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Abstract

The simultaneous rise in housing rents and interest rates over 2022–24 brought scrutiny to the interaction between monetary policy and the housing market. We start by providing evidence on this interaction using data from the United Kingdom and a high frequency identification. Our main empirical finding is that house prices and rents do not move together after an increase in interest rates. House prices fall strongly but gradually, reaching their trough after one year, while nominal rents are stable for one to two years, before eventually falling. Next, we develop a quantitative Heterogeneous Agent New Keynesian model that includes housing and rental sectors. In particular, we model individual landlords as the marginal providers of rental housing. We use the model to examine the housing channel of monetary policy where we find: (1) the housing channel is large and falls disproportionality on mortgagors; (2) deviations from rational expectations mean landlords largely fail to pass on mortgage costs and act more like wealthy hand to mouth; (3) these behavioural biases dampen the potential trade-off between prices and output induced by the rental market; and (4) that it may be optimal for monetary policy makers to look through and accommodate housing supply shocks.

Key words: Monetary policy, housing, heterogeneous agents.

JEL classification: E52, R21, D31, E21.

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1 Introduction

The observed rise in interest rates and housing rental prices across several countries from 2022 to 2024 has drawn increased scrutiny both to the role of monetary policy in determining prices and quantities in the housing market, and also on the importance of the housing market for the transmission of monetary policy. From a theoretical standpoint, it is not immediately clear what either should be. As housing is an asset, its return (e.g., the rent-to-price ratio) should increase in line with the increase in interest rates, which can be accomplished by a mix of fall in house prices and increase in rental prices. However, housing rents are also the price of housing consumption, and prices of goods and services usually fall following contractionary monetary policy. Moreover, credit constraints and possible deviations from rational expectations make it even harder to get a clear prediction.

To help answer these questions, this paper makes two contributions. First, we bring empirical evidence on the impact of monetary policy on prices and quantities in the housing market. We use data for the United Kingdom (UK) and a consistent approach based on a high-frequency monetary policy identification in a Structural Vector AutoRegression (SVAR) model. The 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 come down by 6% after 16 months in a gradual, hump-shaped, profile. In contrast, rental prices are stable for 1.5 to 2 years, and then start falling. Importantly, we find that these patterns are replicated across regions, dwelling types, and sample periods, suggesting a response of prices at the macro level that is robust. Reassuringly, we find that the rent-to-price ratio increases as predicted.

Turning to real variables, we 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%. We also find tentative evidence that the share of renters among those between 20 and 35 years old increases, and is mostly flat for other age groups. The results suggest that the fall in house prices after an interest rate increase is not enough to keep the activity in the housing market and that as a consequence some households might stay in the rental market, pushing up on rental prices.

Our second contribution is to develop a Heterogeneous Agent New Keynesian (HANK) model that is able to replicate the evidence above, and that allows us to investigate the transmission of monetary policy through the housing sector. Our model includes a richly modelled housing sector and several elements that could dampen or amplify the effect of monetary policy: housing as consumption and as an asset, idiosyncratic income risk, Loan-to-Value (LTV) and Loan-to-Income (LTI) borrowing constraints on mortgages, and possible deviations from rational expectations. Importantly, households can choose to become renters, home-owners or landlords, in which case they buy properties that they rent out to other households. This modelling assumption as opposed to a rental commercial sector with deep-pockets is more in line with the data,[1] and we show it is also crucial for the impact of interest rates on the hous-

[1] In the UK 94% of private landlords act as private individuals (Ministry of Housing and Government, 2019). This is similar for France and most of Western Europe, but in the United States the size of the commercial

ing market (Greenwald and Guren, 2021). To the best of our knowledge, we are the first to introduce individual private landlords in a HANK model.

The first important insight that arises from the model is that deviations from Full Information Rational Expectations (FIRE) are important to match the data. Under FIRE, house prices fall the most on impact, while the evidence is that they have a hump-shaped response. We then consider two alternatives: sticky expectations, and extrapolative expectations. While both represent improvements over FIRE, we show that *combining* sticky and extrapolative expectations (i.e., agents adjust their expectations infrequently and, when they do, they extrapolate from past behaviour) delivers the best results, and that they are in line with the evidence of under-reaction in the short-term but over-reaction on the medium term in household price expectations (Adam et al., 2024).[2]

With a model that replicates the empirical findings - it is crucial that our model delivers a realistic response of house prices and rents to a monetary policy shock to be able to decompose its impact - we are then able to investigate the monetary transmission through the housing sector. We find that the housing channel is around 50% of total transmission at the peak impact of monetary policy to household consumption. Transmission is strongest to mortgagors, since they face higher borrowing costs on their mortgages, at the same time that the value of their property has decreased. Those that own their homes outright are the least affected, followed by renters, given that rental prices do not increase and they do not own any house. Landlords are the second most affected, which is surprising at first because they are some of the wealthiest individuals in the economy. This happens because a large fraction of landlords hold negative net financial wealth positions in the model (and data) and because they fail to sufficiently pass through the increase in mortgage costs through rents. In that sense, landlords act in a similar way to the wealthy hand-to-mouth (HTM) of Kaplan and Violante (2014). Thus, rents are not a source of redistribution from high to low marginal propensity to consume agents after a monetary policy shock. Furthermore, the house price is by far the dominant price in closing the rental and broader housing market following a change in the real interest rate. This is due to the high house value-to-income ratio, the long duration of the housing asset, and the lumpiness of its investment.

To highlight the importance of modelling individual private households as landlords, we examine what would happen if the marginal provider was instead an unconstrained commercial entity that operates under FIRE. In this scenario, the commercial sector demands a higher rental yield after an increase in interest rates. House prices are not affected since there is little spillover from the smaller private rental market to the much larger housing market. Therefore, it is rental prices that need to adjust, and they increase substantially in this version of the model, which is not in line with our evidence. In this case, monetary policy generates opposite effects on rental prices (increase) than other prices (decrease). Thus, private landlords that are subject to borrowing constraints and show deviations from FIRE help mitigate this trade-off.

rental sector is relatively larger (Levy, 2021).

[2]We are able to combine sticky and extrapolative expectations by modifying the sequence-space Jacobians of Auclert et al. (2021), as we show in Appendix C.3.

Lastly, we explore the optimal monetary policy in the model in response to a shock in the supply of housing, in the spirit of Bianchi et al. (2024). We find it may be optimal for monetary policy makers to look through housing market shocks and focus on inflation excluding rents. This happens because monetary policy slightly increases rents, while decreasing other prices, making it harder to stabilise both the housing and non-housing market sectors of the economy at the same time. To stabilise inflation inclusive of rents necessitates a significant rise in interest rates and large output gaps.

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.[3] However, the evidence for the response of rents to a positive monetary policy shock is scarce and mixed. Dias and Duarte (2019) and Albuquerque et al. (2024) 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 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 a comprehensive set of results on prices and quantities in the housing and rental market for the United Kingdom, its sub-regions, and different house types.[4] As we argue in our model, a commercial rental sector can increase the response of rents to interest rates, thus the greater role played by the commercial rental sector in the United States can then reconcile our findings of stable rents with those findings of increasing rental prices in the US.

This paper also relates to a broader literature that highlights the importance of the housing sector for the transmission of other shocks. Empirically, Slacalek et al. (2020) find housing to be a large channel of monetary policy. Cloyne et al. (2020) find that mortgagors are the most affected by monetary policy changes, followed by renters and outright home-owners. We find the same relative classification in our model, but argue that landlords are the second-most affected. Within heterogenous-agent models, Kaplan et al. (2020) point to a key role for housing expectations in the propagation from the housing sector to other parts of the economy. Castellanos et al. (2024) analyse the impact of credit shocks on the housing and rental markets, also modelling private individual landlords, but in a real model of the economy. Moreover, heterogeneous agent models are now regularly embedded into the New Keynesian framework (HANK) to study monetary transmission (e.g., Kaplan et al., 2018). Even though some HANK models feature illiquid assets that include housing in their motivation, a rental sector

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

[4]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.

with a realistic modelling of landlords has largely been absent from the HANK literature. Our contribution to this literature is to embed a detailed housing and rental sector into a fully-fledged HANK model along the lines of and solved as in Auclert et al. (2020). We allow for departures from rational expectations as well, and review the literature on the theory and evidence of such departures for housing and non-housing variables in more detail in Section 3.3.

Finally, this paper relates to works that analyse the role of the housing market in shaping optimal monetary policy in a New Keynesian framework. Bianchi et al. (2024) study the optimal response of monetary policy to housing and rental inflation and find that the optimal policy under a supply driven housing sector is to focus on stabilising the demand driven sectors. Adam et al. (2024) study the implications of sluggish adjustment in house price growth expectations in the context of the zero lower bound and the determinants of an optimal inflation target, with deviations from rational expectations of house prices. We extend their setting to a heterogenous agent model, and focus on the implications of the response of housing rents and house prices to a contractionary monetary policy shock.

2 Empirical evidence

The main goal of this section is to better understand the impact of monetary policy on the housing sector. While this is the focus, we find it important that our strategy for identifying the effect of monetary policy is consistent with theory and previous evidence on how other variables, mainly output and inflation, should react.

Therefore, we estimate a proxy SVAR model in the vein of Mertens and Ravn (2013), Gertler and Karadi (2015), and Stock and Watson (2018). The baseline VAR contains six variables: (i) Bank Rate, (ii) seasonally adjusted Consumer Price Index (CPI) core excluding rents, (iii) seasonally adjusted monthly GDP, (iv) the seasonally adjusted UK House Price Index from the Office for National Statistics (ONS), (v) the real level of the FTSE 100, and (vi) the spread between the rate on 75% LTV mortgages and the 2 year yield. The variables included are standard for VARs for the UK (e.g., Cesa-Bianchi et al., 2020; Braun et al., 2024), with two slight deviations. First, we include the mortgage spread instead of a corporate spread given our focus on the housing market. Second, in the model developed in the next section there is non-housing consumption and housing consumption, with separate inflation rates for each of them. To make a better comparison between model and data, we then construct a measure of CPI core inflation excluding all housing expenditures by excluding the "Actual Rents for Housing" component. The monthly VAR is estimated over the 1997-2023 period, with 12 lags. While most aggregate variables are for the whole of the UK, the index for rents that we use is for England only, due to its longer sample. Finally, we include dummies to deal with the Covid period (Cascaldi-Garcia, 2022). With a relatively conservative approach, we include dummies for each month of the duration of the significant pandemic restrictions in the United Kingdom, covering March 2020 to July 2021.

To identify the impact of monetary policy we use the target factor estimated for the UK by

Braun et al. (2024) as the instrument for Bank Rate. We prefer to use the target factor as the instrument because it is the one that comes closer to the exercise using the model developed in the next section.[5] In Appendix B we report the results for the VAR with seven variables (including rents) for different combinations of variables to be instrumented and instruments, and show that the main results in Figure 1 and the response of macro variables in Figure A.1 are robust to different specifications.

Figure A.1 reports the estimated impulse response to a 100 basis point innovation to the policy rate and we observe the expected effects: after an increase in Bank Rate, the CPI displays a prolonged fall, and GDP exhibits a hump-shaped response. In the results below, we always add extra variables one at a time to the original SVAR with six variables to get the response of new variables (e.g., the SVAR that includes the sales volume has seven variables).

2.1 House prices and rents

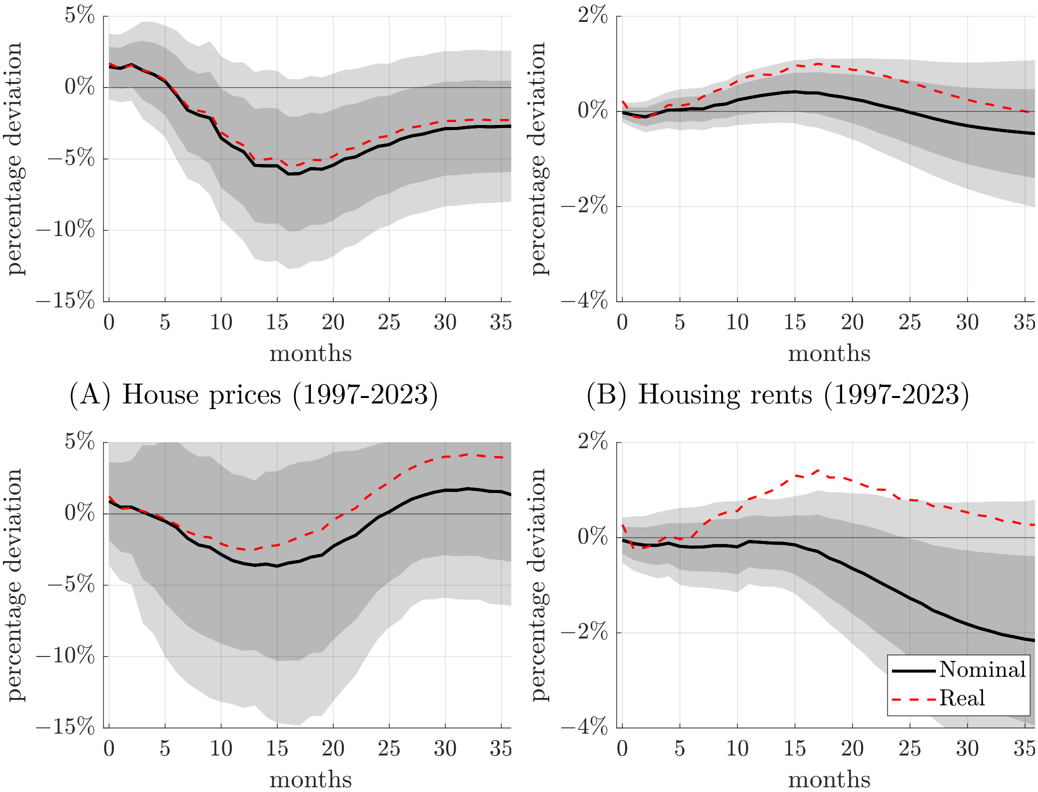
We now turn to our main variables of interest, the response of house prices and rents to a transitory monetary policy shock, shown in Figure 1. As the Index of Private Housing Rental Prices from the ONS is only available post 2005 we show the responses under two sample periods: 2005-2023 and the full sample of 1997-2023, in which we splice the Index of Private Housing Rental Prices with the Owner Occupiers' Housing Costs (OOH) component of the UK CPI Index.[6]

The central estimate of the response of house prices and rents are similar across samples. Nominal house prices exhibit a hump-shaped response, falling gradually to around -6% after one year and starting to revert to its pre-shock level. The response of rents, particularly in contrast to that of house prices, is of primary interest. Instead of falling, nominal rents are either stable or slightly above its 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 in Panel (B), and for two years in Panel (D). Therefore, our results suggest that the relative price of buying a house clearly falls after a monetary policy shock, but the price of renting one stays mostly stable for a long period, and even rises in relative terms. Furthermore, notice that the specification of the SVAR shown in Figure 1 includes both house prices and private rents, thus their response is controlling for each other's response.

