Macro Technical Paper
A UK-HANK Model*

Daniel Albuquerque Ed Hill Sean Lavender Jamie Lenney
Alberto Polo

Abstract

We develop a medium-scale HANK model tailored to the UK, featuring rich household heterogeneity alongside detailed housing, international, and fiscal blocks. The model generates realistic income and wealth distributions as well as marginal propensities to consume consistent with UK evidence. We use the model to decompose monetary transmission into its key transmission channels and assess their relative importance. We then demonstrate the model's versatility through several applications: mortgagors' consumption is most sensitive to house price changes; a lower share of sterling invoicing in exports mildly weakens monetary transmission; monetary transmission is stronger under balanced-budget fiscal reaction functions; and shifts in household balance sheets over the past two decades have dampened the transmission of interest rate changes to prices.

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

*We thank [] for helpful comments and discussions. We also thank Michele Andreolli for generously sharing the Gilt maturity data. The views expressed in this paper are those of the authors and do not necessarily represent those of the Bank of England or any of its committees.

1 Introduction

This document presents UK-HANK, a UK-focused Heterogeneous Agent New Keynesian (HANK) model developed by Bank of England staff for scenario analysis of household sector dynamics and monetary policy counterfactuals. The model was developed in the wake of significant advances in solution methods in recent years, as well as in response to the independent review of the Bank's forecasting and related processes led by Dr Bernanke.

HANK models augment the established New Keynesian framework with a realistic distribution of households over income and wealth. This wealth distribution arises endogenously from idiosyncratic income risk and limits to risk sharing, such as borrowing constraints. The advantage of HANK models over more traditional central bank models lies in their more realistic micro-foundations for household behaviour and their ability to replicate the heterogeneity observed in micro data, while retaining the broader macroeconomic features of previous modelling classes that replicate business cycle dynamics. Importantly, this framework also permits analysis of both the distributional effects of policies and the macroeconomic consequences of heterogeneous developments across the distribution—such as differential changes in real disposable income. The growing availability of high-quality micro data to discipline such analysis makes these exercises increasingly relevant.

UK-HANK focuses on household heterogeneity but captures a wide range of possible monetary policy effects. It includes detailed modelling of the housing sector, international linkages, and fiscal policy, alongside standard treatments of nominal price and wage rigidities, and business investment. A distinctive feature of UK-HANK relative to other HANK models in the literature is its treatment of secured borrowing against housing (i.e., mortgages), which creates substantial negative financial wealth positions for some households. As a result, the transmission channels of monetary policy in the model are far closer to the prevailing narrative, as outlined by Burr and Willems (2024). This proves particularly valuable for policy analysis; for example, UK-HANK has informed scenario simulations at the Bank of England, as discussed in the Monetary Policy Report (November 2025).

We parameterise the model to capture key features of the UK economy over 1993–2023, estimating a subset of parameters to match empirical impulse responses for a range of macroeconomic variables, including inflation and GDP, to monetary policy shocks. The labour income process is calibrated to closely match the historical income risk faced by UK households, and tax and benefit schedules replicate the degree of progressivity in place in the UK. The resulting household income risk, combined with borrowing constraints for unsecured and secured debt, delivers significant and realistic wealth inequality and intertemporal Marginal Propensities to Consume (iMPCs). We analyse monetary transmission and find that, at the peak GDP response, around half of it is directly attributable to interest rate changes (cash-flow channel, intertemporal substitution and cost of capital), with the rest indirectly attributable to exchange rate, housing price and broader general equilibrium channels.

To illustrate the model's wider applications, we perform four experiments and highlight some of its key mechanisms. First, we demonstrate that declines in house prices produce heterogeneous consumption responses by tenure type: mortgagors reduce spending the most, followed by renters, while outright owners maintain relatively stable consumption. Second, we find that the substantial decline in sterling invoicing of UK exports since 2016 has modestly weakened exchange rate pass-through, reducing the cumulative GDP impact over three years of a sterling depreciation by approximately 8% and the cumulative inflation effect by 4%. Third, monetary-fiscal interactions are evident when analysing the impact of monetary policy across different fiscal feedback functions, with the choice of whether to balance the government budget in response to monetary policy exerting the largest influence on GDP outcomes—consistent with existing literature. Fourth, we find that longer-term shifts in household balance sheets over the past two decades have reduced the cumulative impact of monetary policy on inflation by around 25% over three years, while GDP effects remain similar due to offsetting dynamics across channels. These experiments all assume monetary policy operates away from the effective lower bound.

UK-HANK builds on the broader heterogeneous agent literature in general equilibrium, in the tradition of Imrohoroğlu (1989), Huggett (1993), and Aiyagari (1994). However, fully-fledged heterogeneous agent models were only combined with the New Keynesian framework in the 2010s, notably by Oh and Reis (2012), McKay et al. (2016), and McKay and Reis (2016). Kaplan et al. (2018) popularised the term "HANK" and demonstrated how the high MPC present in HANK models, which is more in line with empirical evidence, fundamentally alters the transmission channels of monetary policy relative to the Representative Agent New Keynesian (RANK) benchmark. Since then, a canonical core HANK framework has emerged (Auclert, 2025) on the back of significant but relatively recent advances in solution methods (Boppart et al., 2018; Auclert et al., 2021a; Bayer et al., 2024). As a result, HANK models are gaining traction among central banks, adding to the policy toolkit a framework that can speak to rich household-level transmission mechanisms and distributional questions (e.g., Bardóczy et al., 2024; Kase and Rigato, 2025).

Specifically, UK-HANK is a two-account HANK model in which households can invest in a liquid and an illiquid asset (Kaplan et al., 2018; Auclert et al., 2020), but in our case the illiquid account comprises of housing, as in Albuquerque et al. (2025b). We further incorporate a small open-economy framework following Auclert et al. (2021b), nominal long-term debt as in Andreolli (2021), and deviations from rational expectations drawing on Auclert et al. (2020), Gabaix (2020) and Pfäuti and Seyrich (2022). Section 2 provides complete modelling details and clarifies our implementation and departures from these foundations.

UK-HANK makes three key contributions to this growing literature. First, to the best of our knowledge, it is the first HANK model to integrate household heterogeneity with housing in a small open-economy framework. According to our decomposition, these elements jointly account for around a third of the monetary transmission mechanism in the UK, highlighting their importance. Second, by incorporating secured borrowing against housing, the model captures a redistributive cash-flow channel that has received limited attention in previous monetary policy models, including most other HANK frameworks. Third, it provides one of the few HANK models with UK-specific parametrisation, alongside recent work by Albuquerque et al. (2025b) and Olivi et al. (2023).

The rest of the paper proceeds as follows. Section 2 outlines the model in detail and Section 3 describes the model calibration and solution method. We then explore the monetary transmission mechanism in Section 4 and present the four additional experiments in Section 5. Section 6 concludes.

2 Model

The economy is populated by a continuum of households who consume, choose liquid savings, choose their housing tenure, and work. They are subject to uninsurable idiosyncratic risk to their labour income productivity, which leads to distributions for both labour income and wealth. Households' liquid savings are deposits at a financial intermediary, which pay a nominal interest rate. Thus, UK-HANK is in the vein of HANK models that include liquid and illiquid accounts

(Kaplan et al., 2018; Auclert et al., 2020). However, we explicitly model the illiquid savings as housing, and we include housing consumption services and secured borrowing subject to LTV and LTI constraints. In their housing tenure choice, households decide whether to be renters, owners of small (flat) or large (house) homes, subject to idiosyncratic taste shocks for each tenure. Renters must rent a flat from a commercial rental sector that purchases housing stock to supply rental units to households, subject to nominal price adjustment costs. This framework is similar to that of Albuquerque et al. (2025b), but simplified so that there is a single commercial firm that provides rental housing, as opposed to individual private landlords. We also include deviations from rational expectations for both households and firms by incorporating sticky expectations (Auclert et al., 2020; Carroll et al., 2020) and cognitive discounting (Gabaix, 2020; Pfäuti and Seyrich, 2022), as detailed below.

The financial intermediary uses households' deposits to buy government debt and Central Bank reserves. Government debt is composed of long-maturity nominal bonds (modelled as in Andreolli, 2021), which match the average maturity of UK Gilts, and one-period nominal bonds that match the amount of National Savings and Investments (NS&I) holdings.[1] The government levies progressive taxes that are matched to the UK tax system, and uses taxes to fund government expenditures and transfers, and any deficit (surplus) is made up by increasing (reducing) government debt. Furthermore, the Central Bank sets the short-term interest rate and issues reserves to acquire long-term government debt, effectively reducing its maturity in the consolidated balance sheet of the public sector.

The economy is modelled as a small open economy with trade in final and intermediate goods with the rest of the world following Auclert et al. (2021b). The final consumption good and final output are both bundles of domestic and foreign inputs under a Constant Elasticity of Substitution (CES) function as in Gali and Monacelli (2005). However, with respect to pricing, we impose a structure that is in between the paradigms of prices being fixed in the currency of the consumer (Local Currency Pricing) or being fixed in the currency of the producer (Producer Currency Pricing). It is important to include trade into the model, since foreign shocks are know to be significant drivers of business cycle fluctuations in the UK (e.g., Albuquerque et al., 2025a; Brignone and Piffer, 2025).

The rest of the model is standard. Domestic intermediate good firms produce using labour and capital, operating under monopolistic competition, subject to nominal price adjustment costs. Nominal wages are also subject to adjustment costs and negotiated through a labour union.

Finally, we use the price level P_t associated with non-housing aggregate consumption C_t as the numeraire, and all real prices are denoted by a tilde and defined relative to it. For example, nominal rents are given by $P_{R,t}$, and real rents are $\tilde{P}_{R,t} = P_{R,t}/P_t$.

2.1 Households

The problem of a household $i \in [0, 1]$ can be divided in two stages. In the first stage, idiosyncratic and aggregate shocks are realised, and households choose their housing tenure transition $h_{i,t+1}$.[2] Households can be renters, owners of a flat or owners of a house, where houses have a bigger size

[1] The UK also issues index-linked Gilts that are adjusted for inflation. We take them into account when calibrating the overall level of debt to GDP, but we model all long-term bonds as nominal bonds for simplicity.

[2] Given budget and borrowing constraints are specific to each transition, it is more convenient to track the transition than the housing tenure. For example, a households that has been a renter for the last two periods and now decides to buy a flat transitions from a 'rent-rent' state in the prior period to 'rent-own flat' in the current period as opposed to transitioning from a 'rent' to an 'own flat' state.

than flats: $H_H > H_F$. Having two distinct housing sizes is important because it is what allows for housing demand to increase/decrease due to desires for upsizing/downsizing. While homeowners can live in both flats and houses, renters can only live in flats. In the second stage, conditional on their housing choice, households choose how much to consume $c_{i,t}$ or save $a_{i,t+1}$. Renters pay the same average rent $P_{R,t}$ that applies to all households and the commercial rental sector updates the rental price subject to convex adjustment costs.[3] Section 2.4 provides more details on the problem of the commercial rental sector. To simplify notation, we suppress the time t and household i subscripts in the Bellman equations below.

Stage 1 At the beginning of Stage 1 in a given period households learn the aggregate state of the economy χ and their idiosyncratic labour productivity e. Furthermore, they observe their i.i.d. housing preference shock $\varepsilon(h)$. Households then choose their housing tenure h' such that the households' value function $V^{(1)}$ at the end of the Stage 1 is given by

$$V^{(1)}(e, a, h', \chi) = \max_{\hat{h}} \left[V^{(2)}(e, a, \hat{h}, \chi) + \varepsilon(\hat{h}) - \eta(\hat{h}) \right],$$

where each transition is associated with a deterministic utility loss of moving $\eta(h)$ and $V^{(2)}$ is the value function at the end of Stage 2, not including the exogenous processes $\varepsilon(h), \eta(h)$.

If we assume that the housing tenure preference shock $\epsilon(h)$ follows a Gumbel distribution with scale parameter α_H, then the solution to the choice of transition status h' implies that the probability of a housing transition prior to realisation of the taste shock is described by

$$Prob(e, a, h'|h, \chi) = \frac{\exp\left(\frac{V^{(2)}(e,a,h',\chi)-\eta(h')}{\alpha_H}\right)}{\sum_{h'} \exp\left(\frac{V^{(2)}(e,a,h',\chi)-\eta(h')}{\alpha_H}\right)}$$

The housing utility costs are introduced for different reasons. On the one hand, the deterministic utility losses $\eta(h)$ help us discipline the transition rates between different housing tenures in steady state. On the other hand, the taste shocks $\varepsilon(h)$ that are re-drawn every period help smooth the tenure transition decision of households, allowing us to use the method of Iskhakov et al. (2017)—which extends the endogenous grid method of Carroll (2006) to discrete-choice problems.

Stage 2 Having chosen their housing tenure transition h', households choose how much to consume of the non-housing final good or save, based on the budget and borrowing constraints dictated by that transition. Their problem is:

$$V^{(2)}(e, a, h', \chi) = \max_{c,a'} \left[u(c, h', n) - v(N) + \beta \hat{\mathbb{E}} V^1(e', a', h', \chi') \right]$$

subject to

$$a' + c + c_H(\tilde{P}_H, \tilde{P}_R, h') = \frac{1 + i_A + \omega_{bor} \mathbb{1}_{a<0}}{1 + \pi} a + z\left(e, \widetilde{W}, N, \tau, \tilde{B}_G, div\right)$$

$$a \geqslant \underline{\mathrm{a}}(h', \tilde{P}_H, z(\cdot))$$

where $\hat{\mathbb{E}}[\cdot]$ is the behavioural expectation operator (defined in more detail below), i_A denotes the nominal interest rate promised from period $t-1$ to period t and ω_{bor} represents the wedge between

[3] Having a single, average, rental contract that updates sluggishly allows us to capture rental price stickiness while not having to track individual rents for each household, simplifying the numeric solution.

borrowing and savings interest rates, π is inflation realised in period t, z denotes after-tax income (defined in more detail below) and labour productivity $e = e^P + e^T$ is composed of transitory and persistent terms. We denote labour disutility costs by $v(N)$ and consumption of non-housing goods by c. Labour is chosen by the labour union, detailed in Section 2.3, and aggregate variables are denoted by capital letters (e.g., $C_t = \int_0^1 c_{i,t} di$), which is why hours worked in the household problem has N and not n.

Total expenditure associated with each housing transition is given by $c_H(\tilde{P}_H, \tilde{P}_R, h')$, where $\tilde{P}_H$ is the real price per size of housing and $\tilde{P}_R$ are real rents. The borrowing limit is denoted by $\underline{a}(\cdot)$, which is a function of the housing transition h', since households can access secured borrowing against their homes. We assume that both LTV and LTI constraints apply to the secured borrowing, with limits of $\kappa_H \tilde{P}_H H$ and $\kappa_y z(\cdot)$, respectively. The borrowing limits only bind on a change of tenure, so in that sense mortgages are long term contracts. Table 1 shows in detail the housing costs and borrowing limit for each case. We assume a depreciation rate of δ_H per unit of housing, and a transaction cost F associated with buying and/or selling a home, and no unsecured borrowing. Notice that there is no mandatory amortization with mortgages and that they are included in net liquid wealth a.[4]

Table 1: Budget and borrowing constraints for each housing transition

Transition h'	$c_H(\cdot)$	$\underline{a}(\cdot)$
Own House - Own House	$-\delta_H H_H$	$\min\left[a_-, \max\left[-\kappa_H \tilde{P}_H H_H, -\kappa_y z(\cdot)\right]\right]$
Own Flat - Rent	$\tilde{P}_H H_F - F - \tilde{P}_R H_F$	0
Rent - Own Flat	$-\tilde{P}_H H_F - F - \delta_H H_F$	$\max\left[-\kappa_H \tilde{P}_H H_F, -\kappa_y z(\cdot))\right]$
Rent - Rent	$-\tilde{P}_R H_F$	0
Own House - Own Flat	$\tilde{P}_H(H_H - H_F) - 2F - \delta_H H_F$	$\max\left[-\kappa_H \tilde{P}_H H_F, -\kappa_y z(\cdot)\right]$
Own Flat - Own House	$\tilde{P}_H(H_F - H_H) - 2F - \delta_H H_H$	$\max\left[-\kappa_H \tilde{P}_H H_H, -\kappa_y z(\cdot)\right]$
Own Flat - Own Flat	$-\delta_H H_F$	$\min\left[a_-, \max\left[-\kappa_H \tilde{P}_H H_F, -\kappa_y z(\cdot)\right]\right]$
Own House - Rent	$\tilde{P}_H H_H - F - \tilde{P}_R H_F$	0

We assume the utility function to be of the form

$$u(c_D, c_F, h) = \frac{(c(c_D, c_F)^{1-\phi_H} x(h)^{\phi_H})^{1-\sigma} - 1}{1-\sigma}, \quad x(h) = H(h)(1 + \omega_{oo} \mathbb{1}_{oo})$$

which is a Cobb-Douglas function over consumption of housing services $x(h)$ and non-housing goods and services c, where ϕ_H denotes the expenditure share of housing services, and σ is the coefficient of relative risk aversion. Housing services $x(h)$ depend on the size of the house the household lives in. If the household is a homeowner, they get an extra utility, given by the multiplicative term $1 + \omega_{oo}$. For example, $x(h) = H_F$ for someone becoming a renter, and $x(h) = H_H(1 + \omega_{oo})$ for someone becoming an owner of a house.

Real consumption c of non-housing services is a bundle on goods produced at home and abroad. Reintroducing the time t subscript, let $c_{D,t}$ denote domestically produced goods consumed in the Domestic country, and $c_{F,t}$ denote goods produced abroad that are consumed domestically. We assume a CES aggregator

$$c_t = \left[\alpha_c^{1/\eta_c} c_{F,t}^{(\eta_c-1)/\eta_c} + (1-\alpha_c)^{1/\eta_c} c_{D,t}^{(\eta_c-1)/\eta_c}\right]^{\eta_c/(\eta_c-1)},$$

[4] In that sense, they are similar to the "interest-only" mortgages available to landlords in the UK.

where η_c denotes the elasticity of substitution between domestic and foreign goods, and α_c is the steady-state share of foreign goods consumed. Given households' optimal behaviour we have the usual demand equations

$$c_{D,t} = (1-\alpha_c)\left(\frac{P_{D,t}}{P_t}\right)^{-\eta_c} c_t,$$
$$c_{F,t} = \alpha_c\left(\frac{P_{F,t}}{P_t}\right)^{-\eta_c} c_t,$$

where the non-housing consumption price index, the numeraire, is given by

$$P_t = \left[\alpha_c P_{F,t}^{1-\eta_c} + (1-\alpha_c)P_{D,t}^{1-\eta_c}\right]^{1/(1-\eta_c)}.$$

Accordingly, we have that $\pi_t = P_t/P_{t-1} - 1$.

