & 0 & \frac{1}{1+\delta} & \cdots & 0 \\ \vdots & \vdots & \vdots & \vdots & \ddots & \vdots \\ \frac{-\gamma}{1+\delta} & 0 & 0 & 0 & \cdots & \frac{1}{1+\delta} \end{pmatrix}$$

$$\Lambda_1 = \begin{pmatrix} 1 & 0 & 0 & 0 & \cdots & 0 \\ 0 & 1 & 0 & 0 & \cdots & 0 \\ \frac{-\gamma\delta}{(1+\delta)^2} & \frac{-\gamma}{1+\delta} & \frac{1}{1+\delta} + \frac{\delta}{(1+\delta)^2} & 0 & \cdots & 0 \\ \frac{-\gamma\delta}{(1+\delta)^2} & \frac{-\gamma}{1+\delta} & 0 & \frac{1}{1+\delta} + \frac{\delta}{(1+\delta)^2} & \cdots & 0 \\ \vdots & \vdots & \vdots & \vdots & \ddots & \vdots \\ \frac{-\gamma\delta}{(1+\delta)^2} & \frac{-\gamma}{1+\delta} & 0 & 0 & \cdots & \frac{1}{1+\delta} + \frac{\delta}{(1+\delta)^2} \end{pmatrix}$$

$$\Lambda_2 = \begin{pmatrix} 1 & 0 & 0 & 0 & \cdots & 0 \\ 0 & 1 & 0 & 0 & \cdots & 0 \\ 0 & 0 & 1 & 0 & \cdots & 0 \\ \frac{-\gamma\delta^2}{(1+\delta)^3} & \frac{-\gamma\delta}{(1+\delta)^2} & \frac{-\gamma}{1+\delta} & \frac{1}{1+\delta} + \frac{\delta^2}{(1+\delta)^2} + \frac{\delta^2}{(1+\delta)^3} & \cdots & 0 \\ \vdots & \vdots & \vdots & \vdots & \ddots & \vdots \\ \frac{-\gamma\delta^2}{(1+\delta)^3} & \frac{-\gamma\delta}{(1+\delta)^2} & \frac{-\gamma}{1+\delta} & 0 & \cdots & \frac{1}{1+\delta} + \frac{\delta^2}{(1+\delta)^2} + \frac{\delta^2}{(1+\delta)^3} \end{pmatrix}$$

For arbitrary k, the pattern generalises to:

$$\Lambda_k = \begin{pmatrix} I_{k+1} & 0_{(k+1)\times(T-(k+1))} \\ A_k & B_k \end{pmatrix} \tag{C.6}$$

where $A_{k(i,j)} = \begin{cases} \frac{-\gamma\delta^{k-j}}{(1+\delta)^{k-j+1}} & \text{for } j = 0, 1, \ldots, k \\ 0 & \text{otherwise} \end{cases}$, $B_{k(i,j)} = \begin{cases} \sum_{l=0}^{k} \frac{\delta^l}{(1+\delta)^{l+1}} & i = j \\ 0, & i \neq j \end{cases}$

C.2.2 IRF matching Under Different Expectations Processes

This section reports the IRF matched impulses responses under the different expectations processes. The expectations processes are discussed in section C.2 and the optimised parameters are reported in table C.2.

Figure C.3 shows the IRF profiles under different expectations processes.[29] As discussed in Auclert et al. (2020), rational expectations solutions will tend to fail to recover the humps we see in the empirical data. Households update their information set on impact and this leads to large peak impacts at time zero, as shown in Panel (d) for house prices under rational expectations. Turning to sticky expectations (green line) we see that they recover somewhat the hump shaped response of GDP and house prices. However, the dampening of the expectations

[29] We also tried the case of extrapolative expectations in the growth rate but our IRF matching procedure struggles to replicate the empirical profiles to a greater extent than the other approaches (see Appendix 3.3).

channels also dampens the overall fall in GDP and the relative house price. This is also the case when we don't differentiate between expectations for house prices and other prices (yellow line). This lack of decline in the relative house price spills over to the rental market as relatively higher house prices push up on net rental demand and necessitate a higher relative rental price. Given the above, the combination of sticky and extrapolative expectations is what allows us to best match the IRFs jointly, and also maintain parameter estimates within the reasonable range of the extant literature.