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

[5]The factor is identified as the first principal component from the covariance matrix of the high frequency surprises in 7 UK asset prices, and is rotated such that only this factor loads on the shortest sterling futures contract. In this sense the factor can be thought of as corresponding to a shock to the policy rate.

[6]Both indices take into account all rental contracts, not just new ones. 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 1. 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 as well as private rents, so we choose CPI OOH instead.



(A) House prices (1997-2023)
(B) Housing rents (1997-2023)
(C) House prices (2005-2023)
(D) Housing rents (2005-2023)

Figure 1: House prices and housing rents: 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 Panels (A) and (C) for two different samples. In Panel (D) it shows the response of the ONS Index of Private Housing Rental Prices for the 2005-2023 period for England, while in Panel (B) this index is spliced with UK CPI's "Owner Occupied Housing" component. The results are shown for a VAR with seven variables: the six baseline variables described in the main text, and the measure of rental prices. 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: 57.8

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 4.2.3 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 and, 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.

To investigate whether our results are robust across, or driven by, different sub-samples, we also look at regional house price and rents responses, and the response of prices by dwelling type. In the regional cases, we substitute the national index 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. Figures 2A and 2B display the

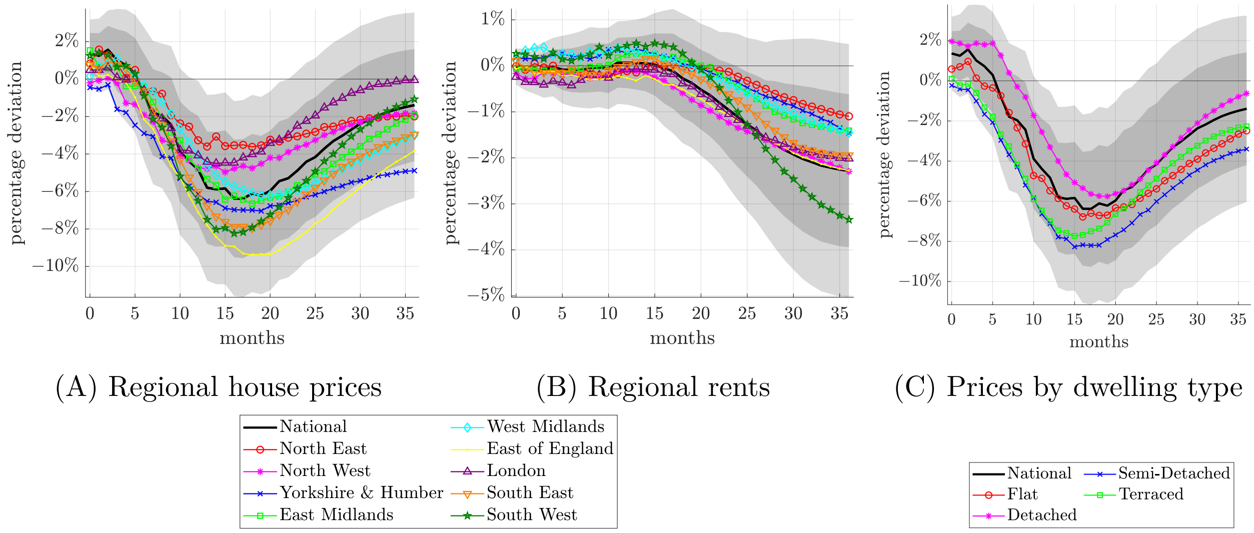
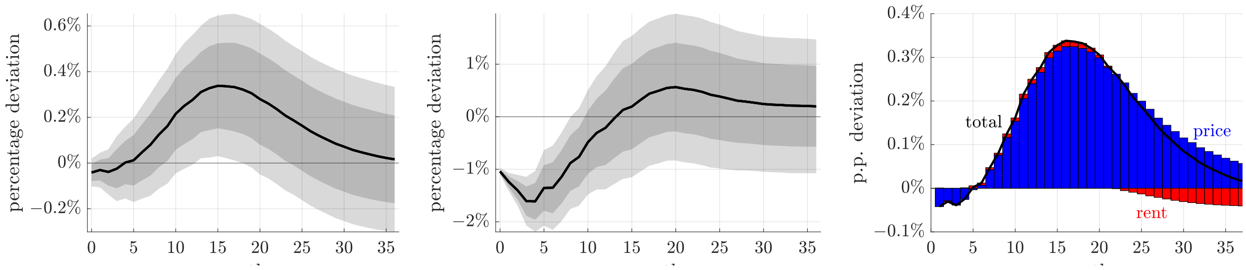


Figure 2: Robustness - regional and dwelling types

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 ONS House Price Index by dwelling type in England in Panel (C). All specifications use UK measures for the other variables of the SVAR. For house prices (either regional or by dwelling type), the SVAR has the six main variables and is estimated from 1997-2023. For rents, we extend the SVAR to seven variables, and have a sample from 2005-2023. 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.

results for the nine regions in England, overlaid with the national responses in panels (A) and (D) from Figure 1. It shows that the qualitative aspects of the national response is 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. Looking at specific regions, it seems that London house prices rebound faster, but it is notable that this does not happen to other wealthier regions like the South East. Furthermore, Figure 2C shows that different dwelling types have broadly similar qualitative responses to a monetary policy shock, with a trough around 15 months. The intensity of the response can differ, but again it is not clear what dictates it, with prices of detached houses responding less, while semi-detached houses respond the most. Our main takeaway from Figure 2 is that, even though average house prices across regions and dwelling types can differ a lot, they all 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 two houses with two different sizes but with a single price per unit (i.e., price per m^2).

Finally, we 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 housing on the rental sector. As Figure 1 shows, house prices fall while rents are broadly flat initially, which means



(A) Rent-to-price ratio (B) Rent-to-price spread (C) Rent-to-price decomposition

Figure 3: Rental yield

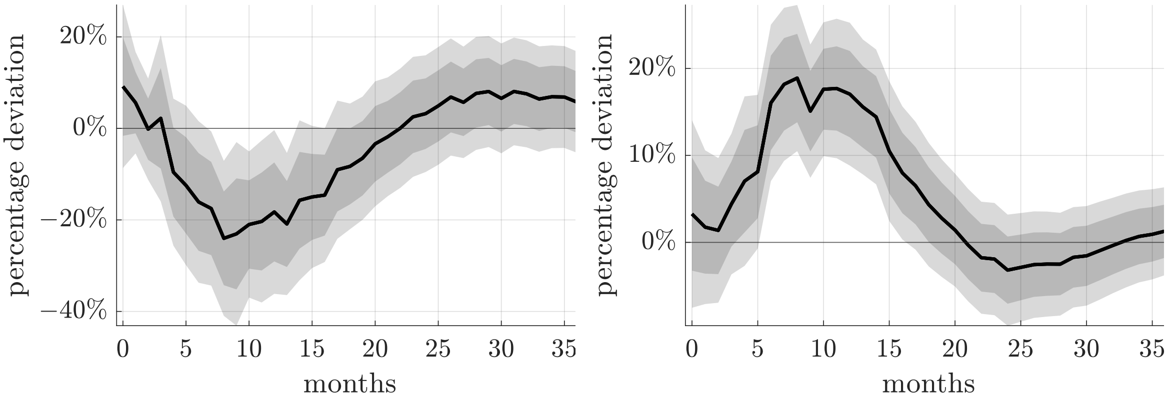
Notes: this figure shows the IRF of the rent-to-price ratio in England in Panel (A) and of the spread between the rent-to-price ratio and the Bank Rate in Panel (B). Both cases have this as an additional variable on top of the baseline six-variables SVAR, and they are estimated over the 1997-2023 period. Panel (C) decomposes the response in Panel (A) into a house price effect and a rent effect, according to Equation (1). In all cases, the rent-to-price ratio was normalised by its average of 5.03% from 2015 to 2023 (see footnote 7 for details), and is displayed as percentage point deviations from this average. The grey shaded areas are 68 and 90% confidence intervals. Confidence intervals are calculated using a residual-based moving block bootstrap.

that we would expect the rent-to-price ratio to increase, which is indeed what we find, as shown in Panel (A) of Figure 3. After five months the rent-to-price ratio starts to increase, and peaks at around 0.34 p.p. after five 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. Panel (B) does just that, and plots the response of the rent-to-price ratio minus the Bank rate. Because the Bank Rate jumps on impact while the rent-to-price ratio displays a more gradual response, the dividend yield on being a landlord when compared to outside options falls, and only becomes positive again after more than 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 reduce by enough the cost of buying a new house and then renting it so as to attract new landlords purely with rental income. Panel (C) further decomposes the response of the rent-to-price-ratio into the response of prices and the response of rents according to

$$\log\left(\frac{p_{r,t+h}}{p_{h,t+h}}\right) - \log\left(\frac{p_{r,t-1}}{p_{h,t-1}}\right) = \underbrace{\Big(\log(p_{r,t+h}) - \log(p_{r,t-1})\Big)}_{\text{rent effect}} - \underbrace{\Big(\log(p_{h,t+h}) - \log(p_{h,t-1})\Big)}_{\text{house price effect}} \tag{1}$$

where $p_{h,t}$ denotes house prices and $p_{r,t}$ denotes rents. Because prices adjust by more, they account for the majority of the response in the first two years, with rents reducing the rent-to-price ratio later. We argue in Section 3 that house prices are the most important dimension of adjustment because they have a bigger impact on both the housing and rental markets.

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

Figure 4: 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.

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 behaves given the price changes that we documented above.

Figure 4 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, slow adjustment, that we found for house prices and rents. Sales volume decline for about a year to around -20%. After that, they rebound, and reach positive territory in the longer run. Even though the stock of housing for sale is not a function only 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 back to its 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 buyers to enter the market. It is only after 10 to 12 months, slightly before house prices reach its trough, that sales start to increase again.

To investigate whether the fall in activity in the housing market can have consequences for the rental market, Figure 5 plots the response of the share of households that declare to be renters in the Labour Force Survey (LFS). Panel (A) of Figure 5 shows that there might not

[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.

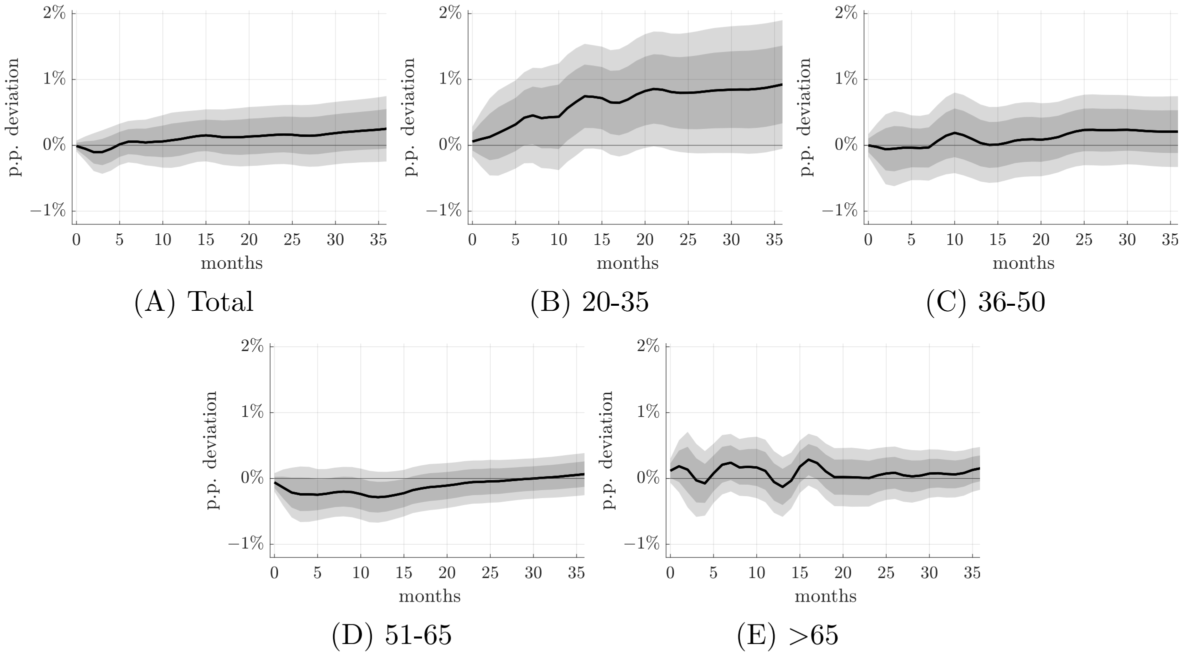


Figure 5: Share of renters - total and by age

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.

be a big change in the overall share of renters after a monetary policy shock. However, when broken down by age groups, it is clear from Panel (B) that those between 20 to 35 years old are more likely to become or stay as renters, and from Pabel (D) that those between 51 to 65 years old are less likely to become renters. The result from Panel (B) is suggestive that the transition from renting to owning is delayed after a monetary policy shock, which can also be related to the slow and gradual response of house prices - if they fell faster, homeownership rates might not have fallen. In the model developed in Section 3 we argue that deviations from rational expectations for house prices are key to understand its slow response, which we turn to next.

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, the response of house prices follows a hump-shaped response and, while the activity in the housing market falls, the share of renters increases among certain population groups, revealing an increase in demand even though rent 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 models in the spirit of the models developed in, e.g., Kaplan et al. (2018) and Auclert et al. (forthcoming) and the related literature. We augment the model by introducing a housing and rental market with fixed housing supply, borrowing constraints, and sticky rents, 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 in between homeownership and renting, or between homeownership and being a landlord.

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 purchase housing up to a Loan-To-Value (LTV) and Loan-To-Income (LTI) constraints, whatever 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.