The labour productivity process is similar to that of Kaplan et al. (2018). Reintroducing the household i subscript, household labour productivity $e_{i,t} = e^P_{i,t} + e^T_{i,t}$ is made of persistent ($e^P_{i,t}$) and transitory ($e^T_{i,t}$) components. The log of each of these components is a mean-reverting process that is subject to jump-shocks that arrive infrequently:

$$\log(e^P_{i,t}) = (1-J^P_{i,t})\rho^P \log(e^P_{i,t-1}) + J^P_{i,t}\epsilon^P_{i,t},$$
$$\log(e^T_{i,t}) = (1-J^T_{i,t})\rho^T \log(e^T_{i,t-1}) + J^T_{i,t}\epsilon^T_{i,t},$$

where $J^P_{i,t} = 1$ and $J^T_{i,t} = 1$ with probabilities ξ^P and ξ^T, respectively, and zero otherwise. The shocks $\epsilon^P_{i,t}, \epsilon^T_{i,t}$ are drawn from normal distributions with mean zero and variance σ^2_P and σ^2_T.

The parameters ρ^s, $s \in \{P, T\}$ govern the degree of mean reversion in each component. Notice that while a shock does not arrive ($J^s_{i,t} = 0$) the process reverts back to zero. But it can jump ($J^s_{i,t} = 1$) to a new value with probability ξ^s. In our estimation, we have $\rho^P > \rho^T$ and find that permanent shocks arrive less frequently, or $\xi^P < \xi^T$. This specification allows us to match the overall distribution of annual labour earnings for the UK, and also moments of the changes in labour earnings for a given household over time, such as volatility and kurtosis.

The cdf of the resulting distribution of $e_{i,t}$ is denoted by Φ. Let W_t be the nominal wage per unit of productivity. We assume pre-tax income is subject to a retention function of the form:

$$z(e_{i,t}, \tilde{W}_t, N_t, \tau_t, G_{B,t}, div_t) = \tau_t(\tilde{W}_t N_t + div_t)e^{1-\lambda}_{i,t} + \lambda_{B,0}e^{\lambda_{B,1}}_{i,t} G_{B,t},$$

which is able to match the progressivity of the tax and benefit system in the UK, and depends on a retention rate τ_t, aggregate benefit spend by the government $G_{B,t}$, the progressivity of the income tax λ, and the progressivity of the government benefit schedule, given by $\lambda_{B,0}, \lambda_{B,1}$. The dividend term $div_t = t_{m,t} + t_{R,t} + t_{X,t} + t_{K,t}$ is composed of profits from: financial intermediaries $t_{m,t}$, commercial rental sector firms $t_{R,t}$, intermediate good producers $t_{x,t}$, and capital firms $t_{K,t}$. The equation above implies that they are distributed to each household in proportion to their labour productivity, as is standard in the literature.

2.2 Expectations in the Model

We depart from rational expectations and adopt "sticky behavioural" expectations with respect to aggregate variables for *all* agents in the model. Firstly, we introduce "cognitive discounting" to aggregate variables following Gabaix (2020) and, for households' expectations in a HANK framework, Pfäuti and Seyrich (2022). Relative to the rational expectations case, an agent's expected deviation of an aggregate variable from its steady-state value in the future is scaled down by a factor M^{CD}:

$$\mathbb{E}_t^{CD}[\mathbf{X}_{t+1}] \equiv \overline{\mathbf{X}} + M^{CD}\mathbb{E}_t[\check{\mathbf{X}}_{t+1}], \text{ with } \check{\mathbf{X}}_t \equiv \mathbf{X}_t - \overline{\mathbf{X}} \text{ and } M^{CD} \in [0,1],$$

where $\overline{X}$ denotes the steady-state value of variable X_t.
We further introduce "sticky expectations", as developed by Carroll et al. (2020) and adopted by Auclert et al. (2020), in addition to the cognitive discounting. Consider the case of a household who last updated their information set k periods ago. With i.i.d. probability $1-\gamma$, households update their information set about aggregate shocks. With probability γ, they retain their previous information set, which will now be $k' = k+1$ periods out of date. However, they always see their individual state variables. We apply this stickiness to all agents and allow the degree of stickiness to differ between households and other agents. For all other agents in the model (firms, financial intermediaries, etc.), the probability of updating their information set in each period is equal to $1-\gamma^f$. Agents' expectations over future aggregate variables can therefore be expressed as:[5]

$$\text{Households: } \hat{\mathbb{E}}_t[V_{t+1,k}(s')|s] \equiv \mathbb{E}_t^{CD}[\gamma V_{t+1,k+1}(s') + (1-\gamma)V_{t+1,0}(s')|s]$$
$$\text{Other agents: } \hat{\mathbb{E}}_t^f[J_{t+1,k}] \equiv \mathbb{E}_t^{CD}[\gamma^f J_{t+1,k+1} + (1-\gamma^f)J_{t+1,0}].$$

As we later illustrate (see Figure 5) these two distinct departures from rational expectations achieve two separate objectives. The adoption of cognitive discounting helps to generate dampening of future shocks and offers a solution to the forward guidance puzzle. Sticky expectations slows down how quickly households and firms initially absorb new information, which helps generate empirically plausible hump shape responses to shocks. We implement these departures from rational expectations by manipulating the relevant Sequence-Space Jacobians following Auclert et al. (2020).

2.3 Labour Unions

To allow for sticky wages we follow the literature (Erceg et al., 2000; Auclert et al., 2021a) and introduce labour unions, who determine the labour supply from households and set the wages. There are $k \in [0,1]$ labour unions, who hire a representative sample of the population to supply $N_{k,t} = \int_0^1 e_{i,t} n_{i,k,t} di$ units of union-specific effective labour at a nominal wage $W_{k,t}$. The labour supply from unions then gets packaged into total labour supply N_t, which is hired by firms:

$$N_t = \left(\int_0^1 N_{k,t}^{(\eta_w-1)\eta_w} dk\right)^{\eta_w/(\eta_w-1)},$$

where η_w is the elasticity of substitution across unions. The firm that packages labour from unions and sells them to firms at price W_t operates under perfect competition. Thus, its demand for union-specific labour is given by

$$N_{k,t} = N_t \left(\frac{W_{k,t}}{W_t}\right)^{-\eta_w} \tag{1}$$

[5] For simplicity of notation, we will use the $\hat{\mathbb{E}}_t$ operator to denote the "sticky behavioural" expectations rather than invoking the full recursive representation.

We assume there are quadratic utility adjustment costs for adjusting nominal wages at a growth rate different than that of steady-state inflation, and that unions aim to maximise the average utility of its members. The problem of a union is then

$$\max_{\{W_{k,t+j}\}_{j=0}^{\infty}} \hat{\mathbb{E}}_t^f \left[\sum_{j=0}^{\infty} \beta^j \left\{ \int_0^1 (u(c_{i,t+j}, h_{i,t+j}) - v(n_{i,t+j}))di - \frac{\varphi_w}{2} \left(\frac{W_{k,t+j}}{W_{k,t+j-1}} - (1+\overline{\pi}) \right)^2 \right\} \right]$$

subject to the demand in Equation (1). The function $v(n)$ denotes the disutility from labour and we assume

$$v(n) = \zeta \frac{n^{1+\nu}}{1+\nu}$$

where ν is the inverse of the Frisch elasticity of labour supply and ζ is a scale parameter. The solution to this optimisation problem (see Appendix A.1) delivers a wage Philips curve given by:

$$(\pi_t^w - \overline{\pi})(1+\pi_t^w) = \frac{\eta_w}{\varphi_w} \left\{ v'(N_t)N_t - (1-\lambda)Z_t \frac{(\eta_w - 1)}{\eta_w} \int u_{c,i,t} di \right\} + \beta \hat{\mathbb{E}}_t^f \left[(\pi_{t+1}^w - \overline{\pi})(1+\pi_{t+1}^w) \right] \tag{2}$$

where wage inflation $\pi_t^w = W_t/W_{t-1} - 1$ is determined by expected wage inflation and the current wedge between average household marginal utility from earnings and their marginal disutiilty from further labour supply. Finally, following Auclert et al. (2024b), unions take into account the average marginal utility of consumption $\int_0^i (u_c(c_{i,t+j}, h_{i,t+j})di$—not the marginal utility at the average consumption level. Therefore, shocks with the same aggregate consumption implications but different distributional implications will affect labour supply and inflation differently.

2.4 Housing Market

We assume a fixed supply of total housing given by $\overline{H}$, which is consistent with our short-run analysis. Let $s_{r,t}$, $s_{oF,t}$ and $s_{oH,t}$ denote the shares of households that are renters, owners of flats and owners of houses, respectively. Equilibrium in the housing market is given by[6]

$$\overline{H} = H_F(s_{r,t} + s_{oF,t}) + H_H s_{oH,t} \tag{3}$$

Other than the housing market, we also need the rental market to be in equilibrium. We assume that there is a commercial rental sector that provides a total amount $H_{R,t}$ of rental units per period. Rental market equilibrium requires that

$$H_{R,t} = s_{r,t} H_F. \tag{4}$$

The commercial rental sector aggregates commercial rental units from individual rental firms indexed by $k \in [0,1]$ that make their nominal rent choices subject to Rotemberg (1982) adjustment costs and monopolistic competition.[7] We assume nominal adjustment costs since rental contracts

[6] Equation (3) combined with the restriction $s_{r,t} + s_{oF,t} + s_{oH,t} = 1$ implies that the total share of households living in a flat or in a house is fixed. For example, the total mass of households living in a flat is given by $s_{r,t} + s_{oF,t} = (H_H - \overline{H})/(H_H - H_F)$. However, notice that the share of renters and homeowners can move.

[7] Because we already assume quadratic adjustment costs with respect to price changes, we simplify the problem and assume that the commercial sector does not need to incur the fixed cost F when changing its housing choice.

usually have a duration of at least one year in the UK. This setup gives rise to a familiar Philips Curve-type equation for rental inflation (see Appendix A.2):

$$\tilde{P}_{H,t} = \left(\frac{\eta_r - 1}{\eta_r}\right)\tilde{P}_{R,t} - \delta_H + \hat{\mathbb{E}}_t^f\left[\frac{\tilde{P}_{H,t+1}}{1+r_t^{ante}}\right] \\ + \frac{\varphi_r}{\eta_r}\left((\pi_{R,t} - \overline{\pi})(1+\pi_{R,t}) - \hat{\mathbb{E}}_t^f\left[\frac{(\pi_{R,t+1} - \overline{\pi})(1+\pi_{R,t+1})}{1+r_t^{ante}}\frac{H_{R,t+1}}{H_{R,t}}\right]\right) \tag{5}$$

where $r_t^{ante} = \mathbb{E}[r_t]$ is the expected real rate between periods t and $t+1$.

Notice that in the perfect competition limit ($\eta_r \to \infty$) without adjustment costs ($\varphi_r = 0$) we have the usual user cost formula

$$P_{H,t} = P_{R,t} - \delta_H P_t + \hat{\mathbb{E}}_t^f\left[\frac{P_{H,t+1}}{1+i_t}\right]$$

where rents are such that the house price today is equal to its dividend $P_{R,t} - \delta_H P_t$ plus the discounted value of re-selling the house tomorrow $\frac{P_{H,t+1}}{1+i_t}$.

2.5 Firms

2.5.1 Final Good

The domestic final good Y_t uses home intermediate goods $X_{D,t}$ and foreign intermediate goods $X_{F,t}$:

$$Y_t = \left[\alpha_y^{1/\eta_y} X_{F,t}^{(\eta_y-1)/\eta_y} + (1-\alpha_y)^{1/\eta_y} X_{D,t}^{(\eta_y-1)/\eta_y}\right]^{\eta_y/(\eta_y-1)}.$$

where η_y is the elasticity of substitution between the two inputs and α_y is the steady-state share of foreign inputs. Let $P_{D,t}^X$ and $P_{F,t}^X$ denote the prices of domestic and foreign intermediate goods used in the home country, respectively. Then, the home demand for intermediate goods and the price index for the home final good $P_{D,t}$ are given by:

$$X_{D,t} = (1-\alpha_y)\left(\frac{P_{D,t}^X}{P_{D,t}}\right)^{-\eta_y} Y_t,$$

$$X_{F,t} = \alpha_y\left(\frac{P_{F,t}^X}{P_{D,t}}\right)^{-\eta_y} Y_t,$$

$$P_{D,t} = \left[\alpha_y\left(P_{F,t}^X\right)^{1-\eta_y} + (1-\alpha_y)\left(P_{D,t}^X\right)^{1-\eta_y}\right]^{1/(1-\eta_y)}.$$

2.5.2 Intermediate Goods

The domestic intermediate good is a CES aggregator of a continuum of domestic firms under monopolistic competition:

$$X_t = \left(\int_0^1 x_{k,t}^{(\eta_x-1)/\eta_x} dk\right)^{\eta_x/(\eta_x-1)}$$

where η_x denotes the elasticity of substitution across varieties. Each firm $k \in [0,1]$ has a constant returns to scale production function in labour and physical capital

$$x_{k,t} = \Omega_t k_{k,t}^{\alpha_k} n_{k,t}^{1-\alpha_k}$$

where Ω_t is the TFP of domestic intermediate producers and α_k is the capital share of value-added. They face a demand of the type

$$x_{k,t} = X_t \left(\frac{P_{D,k,t}^X}{P_{D,t}^X} \right)^{-\eta_x} \tag{6}$$

and pay W_t in nominal wages for each unit of labour, r_t^K for renting capital for the period from capital firms, and quadratic adjustment costs for changing their price. Cost minimisation over inputs and profit maximisation yields the familiar Phillips Curve (see Appendix A.3) for intermediate goods inflation:

$$(\pi_{D,t}^X - \overline{\pi})(1 + \pi_{D,t}^X) = \frac{(1-\eta_x)}{\varphi_x} \tilde{P}_{D,t}^X + \frac{\eta_x}{\varphi_x} \widetilde{MC}_t + \hat{\mathbb{E}}_t^f \left[\frac{(\pi_{D,t+1}^X - \overline{\pi})(1 + \pi_{D,t+1}^X)}{1 + r_t^{ante}} \frac{X_{t+1}}{X_t} \right] \tag{7}$$

with real marginal cost defined by:

$$\widetilde{MC}_t = \frac{1}{\Omega_t} \left(\frac{r_t^k}{\alpha_k} \right)^{\alpha_k} \left(\frac{\widetilde{W}_t}{1-\alpha_k} \right)^{1-\alpha_k} \tag{8}$$

2.5.3 Capital Firms

Capital firms own the stock of physical capital K_t in the economy, invest I_t to build more capital, and rent it to intermediate goods firms at the rate r_t^K. Each period, capital firms pay dividends of

$$t_{K,t} = r_t^K K_{t-1} - I_t$$

and capital evolves according to

$$K_t = K_{t-1}(1-\delta_K) + I_t \left(1 - S\left(\frac{I_t}{I_{t-1}} \right) \right) \tag{9}$$

where δ_K is the rate of depreciation of physical capital, and $S\left(\frac{I_t}{I_{t-1}}\right) = \frac{\varphi_i}{2}\left(\frac{I_t}{I_{t-1}} - 1\right)^2$ is the adjustment cost of investment, such that $S(1) = S'(1) = 0$. Capital firms then maximise

$$\max_{\{I_{t+j}\}_{j=0}^{\infty}} \hat{\mathbb{E}}_t^f \left[\sum_{j=0}^{\infty} \prod_{\tau=0}^{j} \frac{r_{t+j}^K K_{t+j-1} - I_{t+j}}{1 + r_{t+\tau-1}^{ante}} \right]$$

subject to the law of motion for capital in Equation (9). The FOCs for the problem are

$$q_t^K = \hat{\mathbb{E}}_t^f \left[\frac{r_{t+1}^K + q_{t+1}^K (1-\delta_K)}{1 + r_t^{ante}} \right] \tag{10}$$

$$1 = q_t^K \left(1 - S\left(\frac{I_t}{I_{t-1}}\right) - \frac{I_t}{I_{t-1}} S'\left(\frac{I_t}{I_{t-1}}\right) \right) + \hat{\mathbb{E}}_t^f \left[\frac{q_{t+1}^K}{1 + r_t^{ante}} \left(\frac{I_{t+1}}{I_t}\right)^2 S'\left(\frac{I_{t+1}}{I_t}\right) \right] \tag{11}$$

where q_t^K is the Lagrange multiplier associated with the constraint in Equation (9), i.e., it is the shadow value of capital. Equations (10) and (11) define the dynamics of business investment.

2.6 Government

The government issues long- and short-term nominal bonds each period. We denote by L_t the new issuance of long-term bonds with duration δ, and by $\hat{L}_t$ the new issuance of one-period bonds (both expressed in real terms). The long-term bonds are sold to financial intermediaries, the Central Bank and the rest of the world, while short-term bonds are sold only to financial intermediaries. The long-term bonds issued at time t pay a net nominal coupon rate $i_{L,t}$ and the principal due decays at rate δ. Thus, in a period $t+k$ $(k>1)$ the bond issued in t pays $(i_{L,t}+\delta)(1-\delta)^{k-1}$.

Let B_t denote the total real value of long-term government debt. Given the geometric structure of the debt, government bonds carry an average net coupon rate that evolves slowly over time:

$$i_{av,t} = i_{L,t}L_t/B_t + i_{av,t-1}(1 - L_t/B_t).$$

It is useful to define the average market price of government debt $q_{av,t}$ as well:

$$q_{av,t}\tilde{B}_t = \sum_{j=0}^{\infty}(1-\delta)^j \tilde{L}_{t-j} q_t^j$$

where $\tilde{B}_t$ and $\tilde{L}_t$ are the nominal counterparts of B_t, L_t, and q_t^j is the price of a bond issued j periods ago.