Table C.2: IRF Matched Parameters

Parameter	Rational Exp.	Sticky	Sticky + Extrap.	Baseline
Price Philips Curve κ_p	0.003	0.5	0.5	0.01
Wage Philips Curve κ_w	0.18	0.5	0.003	0.003
Fiscal rules (debt stab.)	0.01	0.09	0.09	0.12
Taylor rule $(\phi_\pi, \phi_y, \rho_m)$	(2.5, 0.17, 0.96)	(2.5, 0.0, 0.95)	(2.5,0.0,0.89)	(1.11, 0.0, 0.88)
Price update prob. $\frac{1}{1+\delta_x}$	1.0	0.01	0.04	0.12
House price update prob. $\frac{1}{1+\delta_{p_h}}$	1.0	0.09	0.04	0.37
Price extrapolation γ_x	0.0	0.0	-0.43	-0.41
House price extrapolation γ_{ph}	0.0	0.0	-0.43	0.09

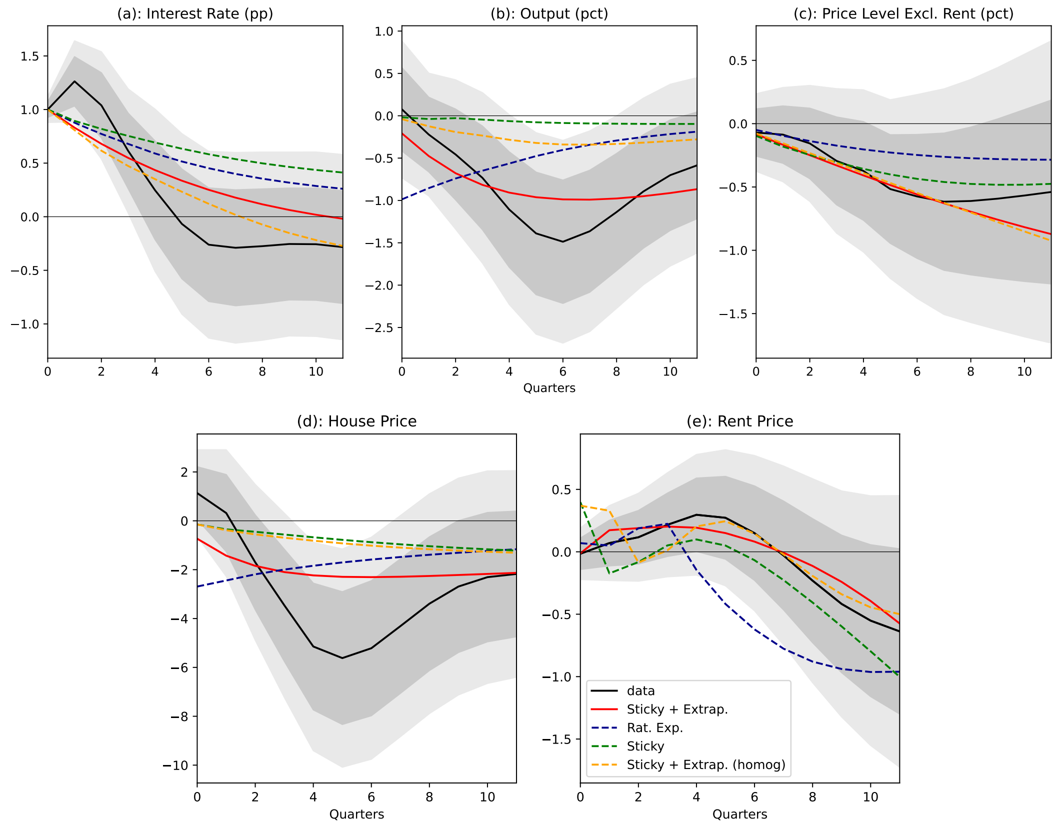


Figure C.3: IRFs under Alternative Expectations Processes

Notes: Figure repeats figure 4 under different expectations process.

C.2.3 Evidence on house price expectations

In order get a sense of the reasonableness of our behavioural parameters we estimate a regression in the style of the reduced form of Kohlhas and Walther (2021) on household house price expectation data. Absent sufficiently long running and reliable data for the UK we turn to the Michigan Survey of Consumers which has asked households by what percent they expect the value of their home to rise or fall over the following year since 2007. Forecast errors are constructed by comparing household forecasts to actual outcomes as measured using the S&P CoreLogic Case-Shiller U.S. National Home Price Index. We deflate this index using the CPI U.S. City Average and compare to real house price forecasts of households by combining households price and house price inflation forecasts.