Households' state space is defined by (χ, h, z, a), where χ is the aggregate state of the economy, h is a housing transition (e.g. rent to own), z is labour productivity and a is net financial asset position. In each period households are modelled as proceeding through three stages:

1. Aggregate and idiosyncratic shocks are realised;
2. Households choose which housing h transition to make;[9]
3. Households consume c and save a' based on transition-specific borrowing constraints.

Stage 1. In this step households value function V is simply updated for the realisation of household level and aggregate shocks which impact z and χ.

$$V^{(1)}(\chi, h, z, a) = \mathbf{E}\left[V^{(2)}(\chi, h, z, a)\right]$$

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

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

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

[9]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 transition from a rent-rent state in the prior period to rent-own state in the current period as opposed to transitioning from a rent state to an own state.

Stage 2. In stage 2 households realise a housing tenure preference shock ϵ_h and then choose a housing tenure transition h' for the current period. Prior to the realisation of the preference shock the household's value function is:

$$\mathbf{E}\left[V^{(2)}(\chi, h, z, a)\right] = \sum_{h'} Prob(h'|h, \chi, z, a)\left(V^{(3)}(\chi, h', z, a) + \varepsilon_h - \eta(h')\right)$$

with preference shocks ϵ_h following a Gumbel $(0, \alpha_z)$ distribution. Then the ex-ante probability of a housing transition is described by:

$$Prob(h'|h, \chi, z, a) = \frac{\exp\left(\frac{V^{(3)}(\chi,h',z,a)-\eta(h')}{\alpha_z}\right)}{\sum_{h'}\exp\left(\frac{V^{(3)}(\chi,h',z,a)-\eta(h')}{\alpha_z}\right)}$$

where we also allow for non-financial fixed utility costs $\eta(h)$ of engaging in certain transitions.[10] Both costs exist to help match the transition rates between housing tenures to the data and the taste shock, in particular, to smooth the transition over discrete states (Iskhakov et al., 2017). In order to capture rental contract stickiness, landlords and renters from the previous period can only choose to transition away from their current status with some probability θ_r. If they cannot transition, the rental price stays fixed at the previous period level, but new renters and landlords get the rental market spot price p_r^*.

Stage 3. 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:

$$V^{(3)}(\chi, h', a, z) = \max_{a'} u(c, h', l) + \beta\mathbf{E}[V^{(1)}(\chi'|\chi, h', z'|z, a')]$$

where period utility depends on consumption, housing tenure and labour supplied. We specify the utility function as:

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

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

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. The general budget

[10] For example a distaste for moving or ending tenancies. We also set this to infinity to rule out certain impossible or prohibited transitions.

and borrowing constraints are:

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

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 current p_r^* and lagged p_r price of rents. Households can engage in secured borrowing against property which is a function of the value of the property and their disposable income.

We detail the costs and borrowing constraints associated with each transition in our baseline model in Table 1. Renters pay market-determined rental costs p_r each period, and 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 a LTV or LTI ratio, whatever binds first.[11] 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.

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

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 $p_{r,t-1}$ otherwise.

[11] In practice, we model the borrowing constraints as the lower of their current debt level (a) or the LTI/LTV available to new home buyers. This means that owner occupiers and landlords can violate the LTI/LTV constraints if the house price falls, but in that case they cannot engage in further borrowing.

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 (Cesa-Bianchi et al., 2020) and other countries. In each period, demand for housing has to match supply $\overline{H}$. House prices p_h need to be such that equilibrium in the housing market holds

$$\overline{H} = H_1(s_{r,t} + s_{ooF,t}) + H_2(s_{ooH,t} + s_{ll,t}) \tag{2}$$

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.[12] Each household exerts pressure on the housing market in proportion to the size of their house H_i. 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

$$H_1 s_{r,t} = H_1 s_{ll1,t} + 2H_1 s_{ll2,t} + \overline{HA}, \tag{3}$$

where $s_{ll1,t}, s_{ll2,t}$, are the measure of landlords with one or two flats. We also 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.

3.3 Household expectations

We allow for deviations of Full Information Rational Expectations (FIRE) in two distinct directions, and a third that combines the previous two, for a total of four possible sets of expectation formations. The first deviation from FIRE are sticky expectations, which 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 the importance of sticky expectations 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 θ_{SE} households update their expectations of future prices, but with probability $(1 - \theta_{SE})$ households maintain their forecast from the previous period. In contrast to the previous literature, where all price forecasts are updated with the same probability, we allow for a different probability θ_{SE,p_h} of adjustment of house price forecasts. This allows for households to be more attentive to house prices as a commonly discussed price in wider society and the media and an important invest-

[12] Notice that Equation (2) 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 $s_{ooH,t} + s_{ll,t} = (\overline{H} - H_1)/(H_2 - H_1)$.

ment, or alternatively they may have particularly sticky beliefs around house prices anchored around their own purchases history and previous capital gains.

Second, there is 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 we allow for the possibility that households may extrapolate from past price behaviour when making their forecasts. Let $\hat{x}_t$ be the deviation of variable x_t from the model's deterministic steady state. Then we model extrapolative expectations as:

$$\mathbf{E}_t[\hat{x}_{t+1}] = \begin{cases} \rho_e \hat{x}_t & x_t \neq p_{h,t} \\ \rho_{e,ph} \hat{p}_{h,t} & x_t = p_{h,t} \end{cases}$$

where we allow again for the house price and other variables to have different degree of extrapolations. Notice that our modelling of extrapolative expectations is different than the extrapolative beliefs of, e.g., Adam et al. (2024), but it is closer to the modelling of extrapolative expectations of Granziera and Kozicki (2015) and Bardóczy and Guerreiro (2023). This setting allows us to modify the sequence-space Jacobians of Auclert et al. (2021) to derive the extrapolative expectations, as detailed in Appendix C.3.

Finally, we also allow for a combination of the above, such that households update their expectations infrequently but, when they do, they extrapolate from current prices. Putting these together implies that one period ahead expectations for a household are of the form:

$$\mathbf{E}_t[\hat{x}_{t+1}] = \begin{cases} \rho_e \hat{x}_t & prob = \theta_{SE} \\ \mathbf{E}_{t-1}[\hat{x}_{t+1}] & prob = 1 - \theta_{SE}, \end{cases}$$

and analogously for $p_{h,t}$, with $\theta_{SE,ph}$ and $\rho_{e,ph}$. As discussed in Section 4, the combination of stickiness and extrapolation allows us to match both the large and hump shaped responses of macroeconomic outcomes in response to a rise in the interest rate. Moreover, we show that the estimated sticky and extrapolative expectations combined generate under-reaction in the short term but over-reaction in the medium term, in line with evidence from Angeletos et al. (2021) and Adam et al. (2024).

3.4 Rest of the model

The rest of the model closely follows the recent HANK literature, and in particular Auclert et al. (forthcoming). 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 $\theta_{A,t}$

$$y_{j,t} = \theta_{A,t} n_{j,t} \tag{4}$$

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 price Philips Curve that describes the evolution of prices around the competitive symmetric zero steady state inflation equilibrium

$$\log(1+\pi_t) = \kappa_p \left(\frac{w_t}{\theta_{A,t}} - \frac{1}{\mu^*} \right) + \mathbf{E_t} \left[\frac{1}{1+r_{t+1}} \frac{Y_{t+1}}{Y_t} \log(1+\pi_{t+1}) \right] \tag{5}$$

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 $\Pi_t(z)$.

Moreover, a labour union negotiates hours and wages on behalf of households. Unions set the wage to maximise average utility of households subject to adjustment costs. In the symmetric equilibrium aggregate wage inflation is determined by a wage Philips Curve:

$$\log(1+\pi_{w,t}) = \kappa_w \left(\phi_l L_t^{\psi_l} - w_t(1-\tau_t) \int_i z_{i,t} c_{i,t}^{-\sigma} di \right) + \beta \mathbf{E_t} \left[\log(1+\pi_{w,t+1}) \right] \tag{6}$$

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

$$i_t = \rho_m i_{t-1} + (1-\rho_m)(r_{ss} + \phi_\pi(\pi_{t,cpi} - \pi_{ss,cpi}) + \phi_y(Y_t - Y_{ss})) + \epsilon_{m,t} \tag{7}$$

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 price inflation and goods price inflation with weights based on the steady state share of rental expenditure.[13]

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).

$$\tau_t = \tau_{ss} + \gamma_{tax} \left(\frac{B_{t-1} - B_{ss}}{Y_{ss}} \right) \tag{8}$$

Public debt then evolves according to the government budget constraint:

$$B_t = (1+r_t)B_{t-1} + G + A_{def,t} - w_t N_t \tau_t - \bar{r} A_{<0,t-1} - \bar{p}_r \overline{HA} - FTR_t \tag{9}$$

with government expenditures including a fixed amount of government purchases G, interest

[13] $\pi_{t,cpi} = \omega_{rent} \pi_{t,rent} + (1-\omega_{rent})\pi_t$ 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	0.59	$\rho_{z,1}, \rho_{z,2}, \sigma^2_{z,1}, \sigma^2_{z,2}$	Bell et al. (2022)
One year earnings change std. dev	0.19	0.19	$\rho_{z,1}, \rho_{z,2}, \sigma^2_{z,1}, \sigma^2_{z,2}$	Bell et al. (2022)
Five year earnings change std. dev	0.78	0.37	$\rho_{z,1}, \rho_{z,2}, \sigma^2_{z,1}, \sigma^2_{z,2}$	Bell et al. (2022)
90-10 income ratio	4.66	4.53	$\rho_{z,1}, \rho_{z,2}, \sigma^2_{z,1}, \sigma^2_{z,2}$	Bell et al. (2022)
Ann. debt to GDP	0.65	0.68	β	ONS (97-23)
Share of renters	0.33	0.35	$\phi_h, \omega_{oo}, p_{r,ss}, \eta_{ll}$	EHS (97-23)
Share of flat owners	0.10	0.16	$\phi_h, \omega_{oo}, p_{r,ss}, \eta_{ll}$	EHS (97-23)
Share of landlords	0.06	0.06	$\phi_h, \omega_{oo}, p_{r,ss}, \eta_{ll}$	WAS (08-20)
Ann. prob of owner $\rightarrow$ renter	0.008	0.013	η_m	EHS (97-23)

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. ONS refers to national balance sheet data for the UK from the Office for National Statistics, EHS is the English Housing Survey, and WAS is the Wealth and Assets Survey.

payments on the previous periods debt, and the 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, housing transaction costs FTR_t, and revenue from its stock of rental housing $\overline{HA}$.

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 $\{h, z, a\}$, 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 $\{c_t(h_t, z_t, a_{t-1})\ ,\ a_t(h_t, z_t, a_{t-1}),\ h_t(h_{t-1}, z_t, a_{t-1})\}$; and household distribution $D_t(h, z, a)$; such that households, firms, and the labour unions optimise, policymakers follow their rules, housing markets clear, goods market clears (Eq (10)) and asset market clears (Eq (11)):

$$Y_t = C_t + G_t + \delta_h \overline{H} \tag{10}$$

$$B_t = \int_i a_t(h_t, z_t, a_{t-1}) di \tag{11}$$

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 nine 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 over the 1997-2023 period. The share of renters and of flat owners is matched to the averages over 1997-2023

Table 3: Externally calibrated parameters

Parameter	Value	Source
Frisch	0.5	Auclert et al. (2020)
EIS	0.25	
Steady State Markup	1.06	Auclert et al. (2020)
Borrowing wedge $\bar{r}(ann)$	0.0126	(avg 97-19 of 2yr 75pct)
Transaction Cost	$0.02p_{h,ss}$	Halifax
$\frac{p_{h,ss}}{\bar{y}}$	6.3	Avg 97-23 ONS; $\bar{H}$
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 (ann) δ_h	0.015	Bureau of Economic Analysis

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. The other steady-state parameters are calibrated to values typically used in the literature,[14] as shown in Table 3.

Table 4: Untargeted Moments

Moment	Model	Data	Source
Housing Wealth to Financial Net Worth	7.3	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	0.53	0.53	English Housing Survey (97-23)
Share of Landlords with Liquid Assets < 0	0.37	0.57	WAS (08-20)
Avg Rent to Renter Disposable Income	0.31	0.33	English Housing Survey

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 MPCs consistent with survey data (see appendix Figure C.3).

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 37% 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]

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

[14]Our selection of a slightly lower elasticity of inter-temporal substitution follows from our experience in subsequent exercises IRF matching the model. In experimenting with values between 0.1 to 0.7, a range consistent with the empirical estimates from Attanasio et al. (2002) and Best et al. (2020), we found that lower values generally improved our ability to match the empirical dynamics.

[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.

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 allows us to use the EGM procedures where the discrete choices can induce multiple solutions for the savings policy function. Finally we depart from rational expectations by rebuilding the household Jacobians using the Fake News matrices discussed by Auclert et al. (2021). These manipulations are detailed in Appendix C.3.

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, with a specific focus on the response of the housing market.

4.1 IRF Matching and the Housing Market

Table 5: IRF Matched Parameters

Parameter	Symbol	IRF matched value
Slope of price Philips Curve	κ_p	0.05
Slope of wage Philips Curve	κ_w	0.17
Debt stab. in fiscal rule	γ_{tax}	0.09
Taylor rule coefficients	$(\phi_\pi, \phi_y, \rho_m)$	(2.31, 0.00, 0.92)
Price forecast adj. prob	θ_{SE}	0.09
House price forecast adj. prob.	θ_{SE,p_h}	0.93
Price extrapolation	ρ_e	0.96
House price extrapolation	ρ_{e,p_h}	0.91

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 minimum distance estimator that attempts to minimise the squared distance between the models IRFs to a monetary policy shock of the interest rate, output, prices, house prices and rents, and their empirical counterparts. We perform the same exercise for the four possible sets of expectation processes we consider: (i) rational; (ii) sticky; (iii) extrapolative; and (iv) sticky and extrapolative. The one that is able to best match the response of house prices and rents is sticky information combined with extrapolative expectations, and Figure 6 shows the resulting IRFs in the model under this baseline assumption compared to the data. Section 4.1.1 discusses the results under the different expectation assumptions.

The matching procedure is able to bring the model close to the data, particularly for the nominal rental price.[16] We are also able to match relatively well the prolonged and large hump shaped response of the house price and GDP. Consistent with the data, the model also produces a prolonged fall in housing sales and an uptick in the rental share (see Figure C.4).

[16]The model does not replicate the magnitude of the decline in the monthly GDP index observed in the UK data. However, the short-run dynamics of the index are heavily influenced by industrial production, which is more cyclical than overall GDP.