The total interest and principal payments on all bonds that are due at time t are given by

$$F_t = (i_{av,t-1}+\delta)\frac{B_{t-1}}{1+\pi_t} + \frac{1+i_{t-1}}{1+\pi_t}\hat{L}_{t-1}.$$

Moreover, let $t_{cb,t}$ denote net transfers from the Central Bank to the treasury. We can then express the flow budget constraint of the government as:

$$T_t + t_{cb,t} + L_t + \hat{L}_t = G_t + G_{B,t} + F_t, \tag{12}$$

where G_t denotes government consumption, T_t are income tax revenues and $G_{B,t}$ are benefit expenditures. We assume that the government buys the same bundles of consumption good as the households, thus, there are also analogous $G_{D,t}$ and $G_{F,t}$, with government expenditures having the same price index P_t. The tax rate τ_t is defined by aggregate revenue requirements and the progressivity of the tax code λ:

$$\tau_t = \frac{\widetilde{W}_t N_t + div_t - T_t}{(\widetilde{W}_t N_t + div_t)\int e_{i,t}^{1-\lambda} d\Phi} \tag{13}$$

2.6.1 Fiscal Policy

We assume that, outside of the steady state, the government responds by: keeping constant the ratio of taxes to non-housing GDP, X_t; keeping constant aggregate benefits; slowly adjusting government consumption to stabilise government debt.[8] This yields the following fiscal reaction functions:

$$T_t = T + \frac{T}{X}(X_t - X)$$
$$G_t = G_{ss} - \phi^G(B_{t-1} - B_{ss})$$
$$G_{B,t} = G_{B,ss}$$

Overall this results in the debt to GDP ratio rising in response to a negative business cycle shock, as government spending will fall less than taxes in the first instance. Notice that the above implies that long-term government debt B_t adjusts so that the budget constraint of the government in Equation (12) is always satisfied.

We chose this as our baseline specification since we find evidence that the debt-to-GDP ratio in the UK rises after a contractionary monetary policy shock (see Figure B.3), but we do not find evidence of a change in the tax-to-GDP ratio (not shown). Section 5.3 analyses what happens under different assumptions for the fiscal feedback rules.

2.6.2 Central Bank

The Central Bank (CB) issues new reserves $\hat{M}_t$ every period to buy a share κ of the new issuance of long-term debt: $\hat{M}_t = \kappa L_t$.[9] It also buys back a share δ of past reserves, so that reserves M_t move in line with government debt B_t. The CB does not buy or sell government bonds otherwise. We allow the CB to issue reserves to buy government bonds to be able to analyse how the effect of 'conventional' monetary policy (i.e., moving the short-term interest rate i_t) is affected by the fact that 'unconventional' monetary policy (i.e., Quantitative Easing) was used in the past (e.g., see Section 5.4).[10]

The CB's budget constraint is then:

$$t_{cb,t} + \frac{(1 + i_{t-1})}{1 + \pi_t} M_{t-1} + \kappa L_t = M_t + \frac{(i_{av,t-1} + \delta)}{1 + \pi_t} \kappa B_{t-1} \tag{14}$$

In Appendix A.4.1 we show that this equation reduces to

$$t_{cb,t} = \frac{i_{av,t-1} - i_{t-1}}{1 + \pi_t} \kappa B_{t-1},$$

[8] In our model, fiscal policy affects inflation and output. This is true of most DSGE models for government expenditure, though Ricardian Equivalence implies that the mix of debt and tax financing is sometimes irrelevant. Accounting for the fiscal policy reaction is therefore important for understanding the effects of monetary policy. Under the assumptions outlined in this section, fiscal policy is effectively passive in the sense of Leeper (1991). This is not a normative statement about the desirability of such policies; rather, we believe it provides an accurate description of historical fiscal policy dynamics, which we then take into account since it is important for how inflation and output react to monetary policy. Feedback functions of the type above are standard in the literature—see, for example, Kaplan et al. (2018) and Auclert et al. (2020).

[9] It is important to emphasize that, while in the model the Central Bank buys bonds directly from the Government, in practice the Bank of England does not buy government bonds directly from the Treasury, but only on the secondary market.

[10] Notice that the equations characterising the actions of the CB in this section were derived under the assumption that the pace of Quantitative Easing (QE) given by the parameters κ, δ, is fixed, thus the model is not suitable for analysing QE policies. Moreover, QE would only generate cash-flows effects between the CB and the government given the model assumptions.

which means that, in steady state, there are no transfers from the CB to the treasury ($t_{cb} = 0$ since $i_{av} = i$). However, if a shock hits the economy, $t_{cb,t}$ can deviate from zero for many periods, while $i_{av,t} \neq i_{t-1}$.[11] Importantly, notice that Equation (14) does not take into account any mark-to-market losses on the CB's bond portfolio. This is a reflection of the current agreement in place between the Asset Purchase Facility (APF) used to perform QE and the Treasury, where the latter indemnifies any losses by the APF only when bonds are sold (e.g., see Box D in Busetto et al., 2022).

Finally, the central bank sets the short-term nominal rate according to a Taylor rule that responds smoothly to deviations of both inflation and output from their steady-state values:

$$\log(1+i_t) = \rho_i \log(1+i_{t-1}) + (1-\rho_i)\Big\{ \log(1+\overline{r}) + \log(1+\overline{\pi}) + \phi_\pi \left[\log(1+\pi_t^{cpi}) - \log(1+\overline{\pi})\right] + \phi_y \left[\log(X_t) - \log(\overline{X})\right] \Big\} + \log(1+\epsilon_{r,t})$$

where $\epsilon_{r,t}$ denotes monetary policy shocks.

The Bank of England targets the inflation rate from the CPI index, which includes re ntal costs paid by renters, but not imputed costs to homeowners (which is included in the CPIH index). Accordingly, we include rental inflation to the inflation measure $\pi_t^{cpi} = P_t^{cpi}/P_{t-1}^{cpi} - 1$ that the Central Bank targets, where

$$P_t^{cpi} = P_t(1-\omega_{rent}) + P_{R,t}\omega_{rent}, \tag{15}$$

and $\omega_{rent} = (P_R s_r H_F)/(PC + P_R s_r H_F)$ is the share of total consumption spent on rental services in the steady state.

2.7 Rest of the World

The rest of the world imports and exports goods from the home country, issues foreign bonds and buys domestic long-term government debt. The rest of the world imports goods produced in the home country $C^*_{D,t}$ with elasticity given by η_c^*:

$$C^*_{D,t} = \alpha_c \left(\frac{P^*_{D,t}}{P^*_t}\right)^{-\eta_c^*} C^*,$$

where $P^*_{D,t}$ denotes the price of home-produced goods sold abroad, P^*_t is the CPI abroad, and total consumption abroad C^* is assumed to be constant.

Imports by the rest of the world of intermediate goods produced in the home country $X^*_{D,t}$ are:

$$X^*_{D,t} = \alpha_y \left(\frac{P^{X,*}_{D,t}}{P^*_{F,t}}\right)^{-\eta_y^*} Y^*,$$

where world final output Y^* is also assumed constant, the degree of openess of the foreign economy is α_y and η_y^* denotes the price elasticity of foreign intermediate goods demand.

Prices abroad are fully flexible. We further assume that the interest rate i_t^* is fixed at the same steady-state level of domestic interest rates, $i_t^* = \bar{i}$, and that this is consistent with prices

[11] Notice that at the time of the shock $t = \tau$ we have $t_{cb,\tau} = 0$ because the interest rates are pre-determined and equal to each other. Transfers different than zero are only possible for $t > \tau$.

growing at the same rate of steady-state domestic inflation $\pi_t^* = \overline{\pi}$. We assume that the home economy is small relative to the rest of the world. Thus, foreign variables are independent of those of the home economy. This is reflected, for example, in the assumption that foreign consumption C^* and output Y^* are constant. It also means that CPI abroad is not affected by the price of home-produced goods, i.e. $P_t^* = P_{F,t}^*$.

Let $\mathcal{E}_t$ denote the nominal exchange rate between domestic and foreign currency, such that an increase signals a depreciation of the pound. Then we define the real exchange rate Q_t as

$$Q_t = \frac{\mathcal{E}_t P_t^*}{P_t}.$$

Given the evidence on sluggish exchange rate pass through to import and export prices (Forbes et al., 2018) we adopt the following rules for the pricing of the home economy's imported final and intermediate goods:

$$P_{F,t} = \rho^M \mathcal{E}_t P_{F,t}^* + \left(1 - \rho^M\right) P_{F,t}^{*,LCP}$$
$$P_{F,t}^X = \rho^M \mathcal{E}_t P_{F,t}^{X,*} + \left(1 - \rho^M\right) P_{F,t}^{X,*,LCP}$$

where $P_{F,t}^{*,LCP}$, $P_{F,t}^{X,*,LCP}$, are the price levels that would prevail under Local Currency Pricing, i.e., if prices were denominated in the currency of the consumer, which in this case is the home economy. Notice that under Producer Currency Pricing we would have, for example, $P_{F,t} = \mathcal{E}_t P_{F,t}^*$. Thus, the parameter ρ^M controls the impact and speed of pass-through from exchange rate movements to import prices and can be interpreted as the share of imports priced in foreign currency. As $\rho^M \to 1$, the model approaches the Producer Currency Pricing limit with 100% impact pass-through of exchange rate movements to the home import price. As $\rho^M \to 0$, the model approaches Local Currency Pricing.[12]

The prices of UK final and intermediate goods exports follow similar rules:

$$P_{D,t}^* = \rho^X \frac{1}{\mathcal{E}_t} P_{D,t} + \left(1 - \rho^X\right) P_{D,t}^{LCP} \tag{16}$$

$$P_{D,t}^{X,*} = \rho^X \frac{1}{\mathcal{E}_t} P_{D,t}^X + \left(1 - \rho^X\right) P_{D,t}^{X,LCP}. \tag{17}$$

Analogously to ρ^M, the parameter ρ^X gives the share of sterling-denominated exports. For export prices, $\rho^X \to 1$ represents the PCP limit, while $\rho^X \to 0$ gives the LCP limit.[13]

Other than trade in goods and services, the rest of the world also has a demand for domestic bonds denoted by $B_{F,t}^*$, which we assume is a constant share κ^* of the domestic long-term

[12]See Appendix A.5 for the profit-maximisation problem of intermediate goods exporters under LCP and its corresponding export price Phillips curve. This Appendix also lists our assumptions for the remaining LCP prices.

[13]Notice that in the problem of the final and intermediate goods firms we assumed that they took into account the prices $P_{D,t}, P_{D,t}^X$ when making their decisions. However, the prices that foreign consumers pay on the share of domestic production that is exported are actually $P_{D,t}^*, P_{D,t}^{X,*}$. Because we assume that the prices of exports follow Equations (16) - (17) above, and not PCP, then these two prices (adjusted for the exchange rate) might differ. Instead of complicating the problem of those firms further, we make a simplifying assumption that there is a rule-of-thumb importer in the rest of the world that pays the prices $P_{D,t}/\mathcal{E}_t, P_{D,t}^X/\mathcal{E}_t$ to the domestic firms and re-sells them to final consumers at the prices $P_{D,t}^*, P_{D,t}^{X,*}$, making any profits/losses from this intermediation. Thus, the prices in Equations (16) - (17) still matter, since they determine the quantities exported—although not the prices. The profit for this importer in their foreign currency is then $t_{I,t}^* = (P_{D,t}^* - P_{D,t}/\mathcal{E}_t)C_{D,t}^* + (P_{D,t}^{X,*} - P_{D,t}^X/\mathcal{E}_t)X_{D,t}$, which is equal to zero in steady state.

government debt. In any period, the rest of the world holds

$$\sum_{j=0}^{\infty} q_t^j B_{F,t}^{j,*} = \sum_{j=0}^{\infty} q_t^j \kappa^* B_t^j = \kappa^* q_{av,t} B_t$$

Finally, the rest of the world issues 1-period nominal bonds $\hat{B}_t^*$ that pay a nominal interest rate i_t^* in the foreign currency. In real terms, holdings of these bonds are denoted B_t^*, with the foreign consumption good as a numeraire. Holdings can be negative, which would mean the home country borrowing from abroad in foreign currency. This variable is allowed to move, to guarantee that the market clearing condition for home-produced goods always holds (equivalently, that net exports equal the change in the net financial accounts).[14]

2.8 Financial Intermediaries

Financial intermediaries buy short-term government debt $\hat{L}_t$ and long-term government debt $\{L_{m,t}^j\}_{j=0}^{\infty}$ in the secondary market, as well as reserves M_t from the Central Bank, and foreign bonds B_t^*. We denote long-term debt held by financial intermediaries $L_{m,t}^j$ with a subscript m to differentiate from those demanded by the Central Bank, or by the rest of the world. Because the financial intermediaries are the only holders of reserves and short-term debt we do not introduce this notation, for simplicity. Let $B_{m,t}^j$ denote the real equivalent of the long-term nominal government bonds issued j periods ago held at time t by financial intermediaries. Intermediaries fund these purchases with deposits A_t from households, and pay dividends $t_{m,t}$ to them. Recall that q_t^j is the price of a bond at time t if it was issued j periods ago, with $q_t^0 = 1$. Their budget constraint is then

$$\begin{aligned} t_{m,t} + \sum_{j=0}^{\infty} q_t^j B_{m,t}^j + \frac{1+i_{A,t-1}}{1+\pi_t} A_{t-1} + M_t + \hat{L}_t + Q_t B_t^* = \qquad (18) \\ \sum_{j=1}^{\infty} [(1-\delta) q_t^j + i_{L,t-j} + \delta] \frac{B_{m,t-1}^j}{1+\pi_t} + A_t + \frac{1+i_{t-1}}{1+\pi_t} M_{t-1} + \frac{1+i_{t-1}}{1+\pi_t} \hat{L}_{t-1} + \frac{1+i_{t-1}^*}{1+\pi_t^*} Q_t B_{t-1}^* \end{aligned}$$

where the left-hand side of the equation above includes the return on previous investments.

The intermediaries maximise:

$$\max_{M_t, A_t, \{B_{m,t}^j\}, B_t^*, \hat{L}_t} \hat{\mathbb{E}}_t^f \left[\sum_{t=0}^{\infty} \left(\prod_{k=0}^{t} \frac{1}{1 + r_{k-1}^{ante}} \right) t_{m,t} \right]$$

subject to the flow budget constraint and the law of motion for capital in Equations (18) and (9),

[14] One might worry that the structure of our model would lead to non-stationarity, as it would probably be the case under a representative agent assumption (Schmitt-Grohé and Uribe, 2003). However, our solution to the model is stationary, and other HANK models with similar features have been found to be stationary (e.g., see Auclert et al., 2021b).

discounting dividends at the real expected rate (with $r_{-1}^{ante} = 0$). The FOCs are:

$$\begin{aligned}
1 + i_t &= \hat{\mathbb{E}}_t^f \left[(1 + \pi_{t+1})(1 + r_t^{ante}) \right] \\
i_t &= i_{A,t}, \\
q_t^j &= \hat{\mathbb{E}}_t^f \left[\frac{(1-\delta) q_{t+1}^j + i_{L,t-j} + \delta}{1 + i_t} \right] \\
1 + i_t &= (1 + i_t^*) \hat{\mathbb{E}}_t^f \left[\frac{\mathcal{E}_{t+1}}{\mathcal{E}_t} \right]
\end{aligned} \tag{19}$$

where we had already imposed from the beginning that the return on short term bonds must equal to i_t in equilibrium. The 4$^{\text{th}}$ equation in (19) is the Uncovered Interest Rate Parity (UIP) condition. The 1$^{\text{st}}$ equation is the Fisher equation. Notice that firms and financial intermediaries use the r_t^{ante} real interest rate to discount future profits, where we made it explicit that it is an an ex-ante, expected rate. However, assets in the economy promise nominal returns. Thus, if shocks hit the economy and inflation is different than expected, the ex-post real interest rate can move, leading to Fisher effects.

We assume that the intermediaries do not have any equity and redistribute all profits/losses made in each period to the households, so that the balance sheet at the end of each period is:

$$\sum_{j=0}^{\infty} q_t^j B_{m,t}^j + M_t + \hat{L}_t + Q_t B_t^* = A_t. \tag{20}$$

Combining the above with the budget constraint in Equation (18), $t_{m,t}$ can be written as:

$$\begin{aligned}
t_{m,t} = &\frac{1}{1 + \pi_t} \left(\frac{i_{L,t} + 1}{i_{L,t} + \delta} - \hat{\mathbb{E}}_{t-1}^f \left[\frac{i_{L,t} + 1}{i_{L,t} + \delta} \right] \right) (i_{L,t-1} + \delta)(1 - \kappa - \kappa^*) q_{av,t-1} B_{t-1} \\
&+ B_{t-1}^* \frac{(1 + i_{t-1}^*)}{1 + \pi_t} \left(Q_t \frac{(1 + \pi_t)}{1 + \pi_t^*} - \hat{\mathbb{E}}_{t-1}^f \left[Q_t \frac{(1 + \pi_t)}{1 + \pi_t^*} \right] \right).
\end{aligned} \tag{21}$$

There are two possible sources of unexpected profits, if shocks hit the economy. The first term in the equation above relates to losses due to changes in the price of long-term bonds bought in the previous period. The second term relates to losses due to fluctuations in the exchange rate. As one can see, if the exchange rate unexpectedly increases (i.e., the pound depreciates) the intermediary makes unexpected profits if the home country is a net creditor ($B_t^* > 0$) and losses otherwise.

2.9 Market Clearing

In equilibrium the endogenous demands for assets, goods and housing must equal their supplies. Net financial wealth demand must equal asset supply comprising of long and short-term government debt, central bank reserves and foreign assets. Moreover, demand and supply for final goods and intermediate goods must balance. We also define GDP in our model (value added from goods and services is equal to X_t).

Assets

$$\begin{aligned}
A_t &= \sum_{j=0}^{\infty} q_t^j B_{m,t}^j + M_t + \hat{L}_t + Q_t B_t^* \\
&= (1 - \kappa - \kappa^*) q_{av,t} B_t + \kappa B_t + \hat{L}_t + Q_t B_t^*.
\end{aligned} \tag{22}$$

Long term government debt

$$(1-\delta)^j L_{t-j} = B^j_{m,t} + \kappa(1-\delta)^j L_{t-j} + \kappa^*(1-\delta)^j L_{t-j}. \tag{23}$$

Domestically-produced goods

Let $DWL_t = DWL_{H,t} + X_t(\varphi_x/2)(\pi^X_{D,t} - \overline{\pi})^2$ be the total dead-weight loss in the economy, with $DWL_{D,t}, DWL_{F,t}$ being the domestic and foreign components of DWL_t, and where $DWL_{H,t}$ is the dead-weight loss associated with the housing sector, which is given by:

$$DWL_{H,t} = TRANS_t \times F + \overline{H}\delta_H + \frac{\varphi}{2}(\pi_{R,t} - \bar{\pi})^2 H_{R,t} - BORROW_t \times \bar{r} + H_R(\tilde{P}_R - \delta_H)$$

Above, $TRANS_t$ denotes the total amount of housing transactions and $BORROW_t$ denotes the mass of households that are borrowers.