Our sample runs from 2007 until 2024. We apply standard outlier treatment, removing observations in the 1st and 99th percentiles for both expectations and forecast errors to eliminate extreme responses likely due to data entry errors or misunderstanding. Regressions are estimated by aggregating to a quarterly frequency as in Coibion and Gorodnichenko (2015) or Adam et al. (2024). As in those approaches we also apply an instrumental variable approach to account for the fact we don't observe sequential forecasts of overlapping periods. We use monetary policy shocks (Bauer and Swanson (2023))) as our IV which does not produce significantly different point estimates however the estimates is much less precise. Adam et al. (2024) applies similar regressions omitting the γ_{p_h} term over a 2007-2020 sample with our point estimates for δ close to what they obtain.

Table C.3: Michigan Survey

	Forecast Error		
	No extrap.	Extrap	IV
γ_{p_h}	-	-0.02	-0.03
	-	(0.05)	(0.04)
δ_{p_h}	1.45	1.46	1.94
	(0.26)	(0.32)	(1.39)
Observations	68	68	68
R^2	0.46	0.46	0.41

Notes: Tables presents for regressions of the form of Kohlhas and Walther (2021) for real log house price expectations in the Michigan Survey: $p_{t+4} - f_{t+1,t+4} = \gamma_{p_h} p_t + \delta_{p_h}(f_{t+1,t+4} - f_{t,t+3}) + \epsilon_t$. As in Adam and Nagel (2023) we also present results instrumenting for the house price news term with monetary policy shocks (Bauer and Swanson (2023)) cumulated to the quarterly frequency following their weighting methodology between quarters. This accounts for the fact that the Michigan survey does not provide overlapping forecasts for the same period. The sample period is 2007-2023.

C.3 Hand-to-Mouth classification

Following Kaplan and Violante (2014), we classify households as hand-to-mouth (HtM) based on their liquid wealth holdings. We distinguish three types:

- **Wealthy HtM:** Low liquid wealth but positive illiquid assets

- **Poor HtM:** Low liquid wealth and zero or negative illiquid assets
- **Non-HtM:** Sufficient liquid wealth to smooth consumption

C.3.1 Data and Sample Selection

We use waves 7-8 of the Wealth and Assets Survey (2018-2022), restricting the sample as in Kaplan et al. to households with heads aged 25-60, positive labour income, and excluding those with income solely from self-employment.

Annual income is constructed from the WAS as the sum of:

- Gross wages and salaries from main and secondary employment
- Net self-employment income for households with multiple income sources
- Government transfers and benefits

We define net liquid wealth as liquid assets (cash, bank accounts, ISAs, stocks, bonds, mutual funds) minus liquid debt (credit cards, overdrafts, unsecured loans). Net illiquid wealth is defined as illiquid assets (housing equity, other real estate, pensions, life insurance) minus illiquid debt (mortgages, home equity loans).

Landlord households are identified using self declared rental income from the WAS. A household is classified as a landlord if they report positive annual rental income.

C.3.2 Classification Rule

We assume monthly pay frequency and set the credit limit to 12 months of income. This is a relatively conservative classification but one that reflects shorter mortgage fixation periods in the UK relative to the US. The share of hand to mouth and wealth hand to mouth households is larger if we use a smaller credit limit.

A household is hand-to-mouth if:

$$\text{Net Liquid Wealth} \in [0, \text{Labour Income}] \quad \text{or} \quad -11 \times \text{Labour Income} < \text{Net Liquid Wealth} < 0 \tag{C.7}$$

I.e if liquid wealth is positive but below one month's income or debt stays within the 12-month credit limit.

Among HtM households, we distinguish **Wealthy HtM** (HtM with positive illiquid wealth), **Poor HtM** (HtM with zero or negative illiquid wealth), and **Non-HtM** (sufficient liquid wealth to smooth consumption). Among landlords in the 2018-2022 WAS, 37% are classified as HtM, with 29% of all landlords classified as wealthy HtM (78% of HtM landlords). [30]

[30] Our baseline classification does not adjust income for ongoing mortgage payments, following Kaplan and Violante (2014)

D Other Model Results

D.1 Response of other Quantities

Figure D.1 plots further impulse responses related to the housing market in the model and compares them to the model under rational expectations. In line with the empirical evidence we see little change in the rental share rental share following a rise in interest rates (panel (d)). We also see a drop in housing transactions which follows from the presence of non-convex transaction costs and sticky expectations in the model which act to widen regions of inaction (Dixit, 1989). In particular, selling households are incentivised to wait to sell, because they expected house prices to recover. This drop is larger than under rational expectations.