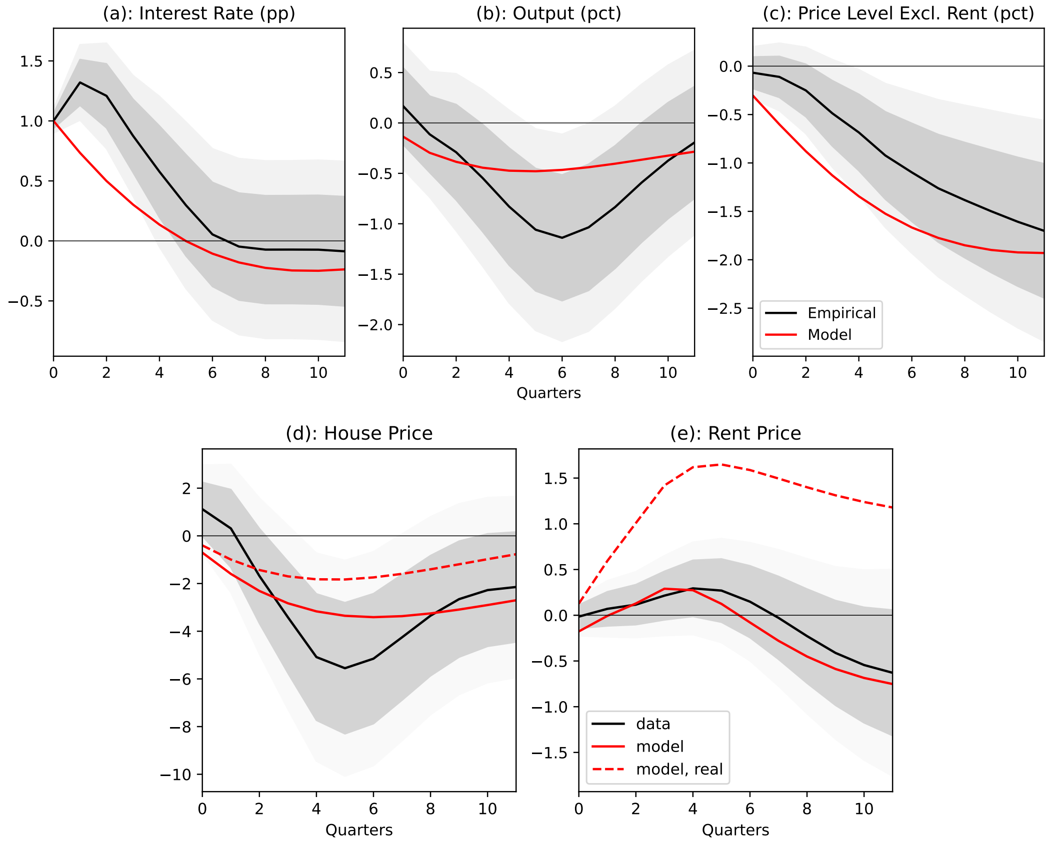


Figure 6: IRF Matching

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.

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 0.09 for prices other than the house price is in line with the estimates of 0.065 from Auclert et al. (2020), who do a similar IRF matching exercise. However, for house prices we find that the model asks for much more regular updating of 0.93, still with a high degree of extrapolation. We take these results as evidence that departures from rational expectations are necessary for a good matching of the model to the data.

4.1.1 Expectation processes

Figure 7 shows the IRF profiles under different expectations processes.[17] 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. Note though that under rational expectations the nominal and relative rental price rise, which is in

[17]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).

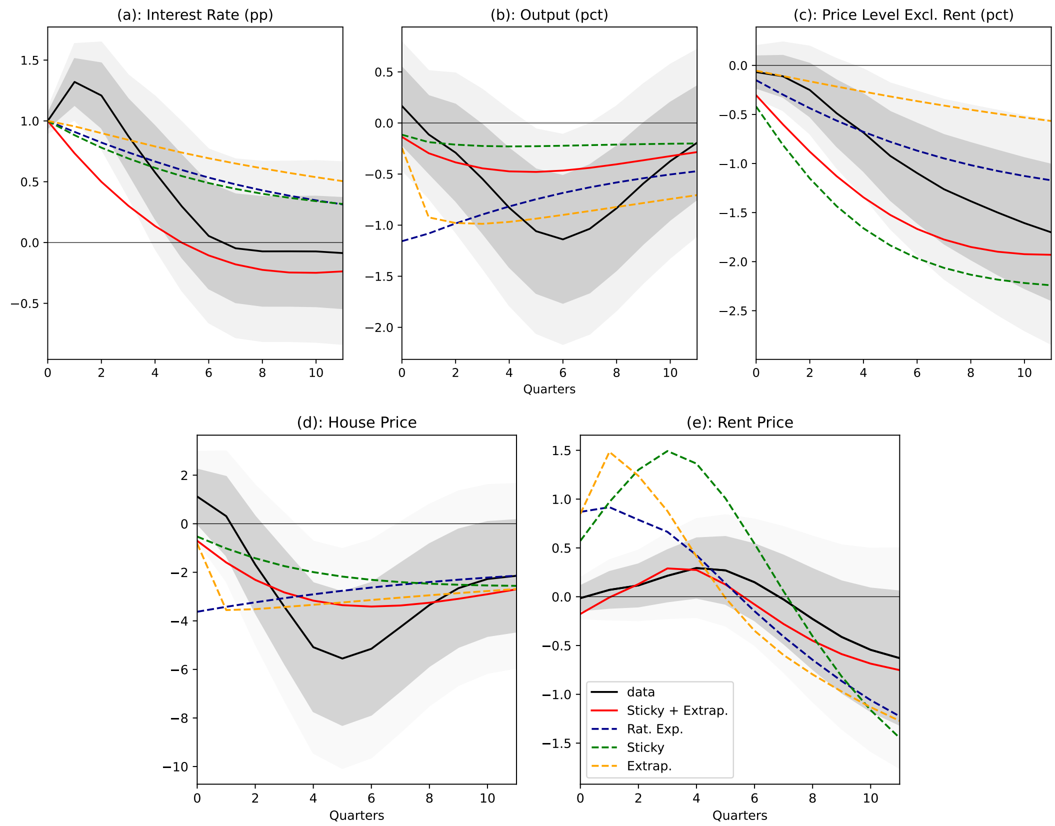


Figure 7: IRFs under Alternative Expectations Processes

Notes: Figure repeats figure 6 under different expectations process. Under Sticky expectations households update forecast infrequently but do so under extrapolative expectations. Under Extrapolative expectations households update every period using an AR1 forecast for each price.

contrast to what one would obtain in a simple representative agent durable goods model where the durable good is in fixed supply. In that model, a rising marginal utility in consumption would push down on the relative rental price. Therefore, we find that the modelling of realistic heterogeneity and frictions in the rental market can produce a rising nominal and relative rental price in these models even 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 channels also dampens the overall fall in GDP and the relative house price. 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. The extrapolative expectations process (yellow line) produces a large response in GDP and the relative house price. Extrapolative expectations cause households to have positively biased forecasts of the interest rate which amplifies the response of output, the fall in housing demand and increase in rental demand. However, like in the rational expectations case households are too reactive, which causes the peak impact of the interest rate increase to occur almost on impact. Given the above, the combination of sticky and extrapolative expectations is what allows us to best match the IRFs jointly.

Is our baseline expectations process of sticky information combined with extrapolative expectations reasonable? Departures from rational expectations induce systematic bias in households forecasts, which have been documented in the literature, including for house prices. Figure 8 replicates the bias in four quarter ahead house price forecasts in the model following a monetary policy shock and compares them to the empirical estimates of Adam et al. (2024) for US households. We find that despite not explicitly targeting these estimates the model replicates them well: the model also features an initial under-reaction to house prices changes followed by an over-reaction (see also Angeletos et al. (2021) for further evidence of under-reaction followed by over-reaction in other macro variables). Figure C.5 decomposes the house price movement into different components, and shows how this deviation from rational expectations is the main contributor for house prices not reacting much on impact. Moreover, the higher house prices needed to maintain equilibrium in the broader housing market also spillovers into higher demand in the rental market that pushes up on relative rental prices. Therefore, our model and analysis underscores the need to include these biases in models in order to adequately match the dynamic response of economic aggregates.

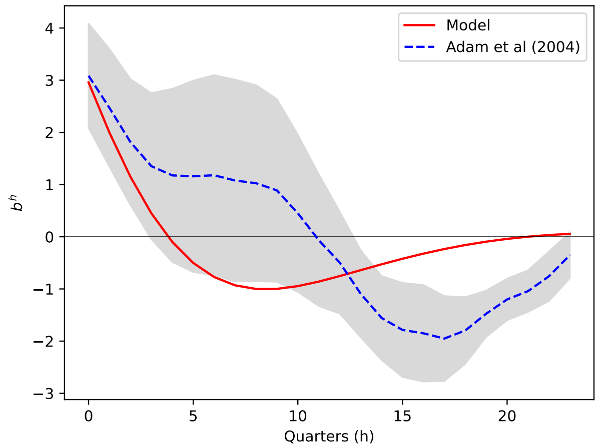


Figure 8: Biased House Price Forecasts

Notes: This chart compares the bias in four quarter ahead forecasts of real house price growth in the model to the empirical findings of Adam et al. (2024) (Figure 1, Panel (b)). The empirical estimates are taken directly from Adam et al. (2024) and plotted in blue with 90% confidence intervals shaded in grey. The regression in that paper is of the form $(p_{t+4+h} - p_{t+h}) - E_{t+h}[p_{t+4+h} - p_{t+h}] = \alpha^h + b^h(p_{t-1} - p_{t-2}) + u_t^h$. We replicate this calculation in the model using the house price IRF to a monetary policy shock, where the shock occurs in period $t-1$ in the context of the above regression.

4.2 The housing market and monetary policy

We now examine in detail the interplay between the housing market and monetary policy in the model.

4.2.1 Housing market clearing

The first exercise is to show what happens to the housing sector after a partial equilibrium real interest rate shock, and then what are the necessary movements in other prices in general

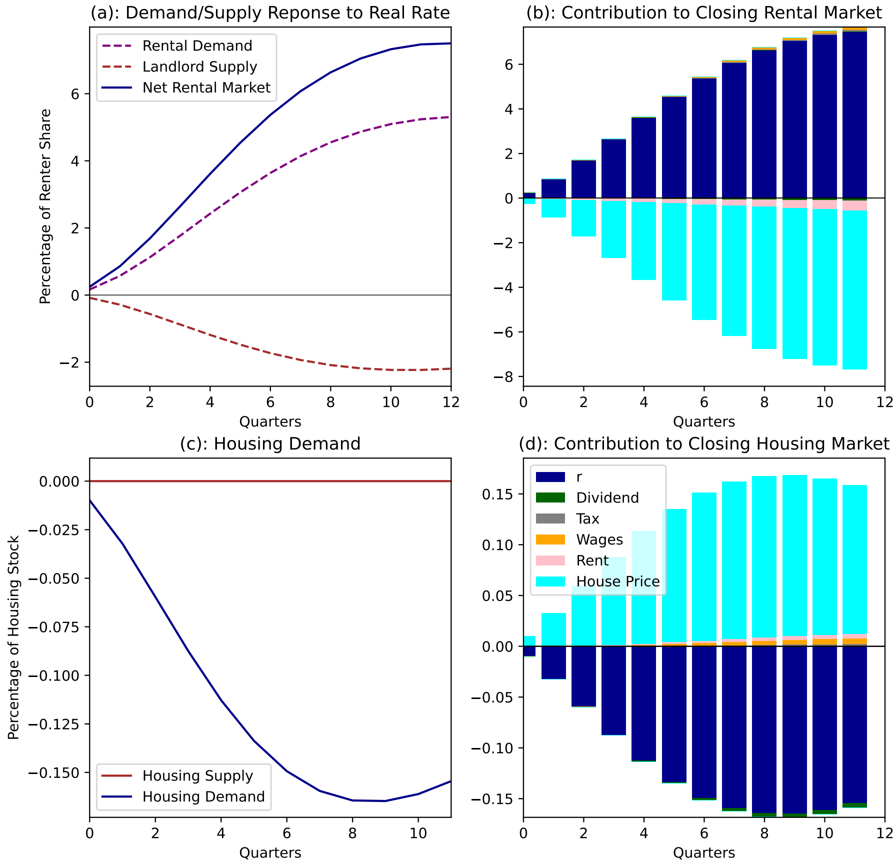


Figure 9: Housing Market Response to Higher Interest Rate

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 6. 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. (2) and Panel (d) the contribution of each price to closing the housing market.

equilibrium to direct the housing sectors into equilibrium. Importantly, the real interest rate shocks considered in this section are matched to the combination of nominal interest rate and inflation shown in Figure 6.

Figure 9 shows the partial equilibrium response to an interest rate shock on the demand and supply in the rental market in Panel (a), and in the housing market in Panel (c).[18] Panel (a) shows that the rise in interest rates pushes up on rental demand and down on landlord supply with an overall effect of creating excess demand in the rental market (blue line). This follows from the fact that all else equal higher interest payments dissuade homeowners and landlords from borrowing to buy a house, while at the same time increasing the relative return on liquid savings (remember 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

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

fixed by assumption.[19]

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 (2) and (3) hold and the rental and housing markets are back in equilibrium. The dark blue bars in both Panels 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. For example, the effect of monetary policy on the housing market through lower wages (yellow) is quite small. 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 for quantities. Based on Panels (b) and (d) we can conclude that it is largely the effect of house prices and interest rate in the rental market and housing market that will determine the rental price adjustment needed to clean up any residual excess demand or supply in the rental market.

4.2.2 The housing channel and consumption

Figure 10 plots the consumption response in the model to a rise in interest rates, decomposed into channels coming from the change in the prices household face when making their consumption choices. This is of interest, as 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, e.g., household average MPCs (Kaplan et al., 2018). Importantly, the model incorporates a role for housing which is considered to play an important role in consumption responses (Slacalek et al., 2020), but is usually absent from HANK models. We can therefore use this model to size up the housing channel in a structural model that matches the aggregate dynamics we see in the data.