Then, market clearing in final domestically-produced goods is:

$$Y_t = C_{D,t} + G_{D,t} + DWL_{D,t} + I_{D,t} + C^*_{D,t}. \tag{24}$$

Intermediate goods

$$X_t = X_{D,t} + X^*_{D,t}. \tag{25}$$

Housing and rental markets

As in Equations (3) and (4).

Resource Constraint Using the market clearing conditions above and the solution to the agents' problems, we can also describe the equilibrium of the model in terms of the final non-housing consumption good:

$$\tilde{P}^X_{D,t} X_t = C_t + G_t + I_t + DWL_t + (exports_t - imports_t) \tag{26}$$

where

$$\begin{aligned} imports_t &= \widetilde{P}_{F,t}\left(C_{F,t} + G_{F,t} + I_{F,t} + DWL_{F,t}\right) + \widetilde{P}^X_{F,t} X_{F,t} \\ exports_t &= \widetilde{P}_{D,t} C^*_{D,t} + \widetilde{P}^X_{D,t} X^*_{D,t} \end{aligned}$$

The left-hand side of the "national accounts" in Equation (26) is non-housing domestic valued-added, which can then be used for final consumption, net exports, or as the several costs included in DWL Finally, we can also express the trade balance in terms of net lending to the rest of the world

$$exports_t - imports_t = \left[Q_t B^*_t - (1 + r^*_t) B^*_{t-1} Q_t\right] - \left[\kappa^* B_t - \frac{\kappa^* B_{t-1}}{1+\pi_t}(1 + i_{av,t-1})\right] \tag{27}$$

where the first term on the right-hand side above is net lending to the rest of the world using foreign bonds B^*_t, while the second term is net borrowing from abroad with domestic long-term bonds B_t.

National accounting GDP Gross domestic product in national accounts includes the consumption of housing services, often computed using the imputed rents method. In this model we follow this method by calculating housing consumption according to the following formula:

$$C_{housing,t} = \overline{H}\tilde{P}_{R,t} \tag{28}$$

From this it follows that total consumption and real GDP (in units of value added) are defined by:

$$C_{tot,t} = C_t + C_{housing,t} \tag{29}$$

$$GDP_t = X_t + \frac{C_{housing,t}}{\widetilde{P}^X_{D,t}} \tag{30}$$

3 Model Calibration

Our model solution strategy follows Auclert et al. (2021a) by representing the model in the sequence space and solving for the dynamics as a local approximation around the model's non-linear steady state. In solving the model, we assume monetary policy operates away from the effective lower bound. We calibrate the steady state to be consistent with key macroeconomic and microeconomic moments in the UK over the period 1993-2023 (where data allows), which corresponds to the inflation targeting regime period (see Table 2). The parameters related to the labour income process are estimated separately to target both the distribution of earnings and moments related to changes in earnings (see Table 3). We further estimate through IRF matching a set of parameters to make the model consistent with the dynamic response of the economy to interest rate innovations (see Table 5).

3.1 Steady State

Table 2 documents the parameter values in the model that are either set externally or internally estimated to align the model with selected target moments. For the external calibration, we set the relative risk aversion coefficient σ to 1.0 based on the review of Elminejad et al. (2022), which aligns with values typically used in the literature, e.g., Auclert et al. (2024a). It is important to note however that sluggish updating by households in response to new information (shocks) means the initial intertemporal elasticity of substitution following a shock is in practice much smaller, and in line with the lower empirical values reported in the literature such as the 0.1 reported by Best et al. (2019).

For the Frisch labour supply elasticity ν we set a value of 0.75 in line with the recommendation of Chetty et al. (2011) and at the upper bound in the review of Elminejad et al. (2023). Macro aggregates relating to taxes, benefits, and government liabilities in the model are set to equal their counterparts in the ONS's national accounts (e.g., the ratio of government benefits to GDP, G_B/GDP). We also use ONS income and benefits data by income decile to calibrate the progressivity elasticities $\lambda, \lambda_{B,0}, \lambda_{B,1}$ to match the average over the period 2001-2023 (when the data was available – see Appendix B Figure B.1).

The capital elasticity α_k and the intermediate goods elasticity η_x are set to match average capital and pure profit shares in market sector output, calculated using staff estimates based on the method of Barkai (2020). The open economy elements are calibrated to short-run elasticities from the literature. Average intermediate and final goods import shares are set in line the ONS's input-output tables.

For housing, the weight of housing consumption in the household utility function ϕ_H is set in line with the housing consumption share in the CPI-H index from the ONS at 0.24. Maintenance costs shares are also set to replicate expenditure shares in the CPI-H. Transaction costs are set at 2% of steady state house prices based on typical stamp duty charges on average UK home prices and typical closing costs cited by UK building societies. Borrowing spreads are set in line with the average spread of 2 year fixed mortgages over 1997-2023.

Finally, we internally calibrate selected parameters and prices to minimise the distance to specific steady-state targets. Heuristically, the household time preference parameter β is adjusted to target the ratio of net liquid wealth to labour income. The house price P_O, rental price P_R, owner-occupier preference parameter ω_{oo} and additive utility cost of moving χ are set to match the: target rental share, total housing wealth, housing market transactions and mortgagor share. Our estimates indicate a slight preference for home ownership (equivalent to living in a home 6% bigger) and a large utility cost of moving, equivalent to 40 percent of average quarterly household consumption in the period they move.

Table 2: Calibrated parameters

Parameter	Value	Description	Moment / Source / Target
		External calibration	
		Household	
σ	1.0	Relative risk aversion	Elminejad et al. (2022)
ν	1.5	Labour disutility curvature	Frish elasticity $1/\nu = 0.75$
ζ	7.566	Labour disutility scale	Normalised labour supply = 1/3
T_{ss}	23.5%	Steady-state tax to GDP ratio	Income tax rate (ONS, 2001-2023)
$G_{B,ss}$	9%	Benefits to GDP ratio	ONS (2001-2023)
λ	0.07	Curvature of labour tax schedule	See Figure B.1
$\lambda_{B,0}$	0.69	Scale of benefit schedule	See Figure B.1
$\lambda_{B,1}$	-0.65	Curvature of benefit schedule	See Figure B.1
		Firms and unions	
η_x	5.45	Goods demand elasticity	Pure profit share = 18%
α_k	0.16	Capital elasticity	Labour share = 68%
η_w	11.0	Labour union elasticity	Wage mark-up = 1.1 (Chan et al., 2024)
		Financial markets and wealth	
r^*	0.44%	Steady-state real rate	Annual real rate = 1.76% (Davis et al., 2024)
π^*	0.5%	Steady-state inflation target	Annual inflation target = 2%
$\hat{L}_{ss}$	24%	Steady-state NS&I holdings relative to quarterly GDP	NS&I holdings-to-Gilts ratio = 0.14 (ONS)
B^*_{ss}	-54%	Steady-state lending to RoW relative to quarterly GDP	Net international investment position in debt instruments (excl. Gilts) ratio to Gilts = -0.33 (ONS)
κ	0.13	Share of long-term debt swapped for reserves	ONS
δ	0.019	Share of long-term debt principal repaid in each quarter	Avg. Gilts maturity = 13 years (1993-2021) (Andreolli, 2021)
		Open economy	
η_c, η_c^*	1.43	Consumer trade elast.	Huo et al. (2024)
η_y, η_y^*	0.89	Intermediate trade elast.	Huo et al. (2024)
α_c	0.18	Share of foreign goods in C	ONS IO tables (1995-2020)
α_y	0.15	Share of foreign goods in Y	ONS IO tables (1995-2020)
κ^*	0.25	Share of foreign ownership of B_{ss}	ONS
		Housing	
ϕ_H	0.24	Share of housing $u(c,h)$	CPI-H weight (2008-2023)
δ_H	0.037	Housing maintenance	CPI-H weight (2008-2023)
F	$0.02P_O$	Transaction cost	Halifax Building Society
ω_{bor}	0.375%	Mortgage spread	2y 75% LTV mortgage - 2y Gilt = 1.5%(1997-2023)
κ_H	0.95	Max loan to value	95th percentile FTB PSD (2005-2023)
κ_y	4.5	Max loan to income	95th percentile FTB PSD (2005-2023)
		Internal calibration	
β	0.9902	Discount factor	Ratio of net financial wealth to avg. annual gross labour income = 34% (WAS & ONS)
P_O	20.27	House price	Housing wealth-to-income ratio = 6.3 (ONS, 1997-2023, ann)
P_R	0.15	Rental price	Renter share = 33% (EHS)
ω_{oo}	1.06	Extra utility from home ownership	Share of owners with mortg. = 54% (EHS)
η	0.32	Utility cost of moving	Own-to-rent transition probability = 1% (EHS)

Notes: This table presents the calibration of the parameters that affect the steady state of the model. For ease of exposition, all steady-state values of aggregate variables are described as ratios to (non-housing) GDP, X_{ss}, which is normalized to unity. All periods refer to 1993-2023 unless otherwise noted. EHS is the English Housing Survey, WAS is the Wealth and Assets Survey. Tax and benefits data are from the ONS 'Effects of taxes and benefits on UK household income' dataset.

3.2 Income Process

The household income process is estimated using data from the Annual Survey of Hours and Earnings (ASHE), which underpins many official UK wage statistics. ASHE is a 1% sample of all UK employees structured as a panel dataset. Following Kaplan et al. (2018), we set the earnings process parameters listed in Table 3 to minimize the distance between moments from the stochastic process and the data over the period 1993-2016. Table B.1 in Appendix B lists the target empirical moments and compares them with the model fit.

The model income process matches the data closely, including the cross sectional standard deviation of earnings and moments related to income changes. Figure 1 shows that the resulting distribution of annual household gross labour earnings from the model closely matches the corresponding distribution in the Wealth and Assets Survey (WAS) data over 2011-2016, which was not used in the estimation.[15]

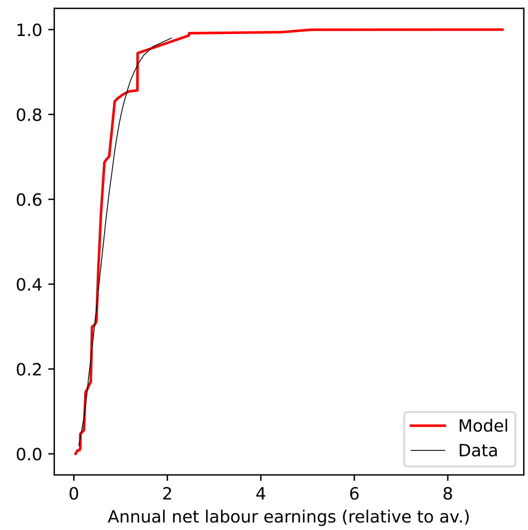
Table 3: Income process

Parameter	Value	Description
		Estimated externally
ξ_T	14%	Probability of transitory shock
ρ_T	0.495	Persistence of transitory shock
σ_T	0.464	Standard deviation of transitory shock
ξ_P	1.1%	Probability of permanent shock
ρ_P	0.995	Persistence of permanent shock
σ_P	0.825	Standard deviation of permanent shock

Notes: Parameters are set to minimize the distance with respect to the empirical moments listed in Table B.1 (Appendix B) based on data from the ASHE 1993–2016. All statistics based on microdata are for households whose head is 25–55 years old, and where at least one member earns the equivalent of 7 hours of work at the minimum wage per week. This is consistent with the model, where all households earn some labour income. The model was estimated at the quarterly frequency.

[15] We use ASHE data on male and female employees aged 25-55. To map individual earnings to the household level, we follow Kaplan et al. (2018) and rescale the standard deviation of residual log real earnings in ASHE by the ratio of the standard deviation of residual log real household earnings to the standard deviation of residual log real individual earnings in WAS over 2011-2016.

Figure 1: Income distribution



Notes: This figure compares the income distribution in the model to that of the Wealth and Assets Survey (2011-2016).

Table 4 reports how the income process endogenously maps to the wealth distribution in the model, and here the model does less well. There are two main reasons for this. First, in the data, the distribution of labour income is less unequal than that of wealth, but it is well known that Aiyagari-type models struggle to generate a distribution of wealth that is more unequal than the distribution of labour income (Benhabib and Bisin, 2018). Second, we imposed limits over how much housing wealth one can accumulate, i.e., there are only two house sizes. There is therefore too much wealth at the bottom of the distribution and too little at the top. However, the model still generates a substantial share of households with no wealth as well as significant wealth inequality. Finally, the model matches the share of households with negative net financial wealth positions.

Table 4: Wealth distribution

	Model	Data
No wealth share	21%	18%
Net Financial wealth < 0	49%	50%
Bottom 50 share	16%	6%
Top 10 share	36%	48%

Notes: Wealth statistics computed from the Wealth and Assets Survey waves 1-7 (2007-2020). Net financial wealth includes all non pension financial wealth and debt including mortgage debt. Consistent with the model, total wealth adds housing wealth to financial wealth.

3.3 Model Dynamics

Table 5: Dynamically estimated parameters

Parameter	Value	Description
		External calibration
M^{CD}	0.85	Cognitive discounting scaling factor (Gabaix, 2020)
		IRF matching
$1-\gamma$	13%	Household's probability of updating
$1-\gamma_f$	16%	Firm's probability of updating
ϕ_T	0.027	Fiscal adjustment speed
φ_x	64.3	Scale of price adjustment cost (pc slope = 0.09)
φ_r	158	Scale of rental price adjustment cost (pc slope = 0.02)
φ_w	385	Scale of wage adjustment cost (pc slope = 0.03)
ρ_i	0.96	Inertia coefficient on the Taylor rule
ϕ_π	1.34	Inflation coefficient on the Taylor rule
ϕ_y	0.05	Output gap coefficient on the Taylor rule
ρ_m	0.51	Final goods price pass through
ρ_x	0.56	Foreign goods price pass through
φ_i	20.1	Scale of investment adjustment cost

Notes: These parameters are estimated to minimise the inverse variance-weighted distance from the model's impulse responses to their empirical counter parts for GDP, Bank Rate, CPI, consumption, debt-to-GDP, the trade balance, the nominal exchange rate, nominal wages, house prices and rental prices. For the price adjustment costs we also report the linear Philips curve slope.

The last set of parameters missing from our calibration are the parameters θ_{IRF} relevant for the model's dynamics. We estimate them by minimising the weighted difference between the stacked model impulses responses Y and the empirical counterparts $\dot{Y}$:

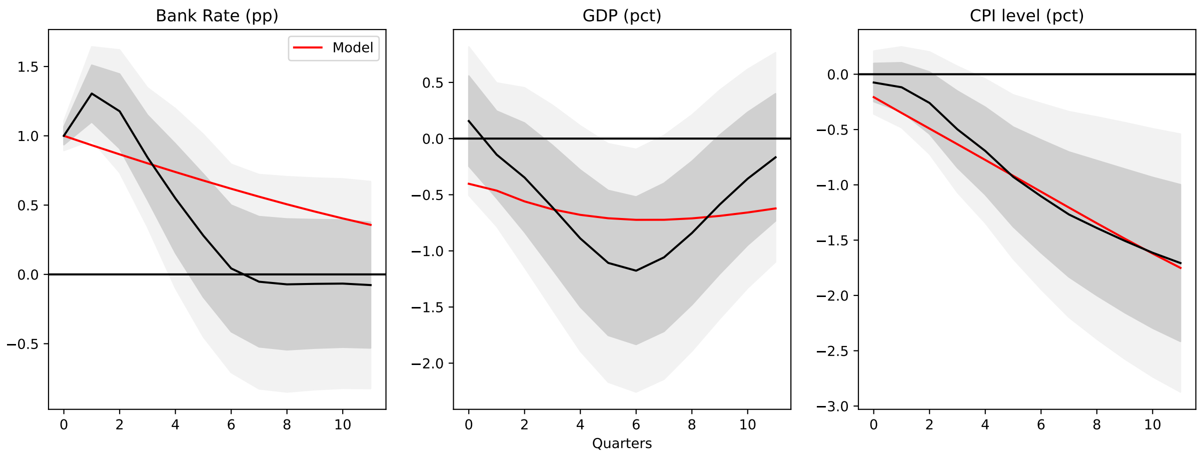
$$MIN_{\theta_{IRF}}(Y(\theta_{IRF}) - \dot{Y})^T W (Y(\theta_{IRF}) - \dot{Y})$$

We take as our empirical evidence the impulse responses functions (IRFs) estimated in Albuquerque et al. (2025b) and extend that evidence to include IRFs for the nominal exchange rate, nominal wages, consumption, the trade balance, and debt-to-GDP. We do so by adding in each instance an extra variable to the VAR. In the case of consumption and nominal wages, we interpolate the ONS's quarterly series to a monthly frequency using the monthly GDP series. The weighting matrix W is a diagonal matrix, with its diagonal equal to the inverse of the variance of the IRF at each point in time, with zero weight given to responses beyond 12 quarters in order to prioritise fit over the policy-relevant period.

In order to be able to match the empirical responses of many IRFs which do not peak on impact, the departures from rational expectations that we outlined in Section 2.2 are crucial. Table 5 reports the estimates for the dynamic parameters, including the two distinct information-update probabilities for households vs non-household agents. The model calls for a high degree of stickiness for households in line with that of Auclert et al. (2020), and also for all other agents. Firms being only slightly more attentive than households may be surprising at face value, but is not inconsistent with the empirical findings of Coibion and Gorodnichenko (2015). The cognitive discounting parameter, which is the same for all agents, is not well identified by our IRF matching procedure and so is set externally at $M^{CD} = 0.85$ prior to the estimation of the other dynamic parameters. This is the value recommended by Gabaix (2020) and effectively focuses agents forecasting horizons to a 5 year window.

Regarding the other parameters, the fiscal adjustment parameter is in line with the literature (see Auclert et al., 2020) and implies a 0.1% spending reduction over 4 quarters while debt-to-GDP is 1 pp above its long run average. The price adjustment costs are consistent with price durations of 4 quarters, 7 quarters and 8 quarters, respectively, for domestic consumption goods, nominal wages and rental prices. Therefore prices are reasonably sticky but not implausibly so or out of line with the literature that estimates these parameters in DSGE models.