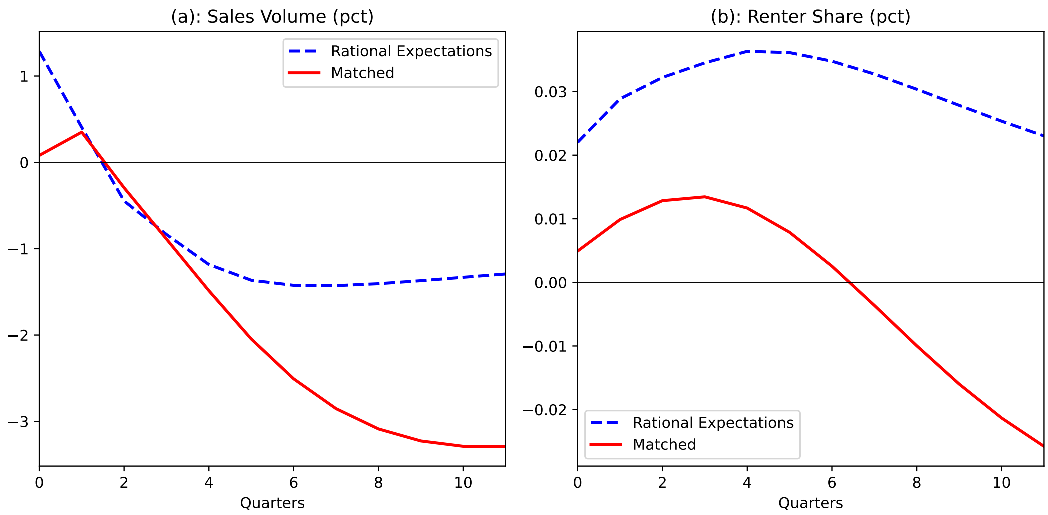


Figure D.1: Other Housing Market IRFs

Notes: Figure reports the impulse response in the model to 1p.p. monetary policy shocks for further selected variables of interest beyond those in the IRF matching exercise in figure 4. Panel (c) plots the actual 3 month ahead house price growth IRF and the expected house price growth by households in the model. They do not match because of sticky house price expectations in the model.

D.2 Responding to a Rental Market Shock

In this exercise we look at the implications of a rental market shock in the baseline model and the response of monetary policy. The rental market shock is constructed by temporarily decreasing the stock of rental housing provided by the housing association $\overline{HA}$, which then unwinds as an AR(1) process with persistence of 0.9. We calibrate the exercise such that it creates a 10% increase in average rental prices on impact, and the results are illustrated in Figure D.3. The red line plots the response under the previously estimated Taylor Rule. Beyond the rental market, the shock causes an increase in house prices due to the overall fall in housing supply. There is also a decline in output and consumption good prices, with higher MPC households forced to cut back on consumption to pay for higher rents, and from the central bank raising interest rates by following a Taylor Rule based on the total CPI basket.