Consistent with the main messages from the HANK literature the decomposition highlights a significant role for general equilibrium income channels that affect households' disposable income (e.g. wages and taxes). The model also indicates a potentially very large role for rental and house prices. Higher relative rental prices redistribute income away from less wealthy higher MPC households (renters). Lower house prices also drag on consumption through lowering overall household wealth and tightening borrowing constraints. These channels combined account for around half the impact of monetary policy on consumption at its peak.

Panel (b) sheds a different light on the role of housing by plotting the consumption response

[19] Note that switching from owning a flat to renting does not change the size of house you demand just how you pay for it and therefore does not affect overall housing demand. However, the lower endogenous demand for housing comes exactly from households wanting to downsize.

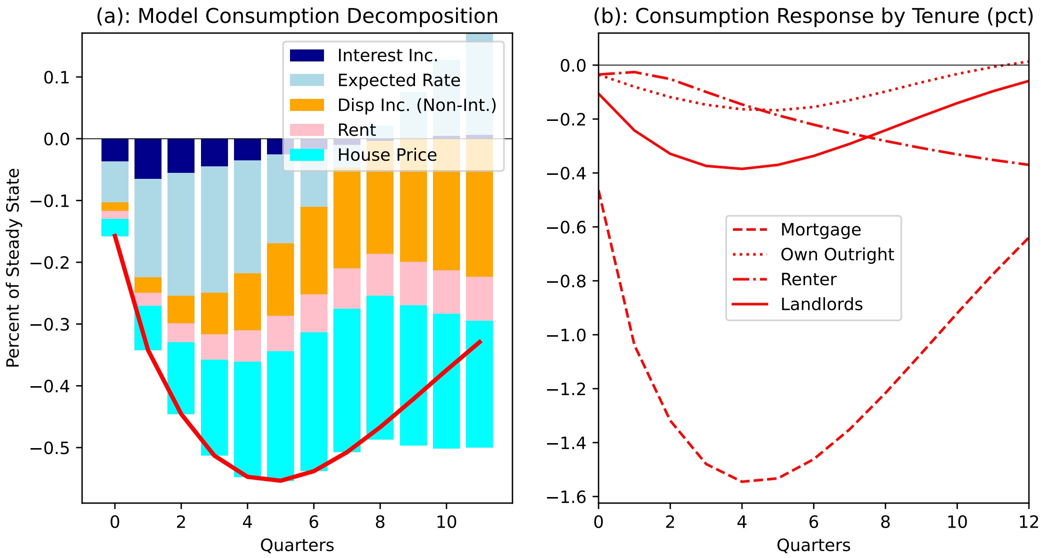


Figure 10: Consumption Decomposition

Notes: Using the estimated household Jacobian of consumption to individual prices and the estimated IRF for each price, Panel (a) decomposes the consumption response in the baseline model. The interest income channel is the effect from current period interest rates. The disposable income channel is the joint effect of wages, hours, taxes and dividends. The expected rate channel largely comprises intertemporal substitution. Panel (b) plots the consumption response in the model by housing tenure relative to the steady state level of consumption for each tenure.

by housing tenure. This plot indicates that the implications of the interest rate rise are largest for mortgagors, who suffer from higher interest payments, lower borrowing capacity and the risk of having to sell in a market downturn. At the peak impact of interest rates on aggregate consumption, around 75% percent of the response is accounted for by mortgagors.[20] In contrast, owner occupiers are the least affected as they hold positive liquid asset positions and receive higher interest income, while at the same time these liquid assets allow them to smooth through any temporary falls in income from other sources. The response of renters moves somewhat in line with the relative rental price which does not respond on impact but then rises over time. This follows from renters holding relatively little wealth and spending a high share of their income on rent. Taken together these results are fairly in line with their empirical counterparts reported by Cloyne et al. (2020).

Finally, somewhat surprisingly at first, landlords experience a fall in consumption second only to mortgagors over the first 6 quarters. This can be rationalised given the fact that a large share of landlords in the model and the data have negative net financial wealth and that, due to adjustment costs and biased house price forecasts, landlords do not initially raise rental prices enough relative to the rise in the real interest rate (in the data, see Figure 3, and in the model, see Figure 11). Therefore, through the lens of this model and the data it matches, the movement in the rental market after an interest rate shock does not represent a distribution

[20] We are modelling all households as being on a variable rate mortgage whereas households in the UK have mortgages with fixation periods varying mostly from 2 to 5 years. Therefore, our estimates of the effect on mortgagors can be interpreted as an upper bound.

of resources from poor HTM to wealthy households. The tenure least affected by monetary policy are those that own outright their property, and thus have liquid savings to help insure themselves.

4.2.3 Commercial versus private landlords

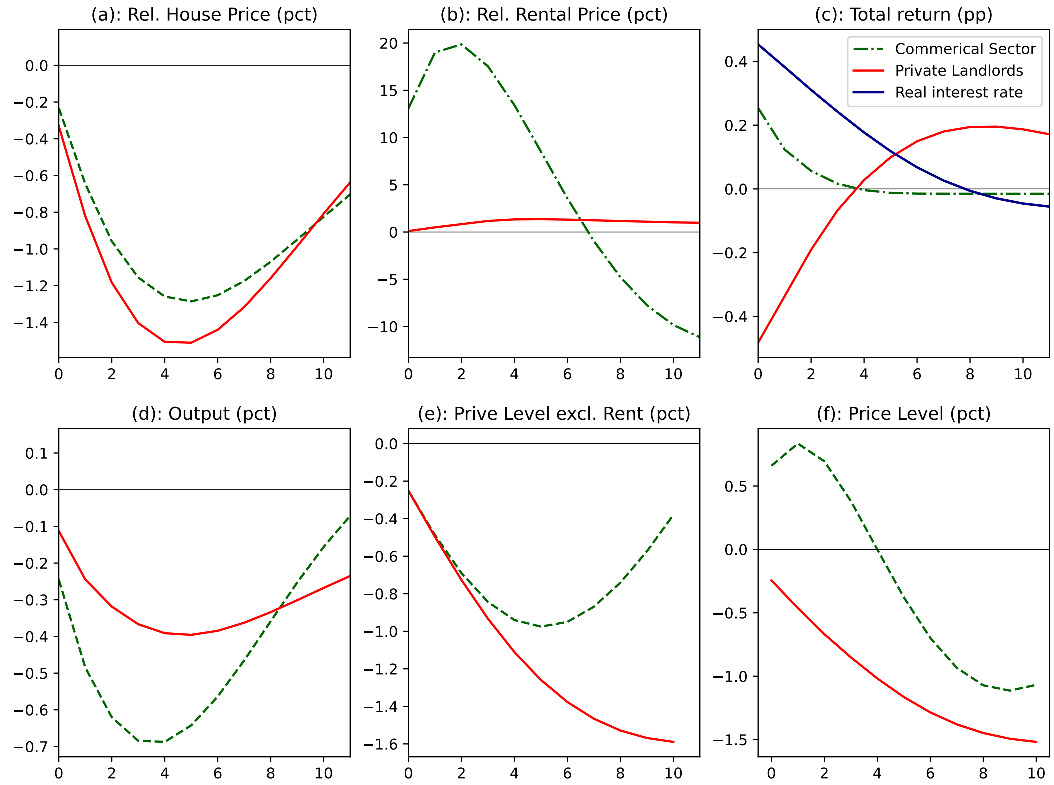


Figure 11: Role of Constrained Landlords

Notes: this figure reports the IRFs to a 1p.p. monetary policy shock for the IRF matched model in red and the model augmented to include a marginal commercial landlord sector in dashed green. The monetary policy shocks in the augmented model are set to produce the same real interest rate path as in the baseline model. The real interest rate path in both models is shown in blue in Panel (c). Panels (a) and (b) plot the response of house prices and rents, respectively, relative to the price of non-housing goods. Panel (c) also plots the total return on housing, defined as the rental yield plus capital gains, i.e., $(p_{r,t} + p_{h,t+1})/p_{h,t} - 1$. Panel (e) plots the price level omitting rental prices from the CPI basket.

A prominent feature of housing markets is the existence of private households acting as landlords, which is particularly relevant for the UK, where 94% of landlords rent property as individual landlords (Ministry of Housing and Government, 2019). In the model detailed above these private landlords have acted as the marginal provider of rental housing. To highlight the importance of this assumption, we now assume that the marginal supplier of rental housing is a deep-pocketed and perfectly rational corporate sector. The latter is a typical assumption of macroeconomic models, e.g., Iacoviello (2005) and Kaplan et al. (2020).

We assume the commercial sector faces rental demand with elasticity ϵ_r and is subject to the same probability of adjusting rental prices as individual landlords, given by θ_r. Furthermore, it borrows at the risk free rate in order to buy housing of private households to then rent them, supplying $H_{CR,t}$ rental units. Moreover, the commercial sector operates under Rational Expectations.[21] Appendix C.2 describes and derives in detail the commercial sector's problem, which will price new contracts at time $t = \tau$ according to:

$$p_{r,t} = E_t \left[\frac{\epsilon_r}{\epsilon_r - 1} \left(\delta_{hf} + \frac{p_{h,t}}{v_{1,t}} - \theta_r \frac{v_{2,t}}{v_{1,t}} \right) \right],$$

where $v_{1,t}, v_{2,t}$ are the usual forwarding looking terms in the solution of firms' problem subject to Calvo pricing. Notice that under $\theta_r = 1$ and $\epsilon_r \to \infty$, the equation above collapses to the usual user cost formula:

$$p_{h,t} = (p_{r,t} - \delta_h) + \frac{E_t [p_{h,t+1}]}{1 + r_{t+1}}$$

The equilibrium in the rental market is now given by

$$H_1 s_{r,t} = H_1 s_{ll1,t} + 2H_1 s_{ll2,t} + \overline{HA} + \underbrace{H_{CR,t}}_{\text{Com. Supply}}$$

Figure 11 compares the baseline model results from the previous section with the model where commercial landlords are the marginal suppliers, under the same path for real rates. The main difference is the response of the rental price, which reacts now much more than when private landlords are the marginal supplier.[22] This stems from the fact that commercial landlords are modelled as rational and forward looking, thus demanding a higher rental yield (Panel (c)) than private landlords, given that they do not under-react to the change in house prices. For this to happen the rental price has to increase. The adjustment happens through higher rents and not lower prices because, as Figure 9 showed, the rental price has limited impact on the broader housing market whereas the house price has a large impact on both the rental and broader housing market. There is therefore less scope for the house price to move as the broader housing market is already in equilibrium in the baseline model under the baseline

[21] While we do not know of a suitable series of households' house price expectations for the UK, the UK Residential Market Survey by RICS asks surveyors about their 3-month house price expectations since October 1998. We use it in Appendix A to investigate the impact of monetary policy on the house price expectations of professionals. However, it is a "net balance" measure, i.e., it is the sum of the share of surveyors who report that they expect prices to increase, minus the share who report that they expect house prices to fall. For example, if 30% of respondents expected prices to increase, 50% to stay the same, and 20% to fall, the net balance is equal to +10. Thus, it is a measure of how widespread is the expectation that house prices will increase or fall, not of the magnitude of such increase/fall. Figure A.4 shows the response of the RICS house price expectation measure. To make it easier to compare the magnitude of the net balance expectations with the realised 3-month house price growth, we have normalised both variables. We interpret the results of Figure A.4 as indicative that expectations of professionals might be slightly sluggish in the very short-term, but that they closely follow the dynamic of realised house prices already a year after the monetary policy shock. This informs our choice of rational expectations in the exercise above. Finally, we do not extrapolate this evidence on the expectations of professionals to those of households, given the literature that highlights that professionals are better forecasters (Carroll, 2003; Mankiw et al., 2003; Coibion et al., 2018).

[22] Corsetti et al. (2022) find tentative evidence that private companies in Germany respond strongly with increased rental prices after an increase in interest rates, while private landlords do not. Moreover, because the commercial rental sector is larger in the United States (Levy, 2021), this can explain why some studies have found that nominal rental prices increase in the US following an increase in interest rates (Dias and Duarte, 2019; Albuquerque et al., 2024) while we have found that nominal rents stay flat in the UK.

house price path and is little affected by the change in the structure in the rental market.

This change in the rental market has significant implications from macroeconomic stabilisation. The greater pass through of interest rate rises to house prices is now a much stronger source of tradeoff between output and overall price stability. Higher rental prices strengthen the transmission to real quantities (Panel (d)) through lower disposable incomes, but at the same time they mechanically push up on the overall CPI basket (Panel (f)).

This exercise highlights how in an interconnected housing market with behavioural frictions, the rental market could be a significant source of tradeoff for monetary policy transmission but those same biases then act to dampen that trade off when private households also act as the providers of rental housing. It also implies a greater role for commercial landlords may in fact increase the pass through of interest rate movements to rental prices if the commercial sectors is more responsive to the prevailing yield in wider financial markets than private landlords.

4.2.4 Optimal response to a housing market shock

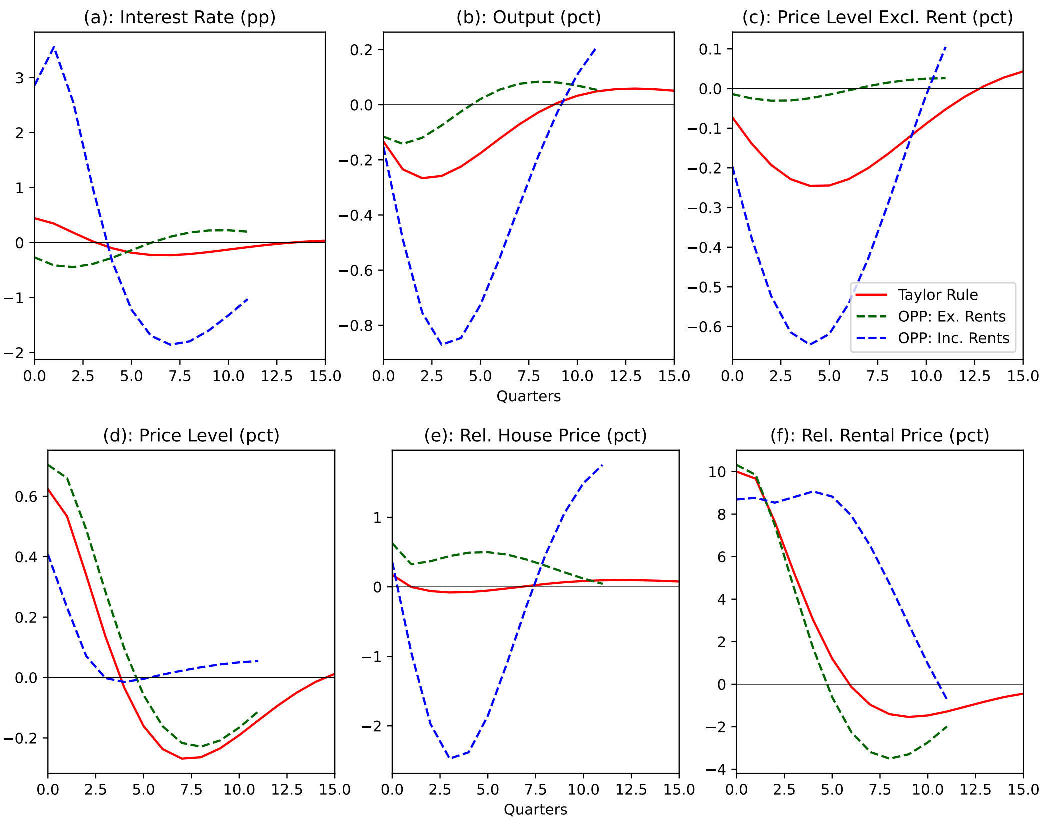


Figure 12: Response to a Housing Market Shock

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.