Figure 2: Impulse response to a monetary policy shock



Notes: The figure reports in red the impulse response to a 1 pp unanticipated monetary policy shock. The black lines are the paths from the SVAR estimates averaged to a quarterly frequency. The shaded areas represent the 68% and 90% confidence intervals for the empirical responses. See appendix Figure B.3 for further variables.

The IRF matching procedure is able to generate a good fit with the empirical counterparts, both in the magnitudes and shapes of the IRFs, as can be seen in Figure 2 (full set of variables available in Appendix Figure B.3). The GDP response is hump shaped and peaks around 6 quarters after the initial policy rate innovation. The price level is very close to the empirical IRF while the interest rate response is on the more persistent end of the IRF confidence bands.

While the dynamic parameters have been calibrated in line with the empirical evidence from one study, we also compare them to a broader selection of estimates published in the academic literature. Table 6 reports the selection of estimates and the simple average over those estimates, relative to UK-HANK. We see the GDP responses for our model are quite close to the average over those studies. The CPI response, while in line with the numbers from Albuquerque et al. (2025b), is around 50 percent higher than the average from the literature.

Finally, we assess how the marginal propensities to consume in the model compare to the data. As outlined by Auclert et al. (2024b), intertemporal marginal propensities to consume (iMPCs) are a key statistic in determining the dynamics of HANK models. Figure 3 plots the response of aggregate consumption in the model to an income transfer given out to all households equal to 1% of average annual disposable income. The response is standardised to report spending relative to the transfer magnitude. The model delivers an initial MPC of around 0.2, meaning households will consume an extra 20 pence in a year if given an extra pound. The MPC to a negative transfer is larger, and households consume 26 pence less if taxed an extra pound. While still a sizeable MPC, this is towards the low end of the estimated range from UK survey evidence from the Household NMG survey, and quite a bit lower than other evidence from Norway. Recent work however pushes

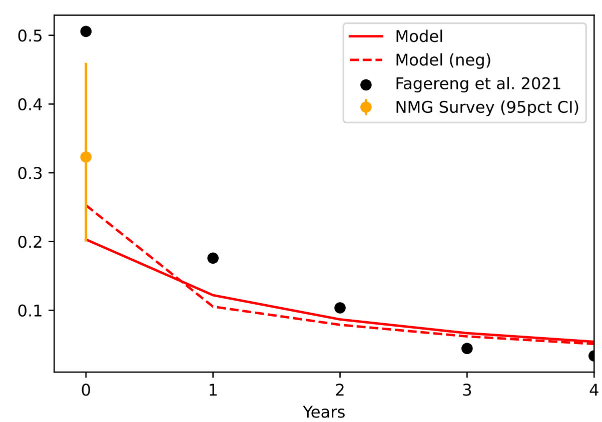
Table 6: Empirical evidence on the effect of monetary policy

Source	GDP Effect		CPI Effect	
	(pp, 4th qtr)	(pp, peak)	(pp, 4th qtr)	(pp, peak)
Albuquerque et al. (2025a)	-0.4	-0.4	-0.4	-0.4
Albuquerque et al. (2025b)	-1.1	-1.5	-0.8	-2.1
Braun et al. (2025)	-1.4	-1.4	-0.25	-0.5
Burgess et al. (2013)	-0.15	-0.4	-0.1	-0.2
Cesa-Bianchi et al. (2020)	-0.7	-1.3	-0.3	-0.3
Cloyne and Hürtgen (2016)	-0.4	-0.5	0.0	-0.9
Ellis et al. (2014)	-0.25	-0.5	-0.75	-2.0
Average	-0.63	-0.86	-0.37	-0.92
UK-HANK	-0.62	-0.71	-0.62	-1.59

Notes: All responses are normalised to an on impact (month/qtr) 1 pp rise in the interest rate. Results from Cloyne and Hürtgen (2016) are based on quarterly VAR. Braun et al. (2025) reports the target factor response. The values reported for the price level and GDP are: effect after 1 year, and the largest absolute value in the 12 quarters after the shock.

back on the plausibility of such high MPC estimates in the broader literature (e.g., see Borusyak et al., 2024; Orchard et al., 2025).[16]

Figure 3: iMPCs



Notes: 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 to values from the Household NMG 2012-2014 survey waves based on responses about temporary income surprises, as used by Bunn et al. (2018). Both sources measure spending on durables and nondurables combined. In addition, we plot consumption response in the model to a negative income shock of the same magnitude.

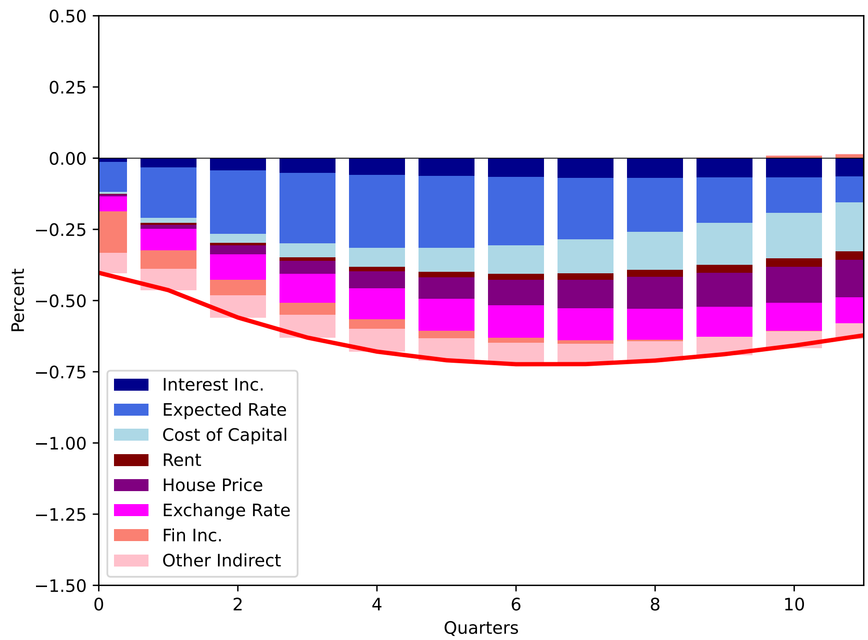
4 Monetary Transmission Mechanism

HANK models have become prominent largely due to their richer description of monetary transmission, as exemplified by Kaplan et al. (2018). They showed that contrary to representative

[16] The fact that households can borrow secured against a substantial amount of their overall wealth sets this model apart from other HANK models in the literature. Households have access to more self-insurance through greater borrowing capacity. This naturally pushes down on the average MPC in the model.

agent models, indirect general equilibrium channels explain as much, or even more, of monetary transmission than direct interest rate channels. We conduct a similar decomposition exercise in our richer model, extending it to total GDP in a framework calibrated to match aggregate monetary policy impulse response evidence. Exercises like this are useful in assessing the relative direct importance of different transmission channels and the sensitivity of monetary transmission to any structural changes that might affect these direct channels.

Figure 4: Transmission channels



Notes: This figure decomposes the impact of a 1pp unanticipated monetary policy shock on GDP (see Figure 2) into partial equilibrium channels and a general equilibrium effect.

Figure 4 decomposes the GDP response to a temporary 1pp monetary policy shock, first shown in Figure 2. Each channel represents its contribution to the GDP fall in partial equilibrium—that is, holding all other prices fixed.[17] For example, the cash flow channel and expected rate channel combined capture the consumption response of households to the general equilibrium real interest rate path response to the monetary policy shock, where all other relevant prices to households (e.g. wages, house prices, ...) are kept at their steady state.[18] The overall speed through which these channels comes through is largely determined by the estimated frictions in the model. For example household forecasting updating probabilities determine the speed of the expected interest rate channel and investment adjustment costs help determine the speed of the cost of capital channel, alongside the estimated speed that businesses update their expectations.

Starting with the direct channels (blue colours), one can see that the expected rate channel, which captures intertemporal substitution (higher rates incentivize saving and debt reduction), remains the largest single channel. However, in this HANK setting it is far from the dominant

[17]One should bear in mind these prices are all determined jointly in general equilibrium, so these channel-specific counterfactuals would never actually materialise in the model (see discussion in Dogra, 2024).

[18]In this instance, we can subdivide the interest rate channel into a cash flow channel and expected rate channel by considering a counterfactual where households see the interest rate path today but then always expect rates to return to steady state tomorrow.

force it would be in a representative agent (RANK) model. The higher cost of capital channel is also important, since higher rates depress investment due to higher hurdle rates. The importance of investment for the transmission of monetary policy is also present in other HANK models, e.g., Auclert et al. (2020). The remaining direct channel, the cash-flow interest income channel reflects the higher rates paid by debtors, and higher rates accrued to savers. Unlike the first two, this channel is small because interest payments constitute a modest share of total income and also because the income effect on debtors and savers cancels out – indebted households have higher marginal propensities to consume and end up depressing aggregate consumption.

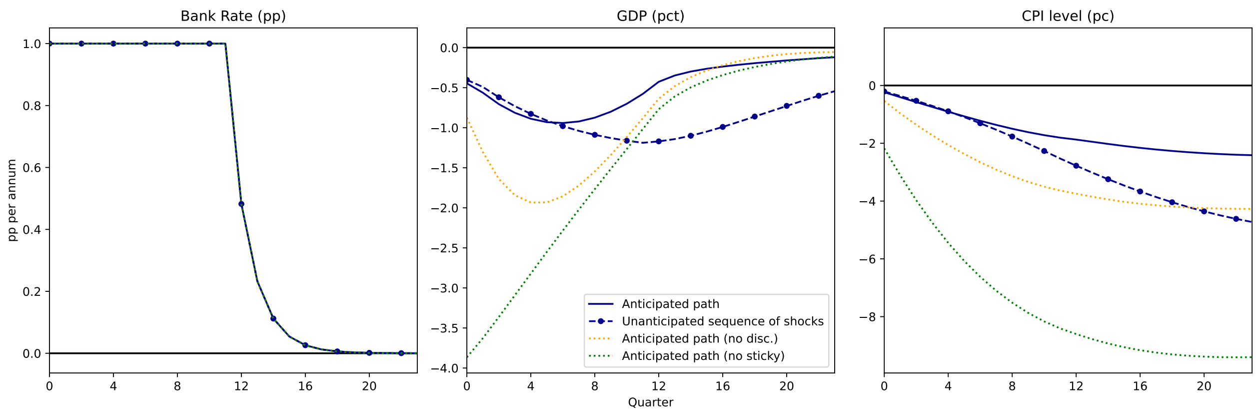
Figure 4 also shows the importance of indirect effects for the transmission of monetary policy, which work through asset prices, income, and fiscal adjustments. First, in our open-economy setting the exchange rate channel is important, and higher domestic rates strengthen the currency, reducing net exports. Second, our modelling of the housing market also shows that the decrease in house prices and the increase in rents (see Figure B.3) jointly account for a sizeable share of the transmission mechanism. Lower house prices reduce consumption through negative wealth and collateral effects, and higher rents affect particularly households with higher MPCs. Third, higher rates depress asset valuations, lowering financial income (including capital gains) on impact, with sustained drag from weaker economic activity. This comes through quickly as the expected real rate response peaks on impact. Finally, other GE effects from lower wages, hours worked, and fiscal adjustment further drag on activity.

At the peak GDP decline (quarter 6) through the lens of our decomposition, the direct channels (interest income, expected rate, and cost of capital) account for around half of transmission with the other half evenly attributable to the exchange rate, housing channels and other channels. This breakdown aligns well with bottom-up quantitative decompositions such as Slacalek et al. (2020).[19]

[19]The directed acyclic graph structure of our model creates a natural mapping from prices to quantities, but going the other way would require re-structuring the model. We therefore cannot similarly decompose CPI responses beyond the direct exchange rate effect on import prices, which accounts for roughly half the impact initially but diminishes as the overall price level falls (see appendix Figure B.4).

4.1 Forward Guidance

Figure 5: Forward guidance



Notes: This figure plots the response in the model when the central bank announces that the policy rate will be raised by 1 pp for 3 years. The dashed line blue plots the response if this policy path is achieved by a series of unanticipated shocks, while in the solid line the announcement is fully anticipated. The orange dotted line plots the anticipated path with no cognitive discounting. The green dotted line is the path with cognitive discounting but no stickiness.

UK-HANK has been calibrated to match the dynamics to an unanticipated monetary policy shock, which was the focus of the decomposition analysis above. However, in practice we will often need to work with anticipated monetary policy paths, for example, scenarios where the monetary policy rate is fixed or in in the case of optimal monetary policy (Alati et al., 2025). This has traditionally been a pain point for New Keynesian models due to the 'forward guidance puzzle' (Del Negro et al., 2023), whereby anticipated future changes in monetary policy generate implausibly large effects on current economic activity. While HANK models may partially attenuate this puzzle through heterogeneous marginal propensities to consume and borrowing constraints (McKay et al., 2016), they do not fully resolve it without additional frictions (Bilbiie, 2020). This motivated our decision to incorporate cognitive discounting—one of the standard remedies for this phenomenon—for both firms and households, following the approach of Gabaix (2020). This is necessary beyond sticky expectations due to the fact that sticky expectations only slows down the transmission of news about shocks. Shocks sufficiently far into the future will still be sufficiently internalised by agents after a number of quarters, producing similar overreaction. Cognitive discounting acts differently by having a consistent effect through time because the level of discounting of news k period ahead is constant unconditional on t. Therefore the two different departures from expectations play two separate roles. Stickiness slows down the reactions of agents whereas discounting shortens the planning window of agents.[20]

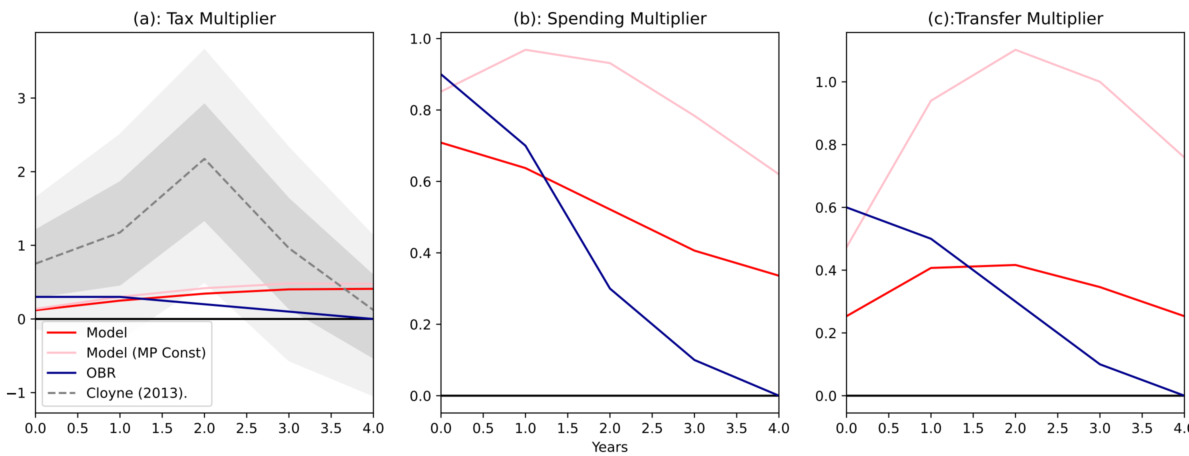
Figure 5 illustrates this by plotting the response of GDP and the CPI price level to an interest rate path that raises the policy rate by 1 percentage point for three years before returning it smoothly returning to zero over the course of 2 years. The solid line depicts the response when this interest rate sequence is pre-announced and eventually incorporated into expectations, while the blue dashed line shows the response when the policy rate evolves due to a sequence of unanticipated monetary policy surprises. The dotted lines remove the effect of cognitive discounting (orange) or stickiness (green). Our combination of sticky expectations and cognitive discounting generates

[20] Figure B.5 further illustrates these different effects.

an initial response that closely resembles the unanticipated path, with only slight amplification from anticipation. Over time, the two paths diverge: in the anticipated case, households gradually update their expectations while simultaneously beginning to anticipate the policy rate's eventual return to zero. By contrast, in the unanticipated case, firms and households implausibly continue to be surprised by the interest rate path and—until quarter 12—expect the elevated rate to persist in line with the high level of persistence shown in Figure 2. The orange dotted line illustrates the dampening effect of cognitive discounting versus the blue line, and the green dotted line shows how stickiness delays reaction leading to a hump shaped response.[21]

4.2 Fiscal Multipliers

Figure 6: Fiscal multipliers



Notes: This figure compares the responses in the model to the fiscal multipliers reported by the Office of Budget Responsibility (OBR – Tetlow and Pope, 2024). The OBR reports the real GDP impacts of permanent 1 percent increase in taxes, government purchases and transfers. In the model we show the response (GDP IRFs) to an anticipated shock to the tax rate, government spending and transfers that seeks to achieve the same objective. In pink we also show what happens in the model when the monetary authority does not respond. In the model we interpret permanent as 5 years (one parliament). Finally, for taxation we have additional evidence from Cloyne (2013) where we also report 68 % and 95% confidence bands.

The HANK literature has emphasised the importance of monetary and fiscal interactions and how the reaction of fiscal policy affects monetary transmission (see Section 5.3). Given the detailed modelling of fiscal policy in the model we can also show in Figure 6 how the model economy responds to changes in fiscal policy. Figure 6 does this by plotting the response of GDP to very persistent changes in taxation, spending and transfers. We assume expansionary changes in taxes, government spending and government transfers worth 1 percent of GDP that last for 5 years and plot the GDP IRF's in response to those plans. After that the government returns to its steady state fiscal plan. The transfer change is distributed in line with the schedule of Figure B.1 such that lower income household receive higher payments. The model responses in red are compared against the standard multipliers embedded in the Office of Budget Responsibilities (OBR) forecasts, and

[21]The rational expectations response to the anticipated path without discounting or stickiness is off the charts by an order of magnitude.

for taxation we can also compare to some established empirical evidence from Cloyne (2013) that also gives us a sense of uncertainty around these multipliers more broadly. Consistent with the OBR evidence the overall economy is most sensitive to direct government spending changes, either through direct government purchases or direct transfer payments.

To establish the role that monetary policy can play in offsetting fiscal policy in the model, we also plot in pink the model response where the nominal interest rate does not react i.e. is held constant at it's steady state value throughout the 5 year period. In all cases endogenous monetary policy mitigates the effect of fiscal policy, in particular for the case of transfers, which are the most inflationary and require the biggest monetary offset.[22] Focusing on the taxation multiplier where we have the additional evidence from Cloyne (2013), the multipliers for both the OBR and the UK-HANK model lie towards the bottom of the confidence bands, which are quite wide. The difference in point estimates may reflect the fact Cloyne (2013) spans a much larger time period (1945-2009), which includes variable monetary policy regimes, while the UK-HANK model is focused on the recent inflation targeting era.