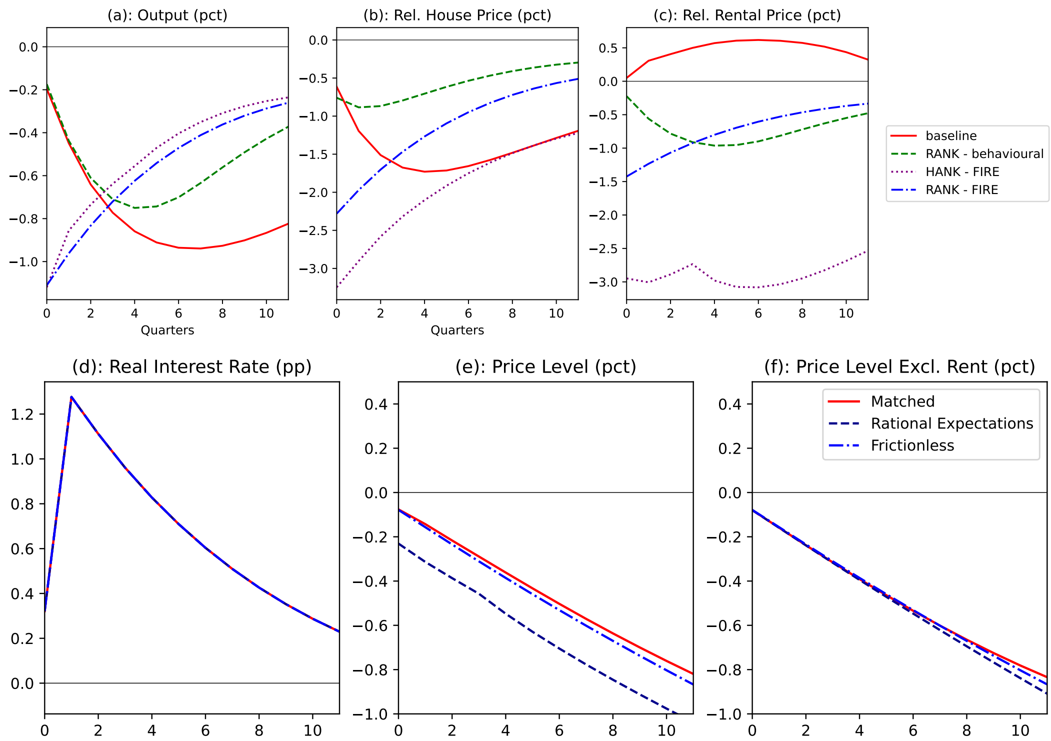


Figure D.2: Frictionless Benchmark

Notes: The real interest rate path is kept constant between the models.

We then consider a counterfactual policy deviation using the framework of Barnichon and Mesters (2023). That is, instead of following a Taylor Rule policy makers minimise the following loss function:

$$L_x = \sum_{t=0}^{20} (\pi_{t,x})^2 \tag{D.1}$$

We choose the same 5 year policy window as in Barnichon and Mesters (2023) and consider an inflation targeting central bank. The inflation rate of interest will either be the total inflation rate ($\pi_{t,cpi}$) or the inflation rate excluding rents (π_t), each of which generates one of the policy paths shown in Figure D.3. The response when targeting the total inflation rate indicates that a very large interest rate response would be necessary to push inflation closer to target. This would result in the opening up of a large output gap and substantial fall in house prices. Notice that it would also push relative rental prices substantially higher on average. When the policy maker just targets the non-rental prices they are able to improve the outcome relative to the baseline in terms of output/consumption through looking through the shock, without large effects in the broader housing market or impacting the broader price level by much. The takeaway from this exercise is that, in the context of this model, where inflation expectations are anchored and housing supply is fixed, the policymaker may be better off looking through the rental market shock and focusing on the demand determined side of the economy.