In our final exercise we look at the implications of a housing market shock in the model and the optimal response of monetary policy. The housing 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 12. 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.

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

$$L_x = \sum_{t=0}^{20} (\pi_{t,x})^2 + \lambda (i_t - i_{t-1})^2 \tag{12}$$

We choose the same 5 year policy window as in Barnichon and Mesters (2023) and we also include an interest rate smoothing term with weight $\lambda = 0.1$ that reflects a policy maker desire not to change interest rates too quickly.[23] 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 Optimal Policy Paths (OPP) shown in Figure 12. 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. 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 interest rate cuts, 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 is better off looking through the housing market shock and focusing on the demand determined side of the economy.

5 Conclusion

We develop and estimate a HANK model with deviations from rational expectations and richly modelled housing sector where households can choose to be renters, owner-occupiers, or landlords. Thus, we deviate from most of the literature and introduce individual private landlords instead of assuming a commercial rental sector, which we argue is more in line with the data and has important consequences for the impact of monetary policy on the housing sector. We show the model is able to match the evidence we gather for the UK on the response of house

[23] While realistic this term is also included to improve the exposition of the exercise as the unsmoothed version $\lambda = 0$ results in a very large interest rate response that makes the chart difficult to view. We provide this unsmoothed result in Appendix C.4.4, which delivers the same qualitative takeaways.

prices and rents after a positive monetary policy shock: a slow and prolonged decline in house prices, and rental prices that are flat during the first one or two years and then fall. The model also matches the untargeted fall in activity in the housing market following an increase in interest rates and the bias in household house price forecasts estimated in other studies.

With the model in hand we are able to perform several exercises to highlight its key features, and some policy implications. First, deviations from rational expectations are necessary for matching the empirical IRFs to monetary policy shock. Second, house prices are the prices that have the largest impact on both the housing and rental market, not rents, due to the long duration of the housing asset, and the lumpiness of its investment. Third, we decompose the channels of monetary policy, and find that the housing channel is large, potentially accounting for 50% of the impact on consumption at its peak. Fourth, the decomposition further highlights how monetary transmission is strongest for secured borrowers, i.e., mortgagors and landlords, the latter also acting as a wealthy hand-to-mouth. Fifth, the rental price channel of monetary policy is stronger and a greater source of trade-off for monetary policy as we move from a rental sector supplied by individual private landlords to an unconstrained commercial sector with rational expectations. Finally, it might be optimal for policymakers to look through housing market shocks and focus on the more demand driven sectors in the economy.

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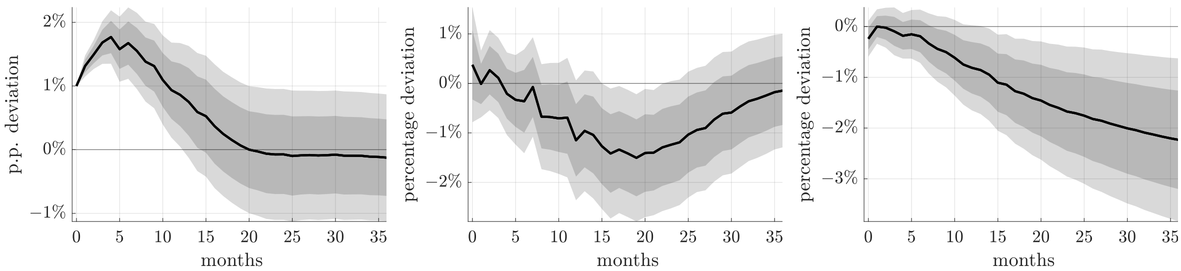
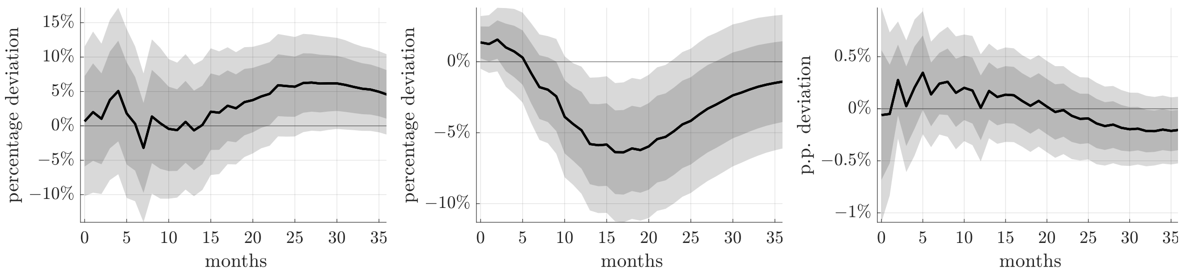
A Additional figures and tables



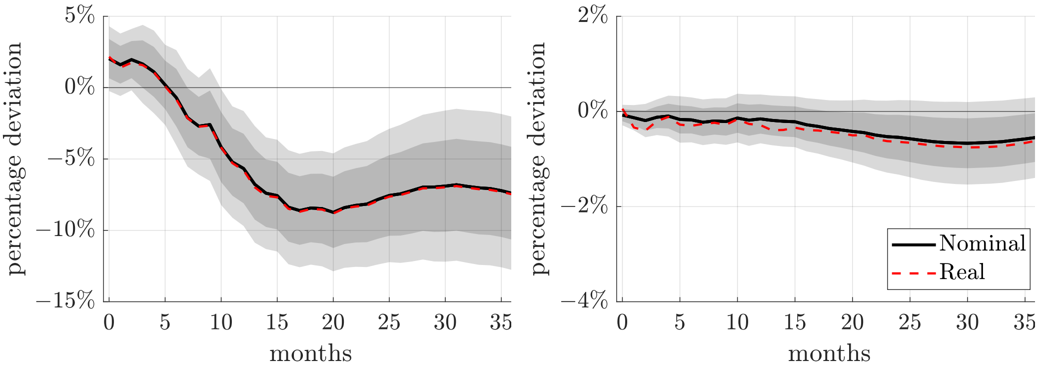
(A) Bank Rate (B) GDP (C) CPI core, ex-rent



(D) FTSE (E) House Prices (F) Mortgage Spread

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 six 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, and (F) the spread between the rate on 75% LTV mortgages and the 2 year yield. The shaded areas represent 68 and 90% confidence intervals. Confidence intervals are calculated using a residual-based moving block bootstrap.



(A) House prices (B) Housing rents

Figure A.2: House prices and housing rents, pre-covid sample (1997-2019)

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. 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.

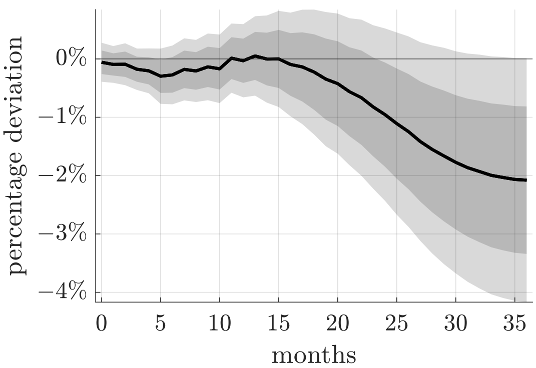


Figure A.3: Response of CPI-OOH, post 2005

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 1D, it shows that both variables show a similar response to monetary policy shock in the period they overlap.

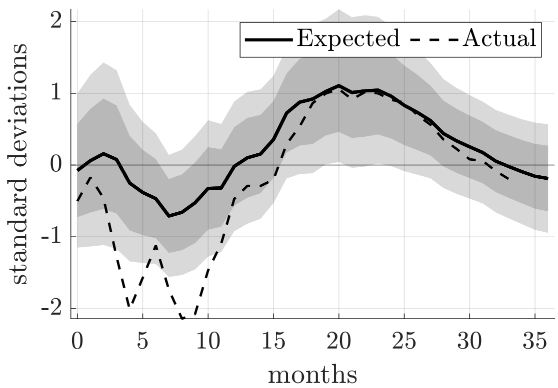


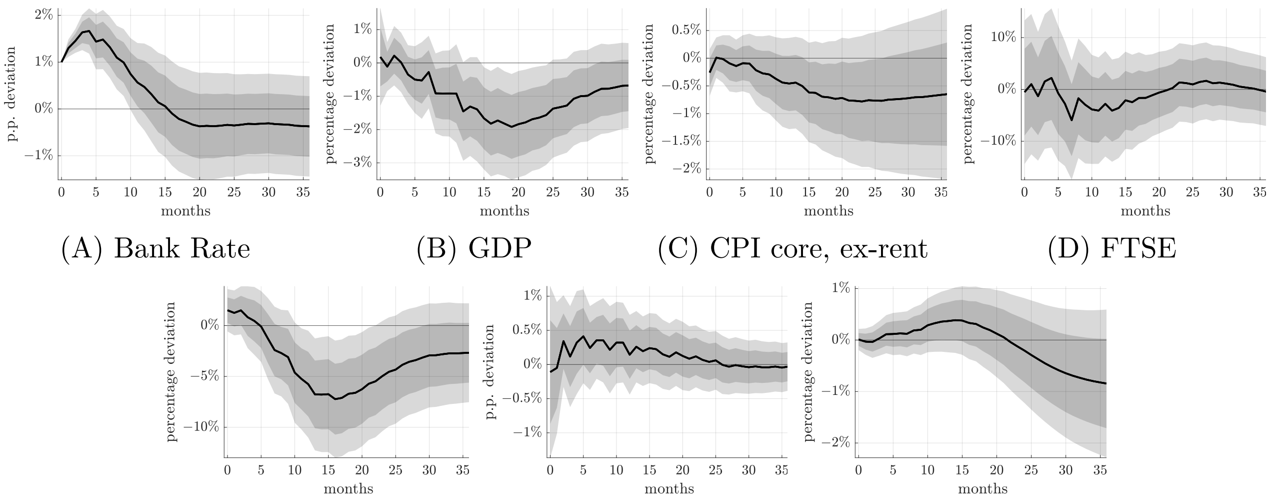
Figure A.4: House price expectations by surveyors, normalised

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.

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.

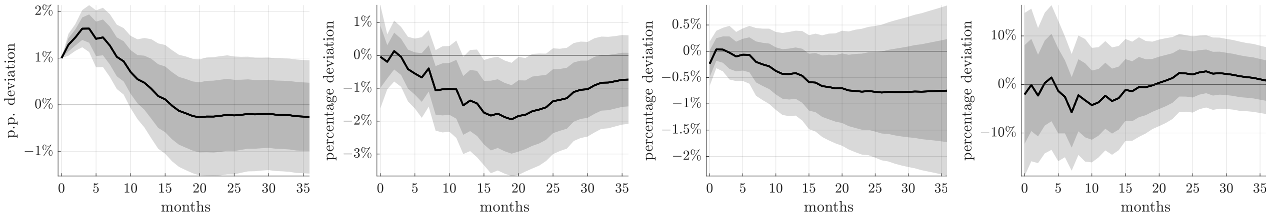


(A) Bank Rate (B) GDP (C) CPI core, ex-rent (D) FTSE

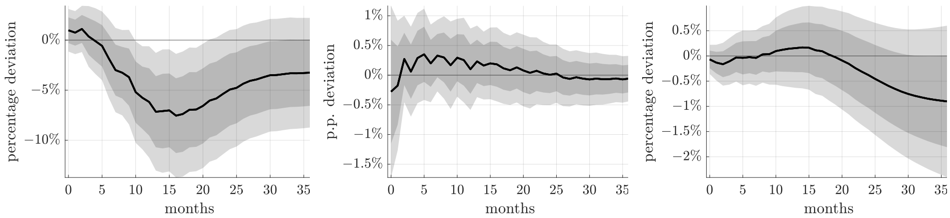
(E) House Prices (F) Mortgage Spread (G) Rents

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.



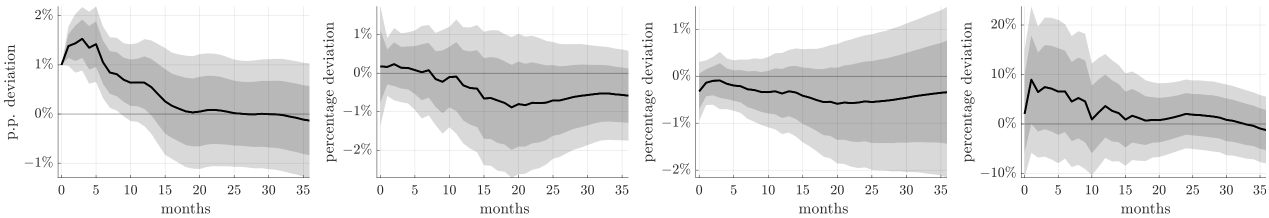
(A) Bank Rate (B) GDP (C) CPI core, ex-rent (D) FTSE



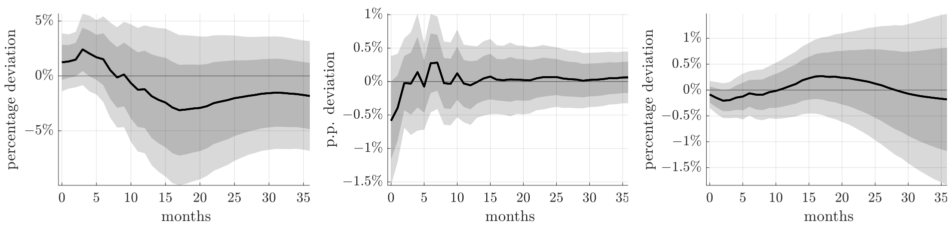
(E) House Prices (F) Mortgage Spread (G) Rents

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.