5 Applications

In this section, we explore various applications of the model, highlighting key blocks that demonstrate its capabilities. While some experiments could in principle be run in representative-agent models or models with tractable heterogeneity, certain features are specific to this setting, such as the endogenous liquid wealth and net foreign asset position arising from various savings motives and government budgetary rules, and the potential interactions among rich household-level channels. These applications allow us to examine how such features shape the model's dynamics.

5.1 Housing and Household Heterogeneity: The Partial-Equilibrium Impact of a House Price Change Across Households

Within the household's problem, housing interacts in a rich way with consumption and saving. Given the discrete change in utility from owning relative to renting housing—and further upgrading the housing arrangement—households trade off consumption with saving for precautionary reasons, and with saving to climb the housing ladder. A natural exercise is then to examine the cross-sectional consumption impact of a house price shock to elicit some of these channels.

As a starting point, we consider in partial equilibrium the real house price path implied by the monetary policy shock of Figure 2 as a proxy for a realistic house price path after a generic shock. Panel (a) of Figure 7 shows this path alongside the response of aggregate consumption to that house price movement, in partial equilibrium. House prices fall by approximately 0.9% at their trough, which leads to a peak fall in consumption of around 0.3%, or a 0.3 elasticity. What drives this response? To help us investigate that, Panel (b) breaks down the response of consumption by household group.

We define groups based on the combination of housing and net financial wealth: *renters* (no housing wealth), *mortgagors* (positive housing wealth and negative net financial wealth), and *outright owners* (positive housing wealth and positive net financial wealth). Given all households' policy functions along the house price path, we can show the consumption response of a panel of households conditional on their group as of $t = 0$ (when the house price shock hits) and relative

[22] This is consistent with evidence in the US documented by Bouscasse and Hong (2023).

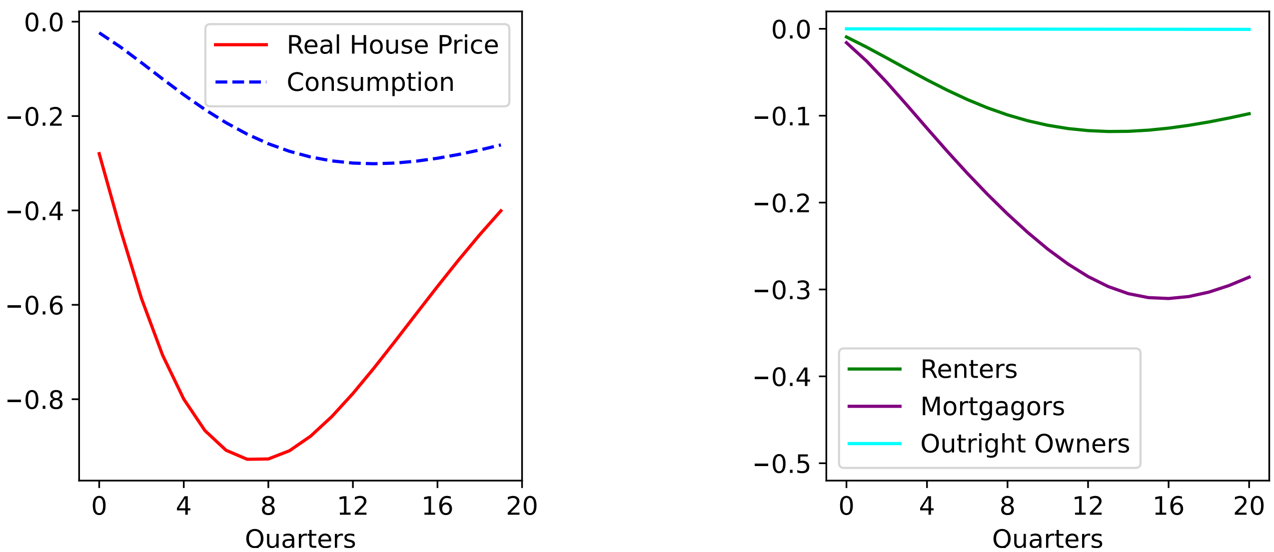
to the counterfactual where their consumption would have evolved according to the steady-state policies.[23]

As panel (b) shows, consumption responses differ markedly across household types. The contraction is most pronounced among mortgagors, smaller among renters, and minimal for outright owners. While the precise magnitudes depend on calibration and modelling choices—such as the implied minimum downpayment to climb the housing ladder, or the absence of a life-cycle dimension—this ordering is intuitive and can be understood heuristically as follows. Renters (green) feel wealthier as properties become cheaper but choose to reduce consumption and increase saving to take advantage and get onto the housing ladder. Mortgagors (purple), who typically own smaller properties, also reduce consumption to climb the next step of the ladder, with those closer to the constraints engaging in additional precautionary saving as their borrowing capacity against housing shrinks. Outright owners (cyan), generally wealthy and positioned at the top of the housing ladder, ride out the temporary price decline with negligible consumption adjustment.[24]

[23]The consumption responses in the two panels are expressed as percentage deviations and shown side by side to illustrate that they are broadly similar, but they are not directly comparable. The aggregate response in panel (a) reflects changes in the shares of households across groups, and the percentage deviation is computed relative to steady-state aggregate consumption—a constant. The group-level responses in panel (b), by contrast, are constructed from a panel that holds group composition fixed at $t = 0$, and percentage deviations are computed relative to the evolving average consumption path for households initially in each group.

[24]Their consumption declines negligibly relative to the counterfactual and is not visible in the chart. In the model's steady state distribution, approximately 99% of outright owners hold—and continue to hold—houses, with the remaining share downsizing to flats or transitioning to renting due to taste and income shocks. This share tends to shrink as house prices fall, since such transactions would crystallise losses. Outright owners are on their Euler equations, but given minimal net sales, the impact of the house price shock on their consumption—and welfare, see Fagereng et al. (2025)—is small. The absence of a life-cycle dimension, which abstracts from downsizing and bequest motives, also affects these results. Finally, note that to construct sticky behavioural household-level policies along the partial equilibrium simulation we perturb the time-dependent policy functions around the steady state house price level—consistent with the aggregate model. This perturbation approach may understate effects that would emerge from fully nonlinear, non-FIRE, time-dependent policy functions.

Figure 7: Consumption responses following a house price shock in partial equilibrium



(a) Aggregate variables

(b) Consumption by household group

Notes: Panel (a) shows the response of real house prices and aggregate consumption in partial equilibrium. Panel (b) shows consumption responses to the house price shock for a panel of households grouped by initial tenure status: renters, mortgagors, and outright owners.

5.2 International Block: Impact of Declining Sterling Invoicing of UK Exports on Exchange Rate Transmission

Garofalo et al. (2024) document that UK businesses predominantly billed their non-EU exports of goods in British pounds prior to the 2016 Brexit referendum. Following the referendum, sterling invoicing declined by over 20 p.p. by 2022. Including goods exports to the EU, we calculate that the share of total UK exports of goods invoiced in sterling fell from 0.44 in 2015 to 0.34 in 2022.

In our international block, the parameter ρ^X in Equation (16) can be interpreted as the share of sterling-denominated exports—introduced to generate an intermediate solution between Local Currency Pricing and Producer Currency Pricing, as required by the IRF matching. To examine how this structural shift affects exchange rate transmission, we compare IRFs to exchange rate shocks across two economies representing the pre-2016 and post-2022 invoicing regimes.[25] While this exercise could be conducted in traditional DSGE models, UK-HANK incorporates features—such as endogenous asset dynamics and rich household-level channels—that such frameworks cannot easily capture. Examining exchange rate transmission in this setting provides a useful check on the model's behaviour.

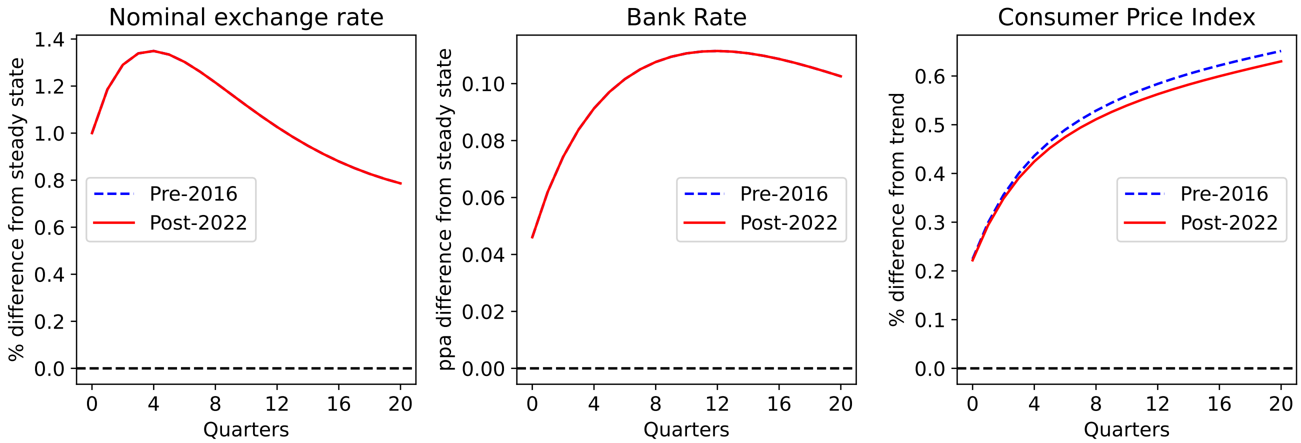
[25] We construct these economies by rescaling the baseline value of ρ^X (0.56, estimated by IRF matching) using the ratio of sterling-denominated export shares of goods for 2015 and 2022 relative to the full sample average (1993-2023). This yields $\rho^X = 0.56 \times 1.03 = 0.57$ for the pre-2016 economy and $\rho^X = 0.56 \times 0.79 = 0.44$ for the post-2022 economy. The rescaling accounts for the fact that our estimation spans 1993-2023, while the counterfactuals focus on specific sub-periods. We note that data limitations restrict invoicing information to goods only, whereas the model encompasses both goods and services. To the extent that services exhibit higher sterling invoicing shares, the sterling-denominated export shares in the model would become closer to the observed shares.

Figure 8 presents the dynamic responses to a 1% sterling depreciation in the pre-2016 economy, modelled as a wedge in the UIP condition with mean reversion at rate 0.9. To ensure comparability, we impose the same exchange rate and Bank Rate paths from the pre-2016 economy onto the post-2022 economy using anticipated shocks. Panel (a) shows the paths for nominal variables, panel (b) displays the responses of real variables. While the initial exchange rate depreciation is the same, subsequent effects diverge markedly. The GDP response in the post-2022 economy is muted, with the cumulative impact over the first three years approximately 8% lower than in the pre-2016 economy. The cumulative inflation effect is reduced by approximately 4% at the three-year mark.[26] This attenuation reflects the weakened transmission mechanism: reduced sterling invoicing implies lower exchange rate pass-through to export prices (see Figure C.6 in Appendix C), which dampens the stimulus to net exports and GDP, producing a smaller inflationary impact. The effects remain concentrated in the international block, with minimal spillovers to consumption given, for example, the absence of labour market segmentation in the model between domestic and export sectors, which might correlate with MPCs.[27]

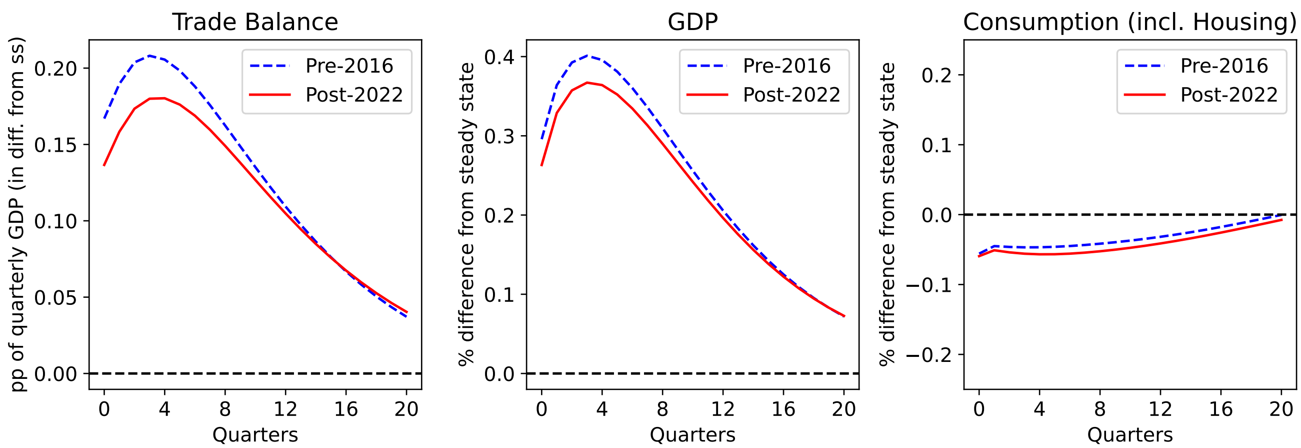
[26] In terms of annual CPI inflation, the peak response occurs after one year and is around 1 basis point lower in the post-2022 economy than in the pre-2016 economy.

[27] The small decline in total consumption visible in Figure 8 reflects mostly the fall in real imputed rents: the response of non-housing consumption to the depreciation over the simulation period is about 1/3 to 1/2 of the total consumption response.

Figure 8: Impulse responses to a 1% sterling depreciation



(a) Nominal variables



(b) Real variables

Notes: Impulse responses to a 1% sterling depreciation across pre-2016 and post-2022 invoicing regimes. Dashed blue lines represent the pre-2016 economy, solid red lines the post-2022 economy.

5.3 Fiscal Block: Monetary and Fiscal Policy Interaction

UK-HANK belongs to the class of modern macroeconomic models in which Ricardian Equivalence fails, meaning that the choice between tax or debt to finance government spending matters for aggregate outcomes. This failure occurs for two reasons: first, incomplete markets, which effectively shortens the planning horizon of households close to the borrowing constraints; second, deviations from Full Information Rational Expectations, which also prevent households from fully anticipating future policy adjustments – such as the future tax increases needed to repay a current tax cut. Thus, when Ricardian Equivalence fails, the effectiveness of monetary policy depends on the mix of fiscal policy between taxes and debt adjustments. Moreover, government spending policies can have a bigger impact since households do not fully take into account future tax movements needed to balance them. However, as shown in Figure 3 (and the surrounding discussion and Footnote 16), iMPCs are modest in the model relative to other HANK models in the literature, which dampens the consumption and GDP effects of fiscal policy changes.

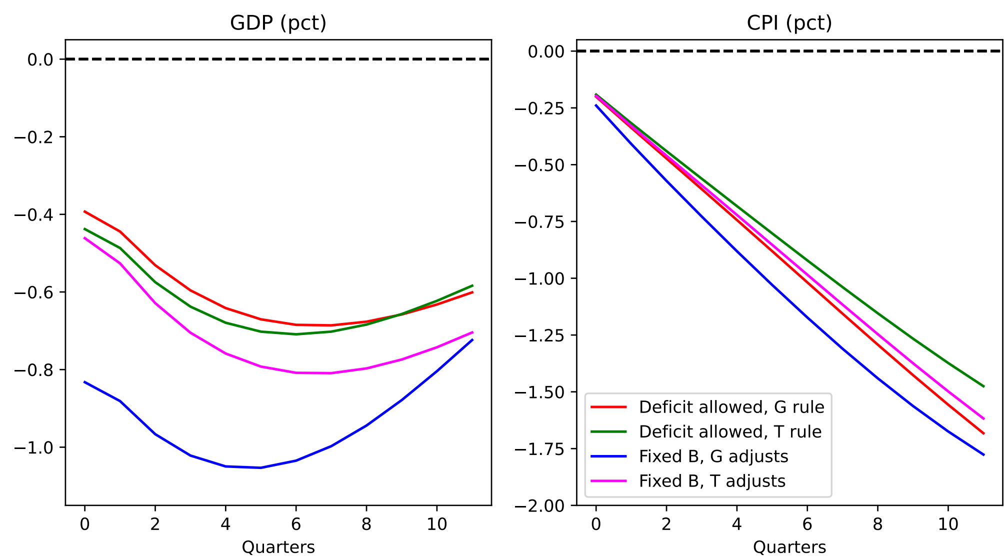
How quantitatively important, therefore, is monetary-fiscal policy interaction in the model? To address this question, we examine the effects of four sets of stylized fiscal reaction functions following an unanticipated monetary policy shock. "**Deficit allowed, G rule**" uses the baseline function outlined in the fiscal block in Section 2.6.1, which assumes that the government keeps the tax-to-(non-housing) GDP ratio and aggregate benefit spending constant while gradually adjusting consumption expenditure to stabilise government debt:

$$T_t = T + \frac{T}{X}(X_t - X), \quad G_{B,t} = G_{B,ss}, \quad G_t = G - \phi^G(B_{t-1} - B_{ss})$$

"**Deficit allowed, T rule**" reverses the roles of T and G, that is, the government keeps the spending-to-GDP ratio fixed. "**Fixed B, G adjusts**" and "**Fixed B, T adjusts**" hold real debt constant (balanced budget) at B_{ss} by instantly adjusting G (holding the tax-to-GDP ratio constant) or T (holding the spending-to-GDP ratio constant) respectively. Therefore, for these latter two cases

$$T_t - G_t = \left(\frac{1 + i_{av,t-1}}{1 + \pi_t} - 1\right) B_{ss} + \left(\frac{1 + i_{t-1}}{1 + \pi_t} - 1\right) \hat{L}_{ss} + G_{B,ss} - t_{cb,t}$$

Figure 9: Impulse responses to a monetary policy shock with different fiscal reaction functions



Notes: Figure reports the impulse response to a 1pp unanticipated monetary policy shock fixing the Bank Rate path to be the same as in Figure 2 across all cases using anticipated shocks. See Appendix C Figure C.7 for further variables.

We show the responses of headline variables to a 1% contractionary monetary policy shock under the four fiscal feedback functions in Figure 9, with additional key variables including consumption reported in Figure C.7 in Appendix C. To ensure comparability, we impose the Bank Rate path from the base case (see Figure 2, which is "Deficit allowed, G rule" here) onto the other cases using anticipated shocks.