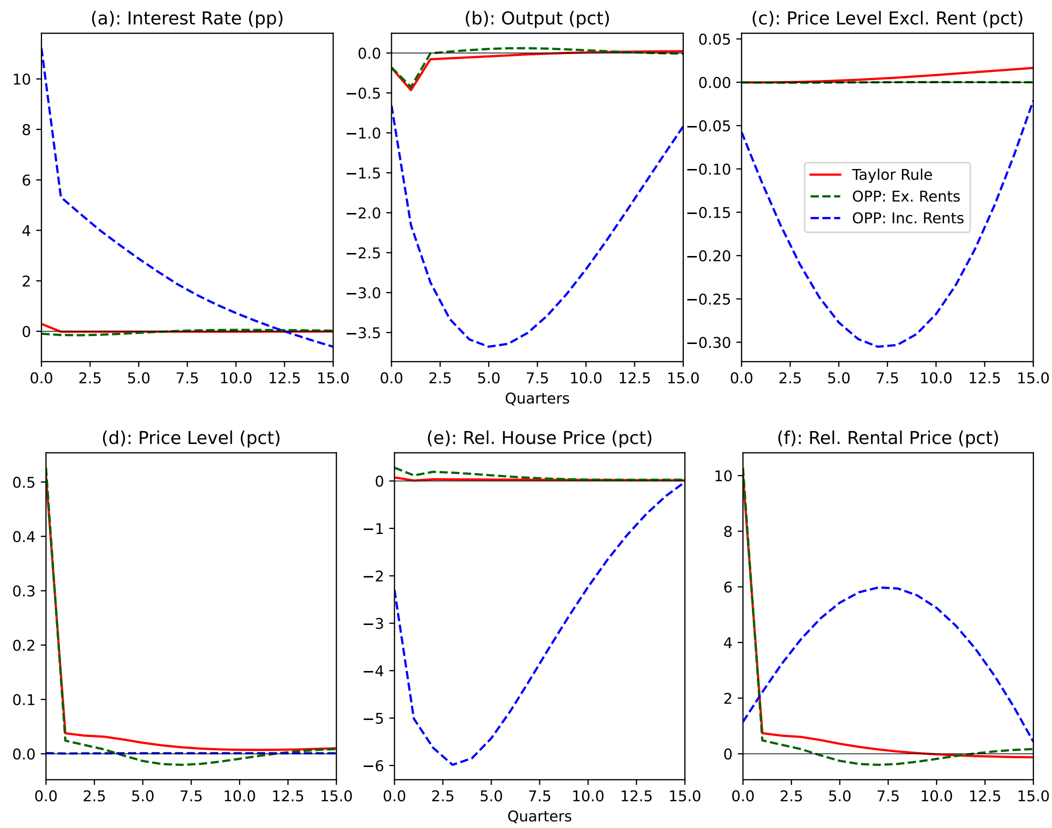


Figure D.3: Response to a Housing Market Shock

Notes: This figure shows the response to a persistent fall in the supply of rental housing calibrated to generate a 10% increase in rental prices on impact under the Taylor rule case, and also under different Optimal Policy Path (OPP) scenarios. The red line plots the responses in the model under the previously estimated Taylor Rule reaction. The green and blue dashed lines report the responses when the policy maker follows an optimal policy of minimising deviations in inflation from target for the non-rental price basket and total price basket respectively. The optimal policy is computed following the method of Barnichon and Mesters (2023) weighting over a 5 year window.

D.3 Frictionless Benchmark Model

This section describes the frictionless RANK benchmark used for comparison in Figures 8 and D.2. The model retains housing and rental markets but removes all housing-specific frictions and heterogeneity to isolate their quantitative importance. Specifically, housing is divisible and can be purchased and rented in any quantity. Also, there are no adjustment costs, borrowing constraints or sticky rents. You could alternatively think of housing in this model as a durable consumption good in fixed supply, where households are forced to pay the maintenance costs. We calibrate the models parameters using the values for the relevant parameters from Tables 2, 3 and 5.

D.3.1 Model Structure

The representative household maximises $\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t u(c_t, h_{l,t})$ subject to

$$a_{t+1} + p_{h,t}h_t + c_t + p_{r,t}(h_{l,t} - h_t) = y_t + (1 + r_t)a_t + (1 - \delta_h)p_{h,t}h_{t-1} \tag{D.2}$$

where c_t is non-durable consumption, $h_{l,t}$ is housing services consumed, h_t is housing owned, and a_t is financial assets. The household chooses to rent ($h_{l,t} > h_t$) or act as landlord ($h_{l,t} < h_t$) without transaction costs ($F = 0$) or borrowing constraints.

Optimality yields the standard no-arbitrage condition:

$$p_{h,t} = p_{r,t} + \beta \mathbb{E}_t \left[\frac{u_c(c_{t+1}, h_{l,t+1})}{u_c(c_t, h_{l,t})} p_{h,t+1}(1 - \delta_h) \right] \tag{D.3}$$

We assume a fixed supply of housing $\overline{H}$, thus housing market clearing is $h_t = \overline{H}$. The supply side follows the model in the main body of the paper. As seen in figure D.2, output responses are similar across rational expectations specifications, suggesting heterogeneity alone plays a limited role. The frictionless model shows the largest initial house price decline; only behavioural expectations can generate empirically-observed humps. The rental yield tracks the real interest rate closely without frictions, unlike the baseline model. These results demonstrate that (i) housing frictions amplify house price responses, (ii) behavioural expectations are essential for matching dynamics, and (iii) the interaction between heterogeneity, frictions, and expectations shapes observed rental market outcomes.

E Model Extensions

Here we report in more detail the assumptions in each model extension, mentioned in the main text in Section 4.5.

E.1 Additional Market Segmentation

In this extension we fix the supply of rental flats at $\overline{H}_F$, while the supply of non-rental flats is denoted by $\overline{H}$. Because rental flats cannot be transformed into non-rental flats, and vice-versa, they can have potentially different prices, denoted by $p_{h,F}$ and p_h, respectively. Instead of the housing equilibrium conditions in Equations (3) and (4) we now have

$$\begin{aligned} \overline{H}_F &= H_1(s_{ll1,t} + 2s_{ll2,t}) + \overline{HA} \\ \overline{H} &= H_1 s_{ooF,t} + H_2(s_{ooH,t} + s_{ll,t}) \\ \overline{H}_1 s_{rr,t} &= H_1(s_{ll1,t} + 2s_{ll2,t}) + \overline{HA} \end{aligned}$$

where the first equation above denotes the new equilibrium in the market for flats that must be rented out. Thus, the share of renters $s_{rr,t}$ is now fixed, since combining the first and last equations above leads to $\overline{H}_F = \overline{H}_1 s_{rr,t}$.