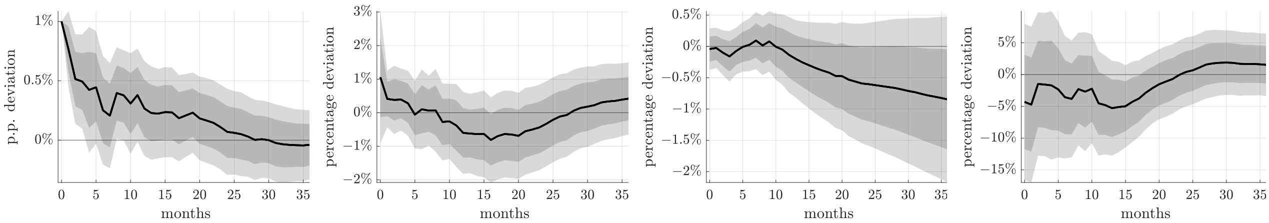
(A) One year yield (B) GDP (C) CPI core, ex-rent (D) FTSE



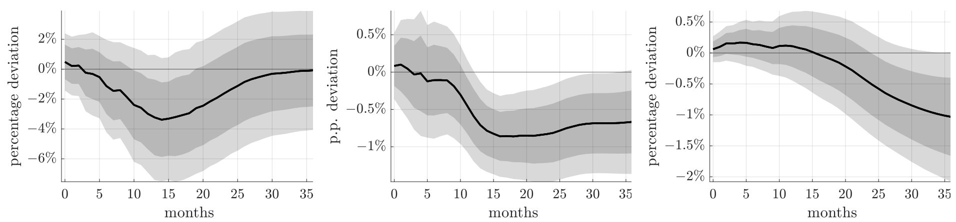
(E) House Prices (F) Mortgage Spread (G) Rents

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

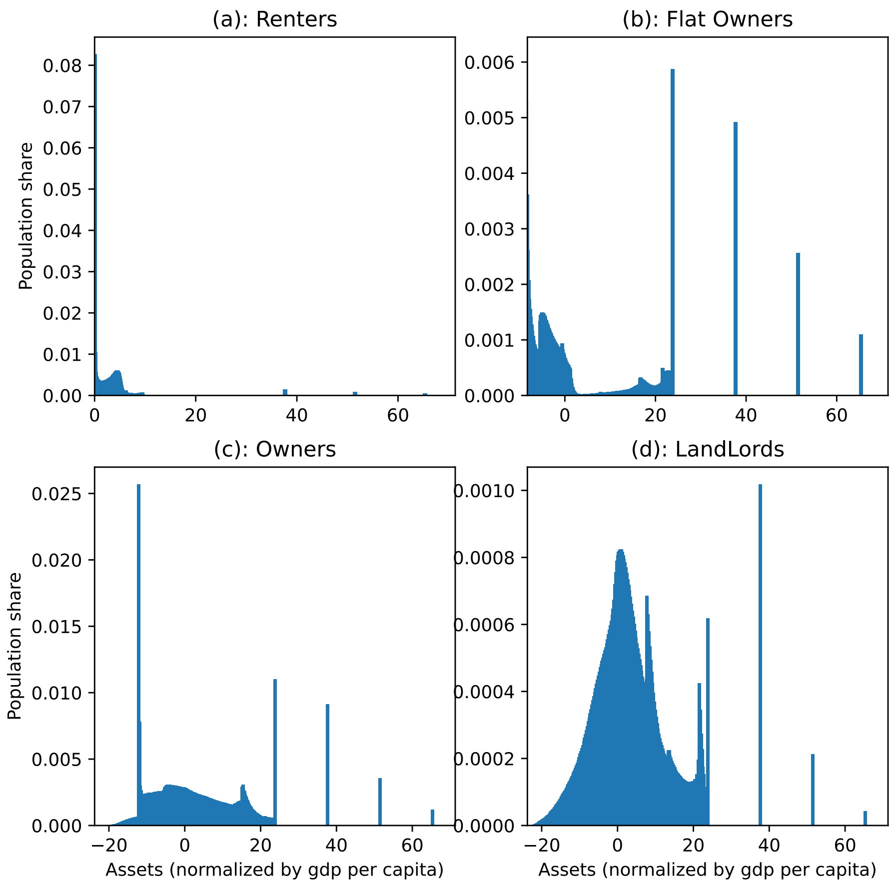
C.1 Calibration and Steady State

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, 3 points are used for the permanent productivity process and 5 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 95% of points unevenly 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.

Table C.1: Asset grid discretisation

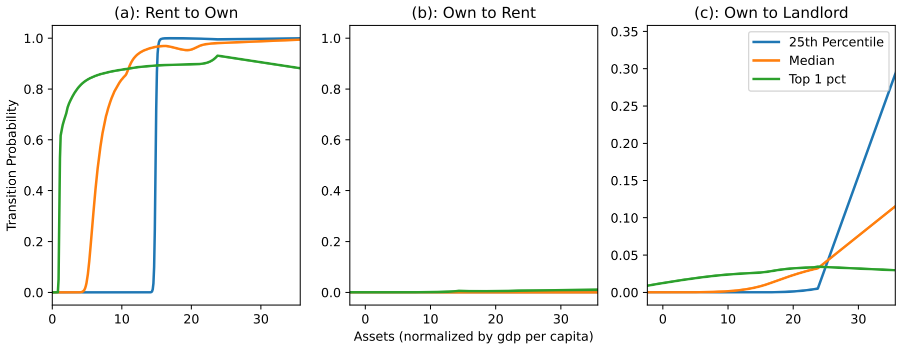
Initial Tenure	Low point	95th pct	Max
Renter	0	$H_2 p_h$	$8H_2 p_h$
Flat Owner	$-H_1 p_h$	$H_2 p_h$	$8H_2 p_h$
Owner	$-H_2 p_h$	$H_2 p_h$	$8H_2 p_h$
Landlord	$-H_2 p_h 2\kappa_h$	$H_2 p_h$	$8H_2 p_h$

Figure C.1: Asset Distribution by Tenure



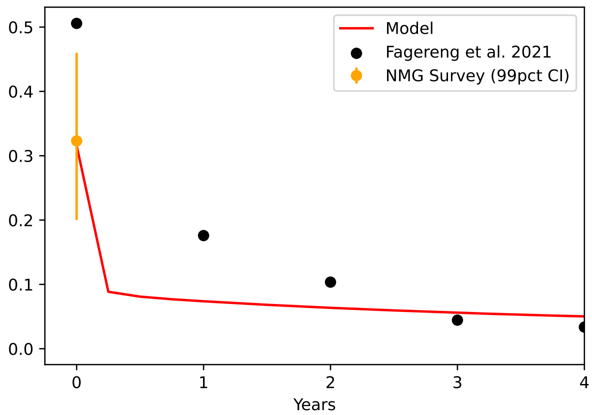
Note: this figure plots the share of households at each asset position in the model steady state by tenure. Each bar represents the mass point on the discretised asset grid.

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 3 different points along the labour income distribution.

Figure C.3: Average iMPCs



Note: this figure plots the consumption response in the model to an unanticipated lump sum transfer. This is compared to the values reported in Fagereng et al. (2021) based on lottery results, and the values reported in the Household NMG survey based on responses to hypothetical questions.

C.2 Commercial Rental Sector Problem

In this exercise we introduce a commercial rental sector as the marginal provider of rental housing. The commercial sector sets the rental price to maximise profits on each rental contract:

$$V = \max_{p_{r,k,t}} E_t \left[(p_{r,k,t} - \delta_h - p_{h,t}) H_{cr,k,t} + \sum_{i=1}^{\infty} \left(\prod_{j=1}^{i} \frac{1}{1+r_j} \right) \Big(\theta_r (1-\theta_r)^{i-1} p_{hf,t+i} + (1-\theta_r)^i (p_{r,k,t} - \delta_h) \Big) H_{cr,k,t} \right]$$

such that $H_{cr,k,t} = (\frac{p_{r,k,t}}{p_{r,t}})^{-\epsilon_r} H_{cr,t}$ i.e. commercial rental companies face a demand elasticity ϵ_r. Commercial rental companies and their tenants enter contracts that break with fixed probability θ_r as in the main model for private landlords. They discount using the risk free rate which is the rate they borrow at from the Bank. We assume that commercial companies face no borrowing constraints.

After substituting in the demand function, the first order optimally condition for this problem is:

$$
\begin{aligned}
\frac{dV}{d_{p_{r,k,t}}} = 0 =& E_t[(1-\epsilon_r)\sum_{i=0}^{\infty}\beta_{cr,t+i}(\frac{p_{r,k,t}}{p_{r,t}})^{-\epsilon_r}H_{cr,t}(1-\theta_r)^i \\
&+ \epsilon\sum_{i=0}^{\infty}\beta_{cr,t+i}\delta_h\frac{1}{p_{r,k,t}}(\frac{p_{r,k,t}}{p_{r,t}})^{-\epsilon_r}H_{cr,t}(1-\theta_r)^i \\
&+ \frac{1}{p_{r,k,t}}\epsilon p_{h,t}(\frac{p_{r,k,t}}{p_{r,t}})^{-\epsilon_r}H_{cr,t} \\
&- \epsilon\theta_r\sum_{i=0}^{\infty}\beta_{cr,t+i+1}p_{h,t+i+1}\frac{1}{p_{r,k,t}}(\frac{p_{r,k,t}}{p_{r,t}})^{-\epsilon_r}H_{cr,t}(1-\theta_r)^i]
\end{aligned} \tag{C.1}
$$

where: $\beta_{cr,t+i} = \begin{cases} \prod_{j=1}^{i}\frac{1}{1+r_{t+j}}, i > 0 \\ 1, i = 0 \end{cases}$. Set to the symmetric equilibrium $p_{r,k,t} = p_{r,k}$ for all firms and simplifying we get:

$$
\begin{aligned}
\frac{dV}{d_{p_{r,k,t}}} = 0 =& E_t[(1-\epsilon_r)\underbrace{\sum_{i=0}^{\infty}\beta_{cr,t+i}(1-\theta_r)^i}_{v_{1,t}} \\
&+ \frac{1}{p_{r,k,t}}\epsilon\delta_{hf}\underbrace{\sum_{i=0}^{\infty}\beta_{cr,t+i}(1-\theta_r)^i}_{v_{1,t}} \\
&+ \frac{1}{p_{r,k,t}}\epsilon p_{hf,t} \\
&- \epsilon\theta_r\frac{1}{p_{r,k,t}}\underbrace{\sum_{i=1}^{\infty}\beta_{cr,t+i+1}p_{hf,t+i+1}(1-\theta_r)^{i-1}]}_{v_{2,t}}
\end{aligned} \tag{C.2}
$$

And a final rearrangement of terms gives the rental price under the commercial rental regime as:

$$
p_{r,t} = E_t\left[\frac{\epsilon_r}{\epsilon_r - 1}\left(\delta_{hf} + \frac{p_{hf,t}}{v_{1,t}} - \theta_r\frac{v_{2,t}}{v_{1,t}}\right)\right] \tag{C.3}
$$

which is that commercial rental companies charge a markup over maintenance costs and the cost of housing minus expected future capital gains discounted at their borrowing rate r, factoring in the rental contract breakage probability. Note the case when $\theta_r = 1$ collapses this to the familiar user cost formula $p_{r,t} = E_t\left[\frac{\epsilon_r}{\epsilon_r - 1}\left(\delta_{hf} + p_{h,t} - \frac{p_{h,t+1}}{1+r_{t+1}}\right)\right]$. Finally we assume fixed costs F_{cm} are incurred by the commercial rental sector such that in steady state they make zero profits.

C.3 Fake News Matrix and Departures from Rational Expectations

We depart from rational expectations in the model by manipulating the household fake news matrices F. As discussed in Auclert et al. (2021), these matrices are key building blocks under the sequence space approach to solving general equilibrium models and capture the response of aggregate outcome to announcements of changes to prices s periods in the future.

$$F_{y,p} = \begin{vmatrix} f_{0,0} & f_{0,1} & \cdots & f_{0,s}\cdots & f_{0,T} \\ \cdots & & & & \\ f_{T,0} & f_{T,1} & \cdots & f_{T,s}\cdots & f_{T,T} \end{vmatrix} \tag{C.4}$$

In the above matrix $f_{s,0}$ is the response of y today to an announcement of a change to a price p in period s. Only for $s = 0$ is this change actually realised. $f_{s,t}$ is then the effect at time t of the announcement of a change in p at time s. Note that $|f_{s,t}| > 0$ for $s > 0, t > 0$ due to the distributional effects of the response to the fake new shocks at time 0. Using this matrix we can compute different Jacobians $J_{y,p}$ that tell us the aggregate change in outcome y to a change in input p as the household level. These Jacobians combine the effects of contemporaneous price changes, future price changes and the lagged effect of past price changes.

C.3.1 Rational Expectations

Under rational expectations we can calculate the household Jacobians from the fake news matrix as follows.

$$J_{t,s} = \begin{cases} f_{t,s} & t = 0 \\ \sum_{i=0}^{t} f_{i,s-t+i} & t \leqslant s \\ \sum_{i=0}^{s} f_{t-s+i,i} & t > s \end{cases} \tag{C.5}$$

Note that to ensure stability of the model at long horizons, in all subsequent departures from rational expectations we assume a very slow convergence back to rational expectations. This can also be motivated by empirical evidence such as in Adam et al. (2024) who find that bias fades over time in the case of house price forecasts. Therefore the final Jacobians are amended such that:

$$\hat{J}^{non-RE}_{:,s} = (1 - \epsilon_{RE})^s J^{non-RE}_{:,s} + (1 - (1 - \epsilon_{RE})^s) J^{RE}_{:,s} \tag{C.6}$$

where ϵ_{RE} is a small number, currently set to 0.005.