"Fixed B, G adjusts" shows the largest GDP response: when government spending adjusts fully to satisfy the budget constraint, the same monetary contraction generates a peak impact on GDP that is 55% larger and a cumulative price level response that is 10 basis points larger over the first three years. The amplified GDP response is intuitive: the entire fiscal adjustment occurs immediately through government spending, which directly enters GDP. This path would lead to lower tax rates in the future than the other cases, but, because households fail to anticipate that, it leads to a larger fall in output.

Monetary policy effects are smaller than in the "Fixed B, G adjusts" case across the remaining fiscal reaction functions, but divergences between cases remain substantial: over the first three years, the peak impact on GDP in "Fixed B, T adjusts" is 20% larger, and the price level response for "Deficit allowed, T rule" is around 20 basis points smaller than the baseline "Deficit allowed, G rule" case.

We can conclude that the transmission of monetary policy is sensitive to the choice of fiscal feedback rule in the model, and that changes in the fiscal reaction function can lead to significant variations in the GDP or CPI response relative to our base case. Consistent with Kaplan et al. (2018), the extent to which the government balances the budget in response to monetary policy changes exerts the largest influence on the eventual GDP impact.

5.4 Balance-Sheet Composition: Long-run Changes to the Monetary Transmission Mechanism

The UK economy's balance-sheet composition—especially for households—changed markedly between the early 2000s and late 2010s. In the earlier period, households held low net liquid wealth and housing wealth relative to labour income, the economy's net international investment position in debt instruments was deeply negative, and central bank reserves were small in the absence of large-scale asset purchases. By the later period, net liquid wealth-to-income, housing wealth-to-income, and central bank reserves all increased substantially, while net foreign borrowing declined.

We use the model to examine changes in the monetary transmission mechanism between two steady states representing these periods. We label these "pre-GFC" and "post-GFC" (for Global Financial Crisis), calibrated to 1993–2007 and 2016–2019 averages respectively, treating the intervening years as transitional. The two steady states differ in the balance sheet variables noted above, as well as in other variables such as the share of government debt held by the rest of the world, the average maturity of government debt, and the long-run real rate r^*. The complete list is provided in Table C.2 in Appendix C. In the interest of brevity, we do not decompose the contribution of each change in steady-state values to the overall effect, though such a decomposition would be largely feasible.[28]

Panel (a) of Figure 10 shows the responses of headline variables to a 1% unanticipated contractionary monetary policy shock, with additional variables reported in Appendix C Figure C.8. As in Section 5.2, we impose the Bank Rate path from the pre-GFC economy onto the post-GFC economy using anticipated shocks. The post-GFC period (blue line) exhibits a slightly stronger GDP response but a weaker inflation response: over the first three years, the cumulative GDP impact is 2% larger, while the inflation response is 25% smaller. This resembles a flattening of the reduced-form Phillips curve, though the model's structural New Keynesian Phillips curves are

[28]The model structure and baseline parametrization are held constant across steady states, except that the values of β, P_O and P_R are re-calibrated for each period, targetting the housing wealth-to-labour income ratio, share of renters and the owner-to-renter transition probability. All other changes in steady-state values are implemented through direct parameter adjustments, such as varying the share of government debt held by the rest of the world.

unchanged—external calibration and dynamically estimated parameters are held constant across the two periods. Several mechanisms contribute to the weaker inflation response. First, aggregate labour supply increases less in the post-GFC economy because households hold larger liquid asset buffers for precautionary reasons, which dampens the wealth effects that would otherwise induce greater labour supply and lower real wages following monetary tightening. Second, higher rental price inflation and weaker sterling appreciation in the post-GFC case partially offset deflationary pressures.[29] Thus, while balance sheet positions differ substantially across steady states, the model indicates these structural changes have limited implications for the overall impact of monetary policy on GDP, but more significant effects on inflation dynamics.

Panel (b) of Figure 10 decomposes the difference in GDP responses between the two periods, revealing that the small aggregate difference masks substantial offsetting forces, whose magnitude ranges up to about 9% of the total GDP response. Intertemporal consumption substitution generates the largest positive effect, boosting post-GFC GDP relative to the pre-GFC period because real interest rates rise less when inflation declines less sharply. Offsetting this, two channels exert negative pressure: reduced financial income (driven almost entirely by larger declines in bank profits) suppresses consumption, and other general equilibrium effects further dampen output. Thus, while the net impact on GDP appears limited, the decomposition highlights significant heterogeneity across transmission channels.

This exercise demonstrates the value of a rich structural model that can simultaneously capture and quantify multiple, potentially offsetting dimensions of monetary transmission.

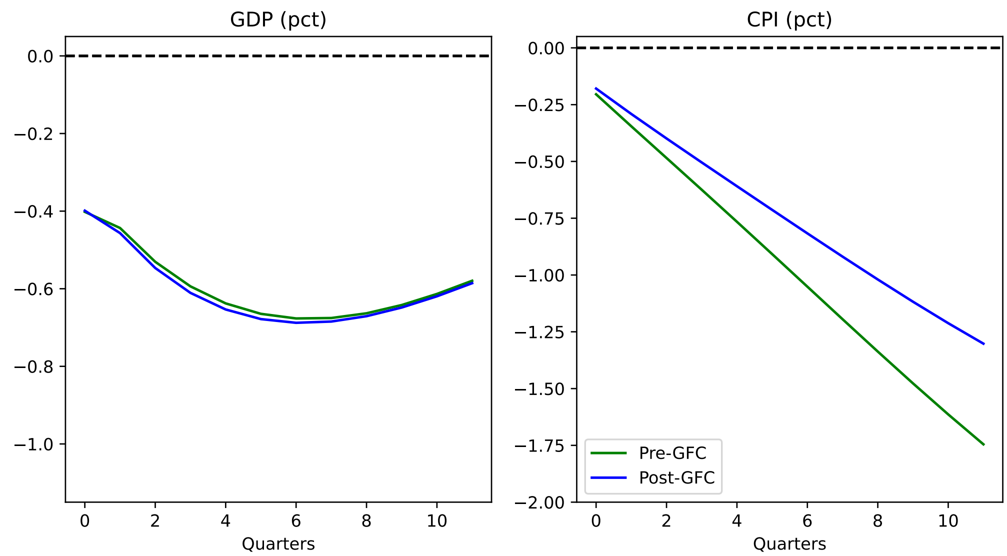
6 Conclusion

This paper presents UK-HANK, a Heterogeneous Agent New Keynesian model that richly captures household heterogeneity through realistic labour income risk, a housing ladder, secured borrowing constraints, and progressive taxes and benefits. The model simultaneously incorporates UK institutional features spanning international linkages, housing markets, fiscal policy, and business investment, while introducing departures from rational expectations to replicate established macroeconomic dynamics and dampen the effects of anticipated policy changes.

The model complements other analytical frameworks in the monetary policy process such as COMPASS (Albuquerque et al., 2025a), with applications ranging from scenario analysis around the household sector to monetary policy counterfactuals. The model's structure enables several promising extensions in the spirit of continuous development. Natural next steps - some already underway - include estimating the model on business cycle data to provide a fuller description of the business cycle, refining the differential incidence of income sources and capital gains across the household distribution, assessing the empirical match between model-implied and observed distributions of marginal propensities to consume out of income and wealth, and incorporating a more sophisticated labour market.

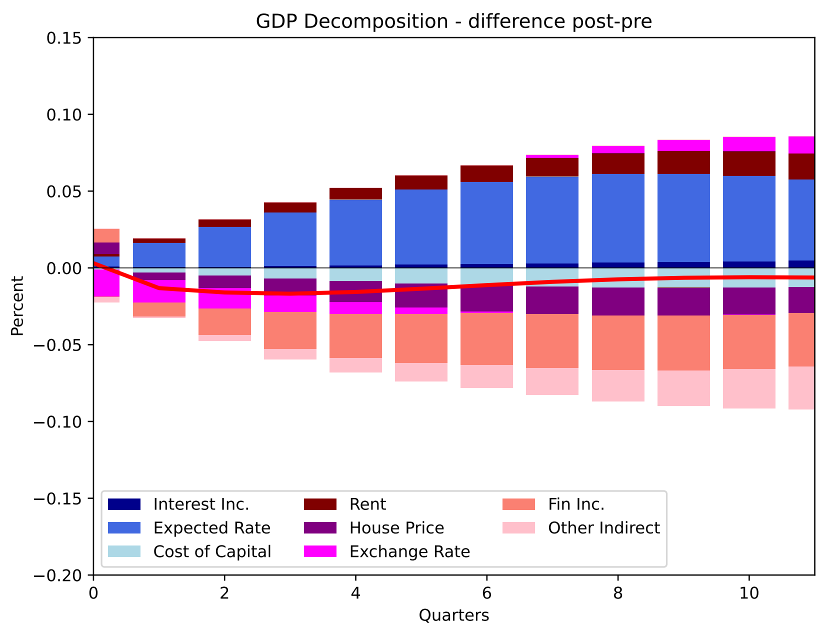
[29] The CPI includes nominal rental costs. As Figure C.8 (Appendix C) shows, the post-GFC period exhibits a larger initial rise in nominal rents and a smaller subsequent decline. These rent dynamics, combined with the exchange rate response, also contribute to the more muted price level decline in the post-GFC simulation.

Figure 10: Changes to the monetary transmission mechanism pre- and post-GFC



Notes: Figure reports the impulse response to a 1pp unanticipated monetary policy shock fixing the Bank Rate path from the pre-GFC economy onto the post-GFC economy using anticipated shocks. See Appendix C Figure C.8 for further variables.

(a) Impulse responses to a monetary policy shock in the pre- and post-GFC states



Notes: The red line is the difference between the green and blue in the left Panel of (a). The bars decompose this line, with a bar being positive meaning that the contribution post-GFC is larger than pre-GFC.

(b) Decomposition of GDP response difference: post-GFC vs. pre-GFC

References

Aiyagari, S Rao (1994). "Uninsured idiosyncratic risk and aggregate saving". *The Quarterly Journal of Economics* 109.3, pp. 659–684.

Alati, Andrea, Martín Arazi, John Barrdear, Andrew Gimber, Alex Haberis, Elspeth Hughes, Lien Laureys, Simon Lloyd, Ozgen Ozturk, Jack Page, Kate Reinold, Eric Tong, Matthew Tong, and Matt Waldron (2025). "Tools for endogenous monetary policy analysis: optimal projections and instrument rules". *Macro Technical Paper 4, Bank of England*.

Albuquerque, Daniel, Chan, Derrick Kanngiesser, David Latto, Simon Lloyd, Sumer Singh, and Jan Žáček (2025a). "Decompositions, forecasts and scenarios from an estimated DSGE model for the UK economy". *Macro Technical Paper 1, Bank of England*.

Albuquerque, Daniel, Thomas Lazarowicz, and Jamie Lenney (2025b). "Monetary Transmission in a HANK Model with Housing and Rental Sectors". *CFM Discussion Paper Series*.

Andreolli, Michele (2021). "Monetary policy and the maturity structure of public debt". *Available at SSRN* 3921429.

Auclert, Adrien (2025). "HANK: A New Core of Usable Macroeconomics". *AEA Papers and Proceedings*. Vol. 115. American Economic Association 2014 Broadway, Suite 305, Nashville, TN 37203, pp. 153–157.

Auclert, Adrien, Bence Bardóczy, Matthew Rognlie, and Ludwig Straub (2021a). "Using the sequence-space Jacobian to solve and estimate heterogeneous-agent models". *Econometrica* 89.5, pp. 2375–2408.

Auclert, Adrien, Matthew Rognlie, Martin Souchier, and Ludwig Straub (2021b). *Exchange rates and monetary policy with heterogeneous agents: Sizing up the real income channel*. Tech. rep. National Bureau of Economic Research.

Auclert, Adrien, Matthew Rognlie, and Ludwig Straub (2020). *Micro jumps, macro humps: Monetary policy and business cycles in an estimated HANK model*. Tech. rep. National Bureau of Economic Research.

— (2024a). *Fiscal and monetary policy with heterogeneous agents*. Tech. rep. National Bureau of Economic Research.

— (2024b). "The intertemporal keynesian cross". *Journal of Political Economy* 132.12, pp. 4068–4121.

Bardóczy, Bence, Jae Sim, and Andreas Tischbirek (2024). "The Macroeconomic Effects of Excess Savings".

Barkai, Simcha (2020). "Declining labor and capital shares". *The Journal of Finance* 75.5, pp. 2421–2463.

Bayer, Christian, Benjamin Born, and Ralph Luetticke (May 2024). "Shocks, Frictions, and Inequality in US Business Cycles". *American Economic Review* 114.5, pp. 1211–47.

Benhabib, Jess and Alberto Bisin (2018). "Skewed wealth distributions: Theory and empirics". *Journal of Economic Literature* 56.4, pp. 1261–1291.

Best, Michael Carlos, James S Cloyne, Ethan Ilzetzki, and Henrik J Kleven (May 2019). "Estimating the Elasticity of Intertemporal Substitution Using Mortgage Notches". *The Review of Economic Studies* 87.2, pp. 656–690. ISSN: 0034-6527.

Bilbiie, Florin O (2020). "The New Keynesian Cross". *Journal of Monetary Economics* 114, pp. 90–108.

Boppart, Timo, Per Krusell, and Kurt Mitman (2018). "Exploiting MIT shocks in heterogeneous-agent economies: the impulse response as a numerical derivative". *Journal of Economic Dynamics and Control* 89, pp. 68–92.

Borusyak, Kirill, Xavier Jaravel, and Jann Spiess (2024). "Revisiting event-study designs: robust and efficient estimation". *Review of Economic Studies* 91.6, pp. 3253–3285.

Bouscasse, Paul and Seungki Hong (2023). "Monetary-fiscal interactions in the United States". *unpublished, Science Po.*

Braun, Robin, Silvia Miranda-Agrippino, and Tuli Saha (2025). "Measuring monetary policy in the UK: The UK monetary policy event-study database". *Journal of Monetary Economics* 149, p. 103645.

Brignone, Davide and Michele Piffer (2025). "A structural VAR model for the UK economy". *Macro Technical Paper 3, Bank of England.*

Bunn, Philip, Jeanne Le Roux, Kate Reinold, and Paolo Surico (2018). "The consumption response to positive and negative income shocks". *Journal of Monetary Economics* 96, pp. 1–15.

Burgess, Stephen, Emilio Fernandez-Corugedo, Charlotta Groth, Richard Harrison, Francesca Monti, Konstantinos Theodoridis, Matt Waldron, et al. (2013). *The Bank of England's forecasting platform: COMPASS, MAPS, EASE and the suite of models*. SSRN.

Burr, Natalie and Tim Willems (2024). "About a rate of (general) interest: how monetary policy transmits". *Bank of England Quarterly Bulletin.*

Busetto, Filippo, Matthieu Chavaz, Maren Froemel, Michael Joyce, Iryna Kaminska, and Jack Worlidge (2022). "QE at the Bank of England: a perspective on its functioning and effectiveness". *Bank of England Quarterly Bulletin.*

Carroll, Christopher D (2006). "The method of endogenous gridpoints for solving dynamic stochastic optimization problems". *Economics letters* 91.3, pp. 312–320.

Carroll, Christopher D, Edmund Crawley, Jiri Slacalek, Kiichi Tokuoka, and Matthew N White (2020). "Sticky expectations and consumption dynamics". *American economic journal: macroeconomics* 12.3, pp. 40–76.

Cesa-Bianchi, Ambrogio, Gregory Thwaites, and Alejandro Vicondoa (2020). "Monetary policy transmission in the United Kingdom: A high frequency identification approach". *European Economic Review* 123, p. 103375. ISSN: 0014-2921.

Chan, Jenny, Sebastian Diz, and Derrick Kanngiesser (2024). "Energy prices and household heterogeneity: Monetary policy in a gas-tank". *Journal of Monetary Economics* 147, p. 103620.

Chetty, Raj, Adam Guren, Day Manoli, and Andrea Weber (2011). "Are micro and macro labor supply elasticities consistent? A review of evidence on the intensive and extensive margins". *American Economic Review* 101.3, pp. 471–475.

Cloyne, James (2013). "Discretionary tax changes and the macroeconomy: new narrative evidence from the United Kingdom". *American Economic Review* 103.4, pp. 1507–1528.

Cloyne, James and Patrick Hürtgen (2016). "The macroeconomic effects of monetary policy: a new measure for the United Kingdom". *American Economic Journal: Macroeconomics* 8.4, pp. 75–102.

Coibion, Olivier and Yuriy Gorodnichenko (2015). "Information rigidity and the expectations formation process: A simple framework and new facts". *American Economic Review* 105.8, pp. 2644–2678.

Davis, Josh, Cristian Fuenzalida, Leon Huetsch, Benjamin Mills, and Alan M Taylor (2024). "Global natural rates in the long run: Postwar macro trends and the market-implied r in 10 advanced economies". *Journal of International Economics* 149, p. 103919.

Del Negro, Marco, Marc P Giannoni, and Christina Patterson (2023). "The forward guidance puzzle". *Journal of Political Economy Macroeconomics* 1.1, pp. 43–79.

Dogra, Keshav (2024). "Paradoxes and problems in the causal interpretation of equilibrium economics". *FRB of New York Staff Report* 1093.

Ellis, Colin, Haroon Mumtaz, and Pawel Zabczyk (May 2014). "What Lies Beneath? A Time-varying FAVAR Model for the UK Transmission Mechanism". *The Economic Journal* 124.576, pp. 668–699. ISSN: 0013-0133.

Elminejad, Ali, Tomas Havranek, Roman Horvath, and Zuzana Irsova (2023). "Intertemporal substitution in labor supply: A meta-analysis". *Review of Economic Dynamics* 51, pp. 1095–1113. ISSN: 1094-2025.

Elminejad, Ali, Tomas Havranek, and Zuzana Irsova (2022). "Relative risk aversion: A meta-analysis". *Journal of Economic Surveys*.

Erceg, Christopher J, Dale W Henderson, and Andrew T Levin (2000). "Optimal monetary policy with staggered wage and price contracts". *Journal of monetary Economics* 46.2, pp. 281–313.

Fagereng, Andreas, Matthieu Gomez, Emilien Gouin-Bonenfant, Martin Holm, Benjamin Moll, and Gisle Natvik (2025). "Asset-price redistribution". *Journal of Political Economy* 133.11, pp. 3494–3549.

Fagereng, Andreas, Martin B Holm, and Gisle J Natvik (2021). "MPC heterogeneity and household balance sheets". *American Economic Journal: Macroeconomics* 13.4, pp. 1–54.