We fix the supply of each type of housing such that the steady state is the same as in the baseline case

$$\overline{H}_F = H_1(s_{ll1} + 2s_{ll2}) + \overline{HA}$$
$$\overline{H} = H_1 s_{ooF} + H_2(s_{ooH} + s_{ll})$$

which also implies that in steady-state $p_{h,F} = p_h$.

E.2 Endogenous Housing Supply

We introduce investment in housing and endogenous housing supply in a way similar to Kaplan et al. (2020). There is a housing development company that buys final goods V_t and land permits $\overline{L}$ to build new housing according to the production function

$$I_{h,t} = \left(V_t\right)^{\alpha_i} \left(\overline{L}\right)^{1-\alpha_i}$$

The housing developer then sells housing units to households at the real price $p_{h,t}$. The number of land permits $\overline{L}$ is assumed to be fixed over time. Because the housing developer takes prices as given, the government is able to capture all the profits from this sector.

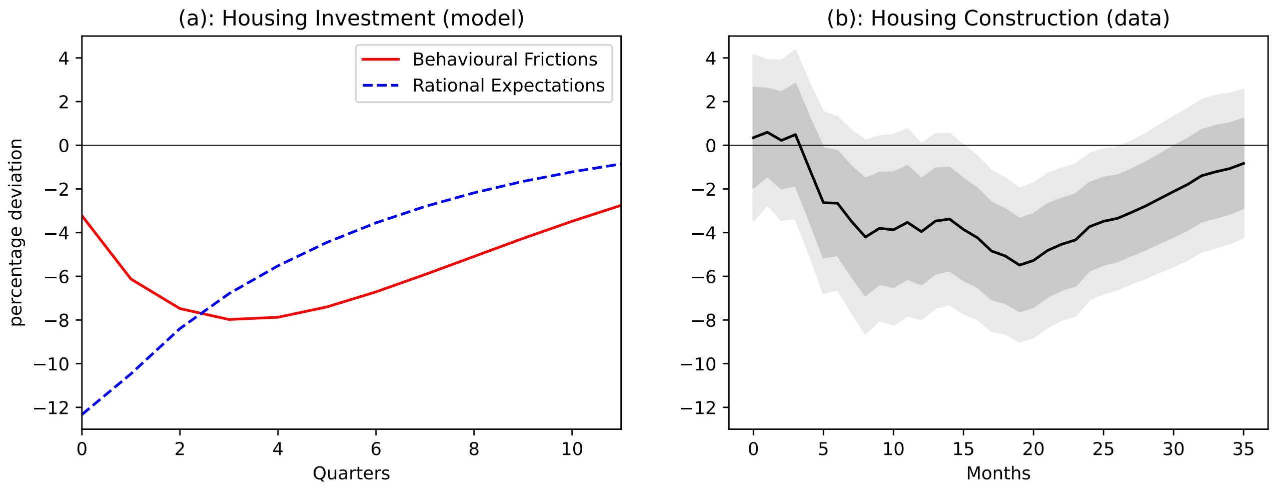


Figure E.1: Model and data responses of housing sector

Notes: This figure shows in Panel (a) the response of housing investment in the extension of the model that includes endogenous housing supply, for both the case of rational expectations and that of behavioural frictions. In Panel (b) it shows the response of the contribution of the construction sector to UK GDP when we include this variable in our 7+1 VAR. Shaded areas correspond to 60 and 90% confidence intervals.

Given that the final good is the numeraire in the economy, the problem of the housing developer is

$$\max_{V_t} p_{h,t}\left(V_t\right)^{\alpha_i}\left(\overline{L}\right)^{1-\alpha_i} - V_t - F_i$$

where F_i are fixed costs introduced to keep profits in the steady-state equal to zero, so that the steady-state in this version is the same as in the baseline. The solution is given by $V_t =$

$(p_{h,t}\alpha_i)^{1/(1-\alpha_i)}\,\overline{L}$, or that housing investment is equal to

$$I_{h,t} = (p_{h,t}\alpha_i)^{\alpha_i/(1-\alpha_i)}\,\overline{L}$$

which means that the elasticity of housing investment to real house prices is given by $\alpha_i/(1-\alpha_i)$. Moreover, we set the fixed costs equal to $F_i = (1-\alpha_i)p_h I_h$. Thus, profits $\Pi_{i,t}$ from the housing investment company that are rebated to the government are equal to

$$\Pi_{i,t} = (1-\alpha_i)p_{h,t}I_{h,t} - (1-\alpha_i)p_h I_h$$

which implies $\Pi_i = 0$ in steady-state.