C.3.2 Sticky Expectations

Under sticky expectations only $(1-\theta)$ households update their expectations in any given period. When they do they forecast under rational expectations. Households do however perfectly observe prices contemporaneously. The Jacobian is computed as follows:

$$J_{t,s} = \begin{cases} f_{t,s} & t = 0, s = 0 \\ (1-\theta) f_{t,s} & t = 0, s > 0 \\ \sum_{k=0}^{t} \theta^k (1-\theta) \sum_{i=0}^{t-k} f_{i,s-t+i} & t \leqslant s, t > 0, s > 0 \\ \sum_{k=0}^{t} \theta^k (1-\theta) \sum_{i=0}^{s-k} f_{t-s+i,i} & t > s \end{cases} \tag{C.7}$$

C.3.3 Extrapolative Expectations

Under extrapolative expectations households forecast using an AR(1) forecasting rule:

$$E_t[\hat{x}_{t+1}] = \rho \hat{x}_t \tag{C.8}$$

This will result in a lower triangular Jacobian such that:

$$J_{t,s} = \begin{cases} \sum_{i=0}^{T} \rho^i f_{t-s,i} & s \leqslant t \\ J_{t,s} = 0 & s > t \end{cases} \tag{C.9}$$

C.3.4 Sticky and Extrapolative Expectations

This expectations process combines sticky and extrapolative expectations. Under this expectations formation process households only adjust their price forecasts with some probability $(1-\theta)$ but when they do, they do so using extrapolative expectations ($E_t[p_{t+1}] = \rho p_t$).This again results in a lower triangular Jacobian.

$$J_{t,s} = \begin{cases} f_{t-s,0} + \sum_{k=0}^{t-s} \theta^{t-s-k} (1-\theta) \sum_{i=1}^{T} \rho^{t-k+i} f_{k,i} & s \leqslant t \\ J_{t,s} = 0 & s > t \end{cases} \tag{C.10}$$

C.3.5 Extrapolative Expectations (Growth)

Under extrapolative expectations in the growth rate, as in Adam et al. (2024) households form expectations around the growth rate using the following process:

$$\hat{g}_{t+1} = \hat{g}_t + \gamma(g_{t-1} - \hat{g}_t) \tag{C.11}$$

where $\hat{g}_{t+1} = E_t[\Delta ln(p_{t+1})]$ and $g_t = \Delta ln(p_t)$. This will again result in a lower triangular Jacobian such that:

$$J_{t,s} = \begin{cases} \sum_{i=0}^{T} f_{0,i}, s = t \\ \sum_{i=0}^{T} f_{1,i} + \gamma \sum_{i=1}^{T} i f_{0,i}, t = s+1 \\ \sum_{i=0}^{T} f_{t-s,i} + \gamma \sum_{i=1}^{T} i f_{t-s-1,i} - \sum_{j=2}^{t} \gamma^2 (1-\gamma)^{j-2} \sum_{i=1}^{T} i f_{t-s-j,i}, t > s+1 \\ J_{t,s} = 0, s > t \end{cases} \tag{C.12}$$

C.4 Other Model Results

C.4.1 Response of other Quantities

Figure C.4 plots further untargeted impulse responses related to the housing market in the model. In line with the empirical evidence we see a slow but small increase in the rental share following a rise in interest rates (panel (a)). 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.

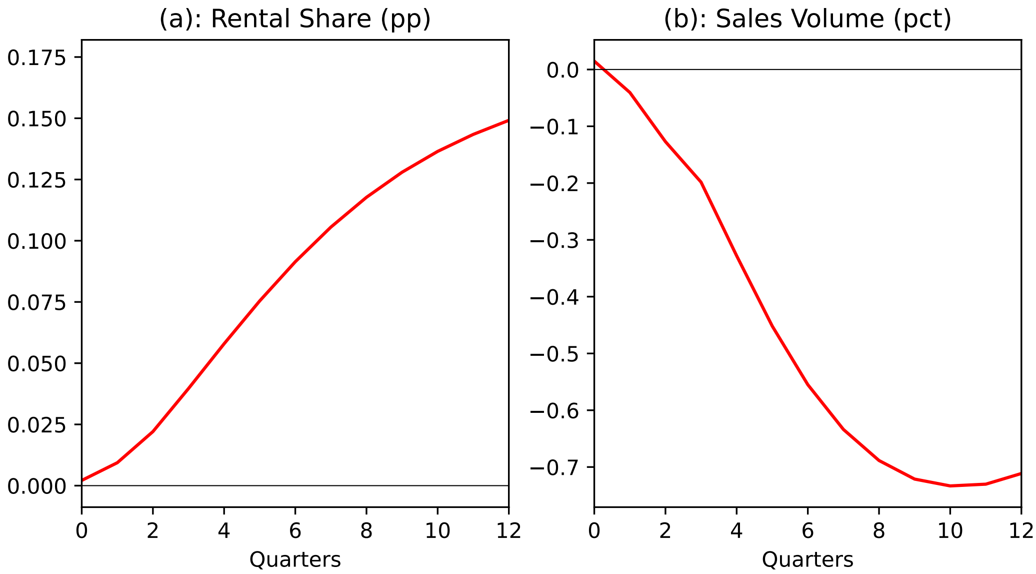


Figure C.4: Other Housing Market IRFs

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 6. 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.

C.4.2 House Price Decomposition

Figure C.5 decomposes the impulse response of the house price using the formula $p_{h,t} = p_{r,t} + E_t[\frac{p_{h,t+1}}{1+r_{t+1}}] + \phi_t$. The $E_t[r_{t+1}]$ and $E_t[p_{h,t+1}]$ are calculated using the actual impulse responses for those variable i.e. under rational expectations. The difference between that calculation and when those terms are calculated using the actual household biased expectation process generates the green bars which we denote as behavioural frictions. The residual is the grey bar which is attributed to other frictions in the model like fixed moving costs and the lumpiness of housing. The decomposition highlights the role these behavioural frictions play in pushing up on the house price. The effect of other frictions and the current rental price is small with the discounting channel dominating ($E_t[r_{t+1}]$).

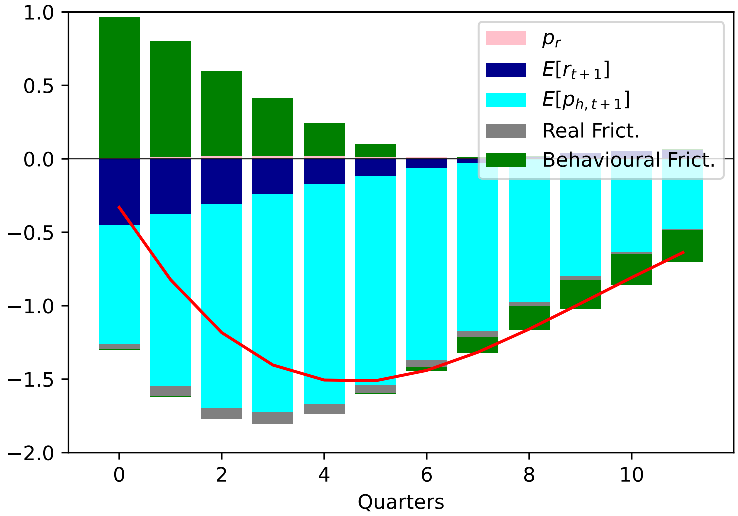


Figure C.5: House Price IRF Decomposition (pct)

C.4.3 IRF matching Under Different Expectations Processes

This section reports the IRF matched impulses responses under different expectations processes. The expectations processes are discussed in section C.3 and the optimised parameters are reported in table C.2.

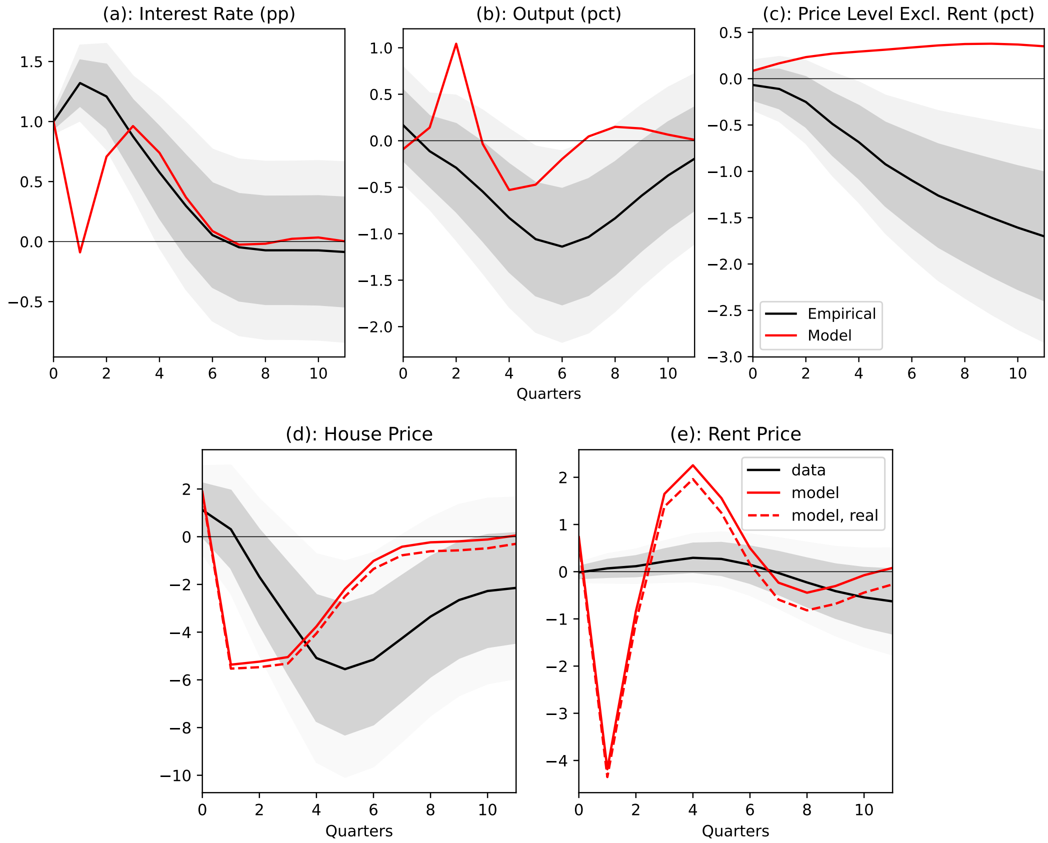
Table C.2: IRF Matched Parameters

Parameter	Rational Exp.	Sticky	Extrap.	Sticky & Extrap. Gr.
Price Philips Curve κ_p	0.005	0.30	0.003	0.30
Wage Philips Curve κ_w	0.16	0.3	0.023	0.29
Fiscal rules (debt stab.)	0.027	0.01	0.15	0.12
Taylor rule (ϕ_π, ϕ_y, ρ_m)	(2.34, 0.0, 0.96)	(1.43, 0.0, 0.96)	(1.28, 0.01, 0.96)	(2.5, 0.0, 0.60)
Price forecast adj. prob θ_{SE}		0.05		0.01
House price forecast adj. prob θ_{SE,p_h}		0.04		
Price extrapolation ρ_e			0.93	0.004
House price extrapolation $\rho_{e,ph}$			0.92	

C.4.4 Optimal policy without smoothing

This exercise replicates the exercise of section 4.2.4 only without any interest rate smoothing. The policy maker sets monetary policy to minimise the following loss function with respect to either the total CPI inflation level or the goods market inflation level i.e. price level excluding rents.

Sticky and Extrapolative Expectations (growth)



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.

$$L_x = \sum_{t=0}^{20} (\pi_{t,x})^2 \tag{C.13}$$

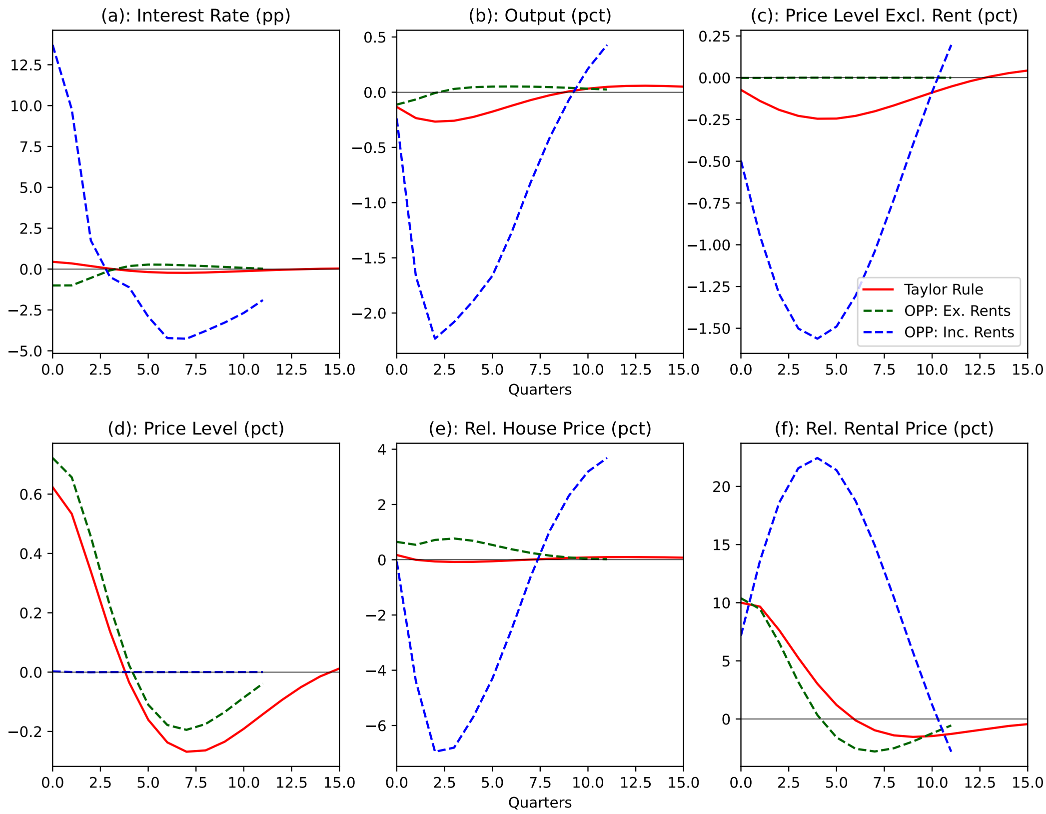


Figure C.6: Response to a Housing Market Shock

Notes: Figure shows response to a persistent fall in the supply of rental housing calibrated to a 10 percent increase in rental prices on impact for the Taylor rule case. 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.