Finally,we make one additional modification to keep the steady-state of the model the same as before. Note that previously households were paying $\delta_h \overline{H}$ for maintenance costs in the steady-state, but now that would cost $p_h \delta_h \overline{H}$ for the same depreciation rate. Thus, we modify the depreciation rate to $\delta_h^* = \delta_h/p_h$, such that total expenditures are the same. The law of motion for the stock of housing is then

$$H_t = H_{t-1} + I_{h,t} - \delta_h^* H_t$$

where notice that the depreciation applies to the current stock of housing because we assumed in the baseline model that households pay depreciation on the housing they are moving to in a given period, not the housing that they are moving out of. We also assume that the government incurs any depreciation costs associated with higher housing prices so that we do not need to keep track of it for the household problem. Thus, households always pay $p_h \delta_H^* \overline{H}_t = \delta_H \overline{H}_t$, and the government pays the difference $(p_{h,t} - p_h)\delta_H^* \overline{H}_t$.

Kaplan et al. (2020) choose a value of $\alpha_i = 0.6$, but we set $\alpha_i = 0.2$ so that the response of housing investment in the model aligns well with that of the construction sector in the UK data, as shown in Figure E.1.

E.3 Sticky Mortgages

Instead of mortgages having a variable rate i_t that follows the interest rate set by the Central Bank, we assume that mortgagors pay a rate $i_{m,t}$ with a law of motion given by

$$i_{m,t} = (1 - 1/\tau_m)i_{m,t-1} + (1/\tau_m)i_{m,t}^*,$$

where $i_{m,t}^*$ is the "spot" rate for mortgages. However, all households pay the same sticky mortgage rate $i_{m,t}$. This assumption is made for computational reasons, so as not to create an additional individual state variable in the model.

Let τ_m denote the fixation period for the representative mortgage rate. The spot mortgage rate $i_{m,t}^*$ is then the average of the nominal interest rate from the current period up to τ_m period ahead

$$i^*_{m,t} = \sum_{s=0}^{\tau_m} \frac{i_{t+s}}{\tau_m}$$

We calibrate $\tau_m = 12$ to reflect an average fixation period of 12 quarters for mortgages in the UK. Finally, as in the baseline model, we assume that the government absorbs any profits or losses associated with providing mortgages to households. Notice that in steady-state there are not profits/losses on top of the borrowing wedge, since $i_m = i$

E.4 Selling Frictions

We follow the modelling of Hedlund et al. (2025) to introduce frictions for house sales. Specifically, we assume that there are house brokers that buy homes from sellers, and then sell these households to buyers. The market between home sellers and brokers is frictional and subject to a matching function, but the market between brokers and home buyers in centralised and frictionless.

The number of matches between brokers and sellers is given by

$$m = n_b^{\gamma_b} n_s^{1-\gamma_b}$$

where n_b, n_s, are the mass of brokers and sellers, respectively.

Let $\theta_b = n_b/n_s$ denote the tightness in the home selling market. Then the probability of home sellers being able to sell a house is given by $\alpha_s = m/n_s = \theta_b^{\gamma_b}$, while the matching probability for a broker is given by $\alpha_b = \theta_b^{\gamma_b - 1}$. We reinterpret the fixed cost of selling a home in our baseline model of F as the cost paid by sellers to brokers. Thus, home sellers get $p_{h,t} - F$ when selling their house to a broker, but brokers resell this house to prospective buyers for $p_{h,t}$.

The model is closed with a free-entry condition for brokers. Let κ_b denote the posting cost for a broker. Then free-entry implies that

$$\kappa_b = (p_{h,t} - (p_{h,t} - F))\alpha_b = F\alpha_b$$

or that $\alpha_b = \kappa_b/F$. Thus, the probability of a seller matching with a broker is also fixed and we have

$$\alpha_s = \left(\frac{F}{\kappa_b}\right)^{\gamma_b/(1-\gamma_b)}$$

We calibrate directly $\alpha_s = 1/(17/13)$ to match the average time on the market for a property of 17 weeks in the UK. With a probability below one of being able to sell a home the steady-state of the model in this extension will change, thus we re-estimate the parameters in Table 2 to match the same moments. Because the average buying time is less than a quarter we assume a 100 percent chance of success at finding a home on the buying side in the model. We do not re-estimate the dynamic parameters in the IRF matching exercise.