Forbes, Kristin, Ida Hjortsoe, and Tsvetelina Nenova (2018). "The shocks matter: Improving our estimates of exchange rate pass-through". *Journal of International Economics* 114, pp. 255–275. ISSN: 0022-1996.

Gabaix, Xavier (2020). "A behavioral New Keynesian model". *American Economic Review* 110.8, pp. 2271–2327.

Gali, Jordi and Tommaso Monacelli (2005). "Monetary policy and exchange rate volatility in a small open economy". *The Review of Economic Studies* 72.3, pp. 707–734.

Garofalo, Marco, Giovanni Rosso, and Roger Vicquéry (2024). "Dominant currency pricing transition".

Huggett, Mark (1993). "The risk-free rate in heterogeneous-agent incomplete-insurance economies". *Journal of economic Dynamics and Control* 17.5-6, pp. 953–969.

Huo, Zhen, Andrei A Levchenko, and Nitya Pandalai-Nayar (Mar. 2024). "International Comovement in the Global Production Network". *The Review of Economic Studies* 92.1, pp. 365–403. ISSN: 0034-6527.

Imrohoroğlu, Ayşe (1989). "Cost of business cycles with indivisibilities and liquidity constraints". *Journal of Political economy* 97.6, pp. 1364–1383.

Iskhakov, Fedor, Thomas H Jørgensen, John Rust, and Bertel Schjerning (2017). "The endogenous grid method for discrete-continuous dynamic choice models with (or without) taste shocks". *Quantitative Economics* 8.2, pp. 317–365.

Kaplan, Greg, Benjamin Moll, and Giovanni L Violante (2018). "Monetary policy according to HANK". *American Economic Review* 108.3, pp. 697–743.

Kase, Hanno and Rodolfo Rigato (2025). "Beyond averages: heterogeneous effects of monetary policy in a HANK model for the euro area".

Leeper, Eric M (1991). "Equilibria under 'active'and 'passive'monetary and fiscal policies". *Journal of monetary Economics* 27.1, pp. 129–147.

McKay, Alisdair, Emi Nakamura, and Jón Steinsson (2016). "The power of forward guidance revisited". *American Economic Review* 106.10, pp. 3133–3158.

McKay, Alisdair and Ricardo Reis (2016). "The role of automatic stabilizers in the US business cycle". *Econometrica* 84.1, pp. 141–194.

Oh, Hyunseung and Ricardo Reis (2012). "Targeted transfers and the fiscal response to the great recession". *Journal of Monetary Economics* 59, S50–S64.

Olivi, Alan, Vincent Sterk, and Dajana Xhani (2023). *Optimal Monetary Policy during a Cost of Living Crisis*. Tech. rep. mimeo, UCL. 1.

Orchard, Jacob D, Valerie A Ramey, and Johannes F Wieland (2025). "Micro MPCs and macro counterfactuals: the case of the 2008 rebates". *The Quarterly Journal of Economics*.

Pfäuti, Oliver and Fabian Seyrich (2022). *A behavioral heterogeneous agent new keynesian model*. Tech. rep. DIW Discussion Papers.

Schmitt-Grohé, Stephanie and Martın Uribe (2003). "Closing small open economy models". *Journal of international Economics* 61.1, pp. 163–185.

Slacalek, Jiri, Oreste Tristani, and Giovanni L. Violante (2020). "Household balance sheet channels of monetary policy: A back of the envelope calculation for the euro area". *Journal of Economic Dynamics and Control* 115.

Tetlow, G. and T. Pope (2024). "Fiscal multipliers: How does the OBR estimate the demand impact of government policies?" *Working Paper* 103.

A Detailed calculations

In this Appendix we provide more details on calculations that were not explicitly shown in the main text.

A.1 Labour Unions

There are $k \in [0,1]$ labour unions who hire a representative sample of the population to supply union-specific labour supply. The labour supply from unions then gets packaged into total labour supply. Labour unions are subject to quadratic costs to readjusting their nominal wages at a rate different from that of steady-state inflation $\bar{\pi}$. Re-stated here for convenience, the problem of labour union $k \in [0,1]$ is

$$\max_{\{W_{k,t+j}\}_{j=0}^{\infty}} \hat{\mathbb{E}}_t^f \left[\sum_{j=0}^{\infty} \beta^j \left\{ \int_0^i (u(c_{i,t+j}, h_{i,t+j}) - v(n_{i,t+j}))di - \frac{\varphi_w}{2} \left(\frac{W_{k,t+j}}{W_{k,t+j-1}} - (1+\bar{\pi}) \right)^2 \right\} \right]$$

subject to

$$N_{k,t} = N_t \left(\frac{W_{k,t}}{W_t} \right)^{-\eta_w}$$

and where we assumed that disutiliry of labour takes the form of

$$v(n) = \zeta \frac{n^{1+\nu}}{1+\nu}.$$

Notice that while the adjustment costs for commercial rental firms and for goods firms are output costs and so should be taken into account as dead weight loss in output, the cost here is an utility cost.

Auclert et al. (2024b) show that:

$$\frac{\partial c_{i,t}}{\partial W_{k,t}} = \frac{\partial z_{i,t}}{\partial W_{k,t}} \text{ , and } \frac{\partial n_{i,t}}{\partial W_{k,t}} = -\eta_w \frac{\partial N_{k,t}}{\partial W_{k,t}}, \tag{31}$$

where

$$\frac{\partial z_{i,t}}{\partial W_{k,t}} = (1-\lambda)\tau_t \left(\frac{W_{k,t}}{P_t} e_{i,t} N_{k,t} \right)^{-\lambda} \frac{e_{i,t}}{P_t} N_{k,t}(1-\eta_w) \tag{32}$$

Thus, the FOC in the symmetric equilibrium $W_{k,t} = W_t, N_{k,t} = N_t$, is

$$\begin{aligned}
0 = &\int_0^1 \left\{ u_c(c_{i,t}, h_{i,t})(1-\lambda)\tau_t \left(\frac{W_t}{P_t} e_{i,t} N_t \right)^{-\lambda} \frac{e_{i,t}}{P_t} N_t (1-\eta_w) W_t + v'(n_{i,t}) \eta_w N_t \right\} di \\
&- \varphi_w(\pi_t^w - \bar{\pi})(1+\pi_t^w) + \beta \varphi_w (\pi_{t+1}^w - \bar{\pi})(1+\pi_{t+1}^w) \\
= &N_t \eta_w \int_0^1 \left\{ (1-\lambda)\tau_t \left(\frac{W_t}{P_t} N_t \right)^{-\lambda} \frac{(1-\eta_w)}{\eta_w} \frac{W_t}{P_t} u_c(c_{i,t}, h_{i,t}) e_{i,t}^{1-\lambda} + v'(n_{i,t}) \right\} di \\
&- \varphi_w(\pi_t^w - \bar{\pi})(1+\pi_t^w) + \beta \varphi_w (\pi_{t+1}^w - \bar{\pi})(1+\pi_{t+1}^w) \\
= &N_t \eta_w \int_0^1 \left\{ (1-\lambda) \frac{Z_t}{N_t \int e_{i,t}^{1-\lambda} di} \frac{(1-\eta_w)}{\eta_w} u_c(c_{i,t}, h_{i,t}) e_{i,t}^{1-\lambda} + v'(n_{i,t}) \right\} di \\
&- \varphi_w(\pi_t^w - \bar{\pi})(1+\pi_t^w) + \beta \varphi_w (\pi_{t+1}^w - \bar{\pi})(1+\pi_{t+1}^w)
\end{aligned}$$

where Z_t is the aggregate after-tax labour income

$$Z_t = \tau_t \left(\frac{W_t N_t}{P_t}\right)^{1-\lambda} \int e_{it}^{1-\lambda} d\Psi_t,$$

Thus, rearranging the FOC we get the wage Phillips curve

$$(\pi_t^w - \overline{\pi})(1+\pi_t^w) = \frac{\eta_w}{\varphi_w}\left\{v'(N_t)N_t - (1-\lambda)Z_t\frac{(\eta_w - 1)}{\eta_w}\int_0^1 u_{c,i,t}\right\} + \beta\hat{\mathbb{E}}_t^f\left[(\pi_{t+1}^w - \overline{\pi})(1+\pi_{t+1}^w)\right]. \tag{33}$$

A.2 Commercial Rental Sector

Total rental supply $H_{R,t}$ is provided by a commercial rental sector that aggregates commercial rental units from individual rental firms indexed by $k \in [0,1]$ that make their price choices subject to Rotemberg (1982) adjustment costs and monopolistic competition. Aggregate rental supply is given by

$$H_{R,t} = \left(\int_0^1 H_{R,k,t}^{(\eta_r - 1)/\eta_r} dk\right)^{\eta_r/(\eta_r - 1)}$$

which gives rise to the usual demand that individual firms face

$$H_{R,k,t} = H_{R,t}\left(\frac{P_{R,k,t}}{P_{R,t}}\right)^{-\eta_r} \tag{34}$$

where $P_{R,t}$ is the aggregate rental index, and $P_{R,k,t}$ are the rents charged by each individual firm. The problem of an individual firm is then

$$\max_{\{P_{R,k,t+j}\}_{j=0}^{\infty}} \hat{\mathbb{E}}_t^f\left[\sum_{j=0}^{\infty}\prod_{\tau=0}^{j}\frac{1}{1+r_{t+\tau-1}^{ante}}\left\{H_{R,k,t+j}\left(\frac{P_{R,k,t}}{P_{t+j}} - \delta_H\right) - \frac{\varphi_r}{2}\left(\frac{P_{R,k,t+j}}{P_{R,k,t+j-1}} - (1+\overline{\pi})\right)^2 \mathbb{Y}_{t+j}\right.\right. \tag{35}$$

$$\left.\left. - F_R + \frac{P_{H,t+j}}{P_{t+j}}\left(H_{R,k,t+j-1} - H_{R,k,t+j}\right)\right\}\right], \text{ subject to Equation (34)}$$

where $r_{-1}^{ante} = 0$ and F_R are fixed costs to running a commercial firm and notice we assumed that the depreciation cost grows in line with the the price index P_t. Finally, the last term in the objective function represents the cost of buying and selling the necessary amount of housing to be able to supply it.

The FOC of the problem above is

$$\begin{aligned}
0 =& \frac{H_{R,k,t}}{P_t} - \eta_r\frac{H_{R,k,t}}{P_{R,k,t}}\left(\frac{P_{R,k,t}}{P_t} - \delta_H\right) - \varphi_r\left(\frac{P_{R,k,t}}{P_{R,k,t-1}} - (1+\overline{\pi})\right)\frac{\mathbb{Y}_t}{P_{R,k,t-1}} + \eta_r\frac{P_{H,t}}{P_t}\frac{H_{R,k,t}}{P_{R,k,t}} \\
&+ \hat{\mathbb{E}}_t^f\left[\frac{1}{1+r_t^{ante}}\left\{\varphi_r\left(\frac{P_{R,k,t+1}}{P_{R,k,t}} - (1+\overline{\pi})\right)\frac{P_{R,k,t+1}}{(P_{R,k,t})^2}\mathbb{Y}_{t+1} - \eta_r\frac{P_{H,t+1}}{P_{t+1}}\frac{H_{R,k,t}}{P_{R,k,t}}\right\}\right] \\
=& \tilde{P}_{R,t} - \eta_r\left(\tilde{P}_{R,t} - \delta_H\right) - \varphi_r(\pi_{R,t} - \overline{\pi})(1+\pi_{R,t})\frac{\mathbb{Y}_t}{H_{R,t}} + \eta_r\tilde{P}_{H,t} \\
&+ \hat{\mathbb{E}}_t^f\left[\frac{1}{1+r_t^{ante}}\left\{\varphi_r(\pi_{R,t+1} - \overline{\pi})(1+\pi_{R,t+1})\frac{\mathbb{Y}_{t+1}}{H_{R,t}} - \eta_r\tilde{P}_{H,t+1}\right\}\right]
\end{aligned}$$

where in the second equality we have used the symmetric equilibrium $P_{R,k,t} = P_{R,t}$ since the problem is the same for all individual firms, and have multiplied all terms by $P_{R,t}/H_{R,t}$. Notice that $\pi_{R,t} = P_{R,t}/P_{R,t-1} - 1$ is the growth rate of nominal rental prices, not real ones. Further assuming $\mathbb{Y}_t = H_{R,t}$ and rearranging we have

$$\tilde{P}_{H,t} = \left(\frac{\eta_r - 1}{\eta_r}\right)\tilde{P}_{R,t} - \delta_H + \hat{\mathbb{E}}_t^f\left[\frac{\tilde{P}_{H,t+1}}{1 + r_t^{ante}}\right] + \frac{\varphi_r}{\eta_r}\left((\pi_{R,t} - \overline{\pi})(1 + \pi_{R,t}) - \hat{\mathbb{E}}_t^f\left[\frac{(\pi_{R,t+1} - \overline{\pi})(1 + \pi_{R,t+1})}{1 + r_t^{ante}}\frac{H_{R,t+1}}{H_{R,t}}\right]\right) \tag{36}$$

The condition above is the usual Phillips Curve that arises in models with adjustment costs with two modifications: (i) because the aggregate $P_{R,t}$ of the price $P_{R,k,t}$ that is being chosen is not the numeraire, then the real rental price appears, not only its inflation rate; and (ii) the present value of the expected capital gain $\tilde{P}_{H,t} - \hat{\mathbb{E}}_t^f[\tilde{P}_{H,t+1}/(1 + r_t^{ante})]$ also appears because housing is a durable good.

Finally, per-period profits of the commercial rental sector are given by

$$t_{R,t} = H_{R,t}(\tilde{P}_{R,t} - \delta_H) - (\varphi_r/2)(\pi_{R,t} - \bar{\pi})^2 H_{R,t} + \tilde{P}_{H,t}(H_{R,t-1} - H_{R,t}) - F_R \tag{37}$$

Thus, the commercial sector does not borrow money from households, but just gives back all the flow profits/losses period by period. Furthermore, it helps with the numerical solution if we assume that there are fixed cost F_R such that profits from the rental sector are zero in steady state $t_R = 0$. Then, this fixed cost must be $F_R = H_R(\tilde{P}_R - \delta_H)$.

A.3 Intermediate Goods Firms

It is convenient to separate the firms' problem into an intratemporal problem over how to split its marginal cost MC_t between capital and labour, and an intertemporal problem of deciding the path of marginal costs over time.

The intratemporal problem is to minimise total cost subject to a fixed level of production

$$\min_{n,k} \widetilde{W}n + r^k k \text{ , subject to } y = \Omega n^{1-\alpha_k} k^{\alpha_k}$$

The optimality condition can be written as

$$\frac{\widetilde{W}n}{r^k k} = \frac{1 - \alpha_k}{\alpha_k} \tag{38}$$

Substituting out n, total cost is then equal to $\widetilde{W}n + r^k k = r^k k/\alpha_k$. Given that output can be written as $y = \Omega k \left(\frac{1-\alpha_k}{\alpha_k}\frac{r^k}{\widetilde{W}}\right)$, total real cost as a function of total output is given by $\widetilde{TC} = \frac{y}{\Omega}\left(\frac{r^k}{\alpha}\right)^{\alpha_k}\left(\frac{\widetilde{W}}{1-\alpha_k}\right)^{1-\alpha_k}$, which means that the real marginal cost is

$$\widetilde{MC} = \frac{1}{\Omega}\left(\frac{r^k}{\alpha_k}\right)^{\alpha_k}\left(\frac{\widetilde{W}}{1 - \alpha_k}\right)^{1-\alpha_k} \tag{39}$$

with nominal marginal costs given by $MC_t = \widetilde{MC}_t P_t$. Notice that the marginal cost is independent of the output level and is the same for all firms.

The intertemporal problem it then to solve

$$\max_{\{P^X_{D,k,t+j}\}_{j=0}^{\infty}} \hat{\mathbb{E}}^f_t \left[\sum_{j=0}^{\infty} \prod_{\tau=0}^{j} \frac{1}{1+r^{ante}_{t+\tau-1}} \left\{ x_{k,t+j} \frac{(P^X_{D,k,t} - MC_t)}{P_{t+j}} - \frac{\varphi_x}{2} \left(\frac{P^X_{D,k,t+j}}{P^X_{D,k,t+j-1}} - (1+\overline{\pi}) \right)^2 X_{t+j} \right\} \right]$$

subject to Equations (6) and (39). Noting that $x_{k,t} = X_{D,t}$ and $P^X_{D,k,t} = P^X_{D,t}$ in equilibrium, the FOC of the problem above can be re-arranged into the price Phillips Curve

$$(\pi^X_{D,t} - \overline{\pi})(1+\pi^X_{D,t}) = \frac{(1-\eta_x)}{\varphi_x} \tilde{P}^X_{D,t} + \frac{\eta_x}{\varphi_x} \widetilde{MC}_t + \hat{\mathbb{E}}^f_t \left[\frac{(\pi^X_{D,t+1} - \overline{\pi})(1+\pi^X_{D,t+1})}{1+r^{ante}_t} \frac{X_{t+1}}{X_t} \right] \tag{40}$$

where $\pi^X_{D,t} = P^X_{D,t}/P^X_{D,t-1}$ is growth rate of nominal intermediate goods prices.

Capital output firms choose investment I_t today to build capital K_{t+1} tomorrow. Thus, total capital demand from intermediate firms must equal total capital supplied by capital firms: $\int k_{k,t} dk = K_{t-1}$.Total output is then

$$X_t = \Omega_t K^{\alpha_k}_{t-1} N^{1-\alpha_k}_t \tag{41}$$

Total profits $t_{x,t}$ from the intermediate goods sector is given by

$$\begin{aligned} P_t t_{X,t} &= P^X_{D,t} X_t - W_t N_t - P_t r^k_t K_{t-1} - (\varphi_x/2)(\pi^X_{D,t} - \overline{\pi})^2 X_t P_t \\ &= X_t \left(P^X_{D,t} - MC_t - (\varphi_x/2)(\pi^X_{D,t} - \overline{\pi})^2 P_t \right) \end{aligned} \tag{42}$$

where the equality follows from the solution to the $x_{k,t}$ firms' problem.

A.4 Government

We denoted by L_t the new issuance of long-term bonds with duration δ (in real terms). Thus, the law of motion for real government debt is given by

$$B_t = L_t + (1-\delta) \frac{B_{t-1}}{1+\pi_t}. \tag{43}$$

Moreover, we defined as $q_{av,t}$ the average market price of government debt. Appendix A.6.2 shows that we can express it in terms of the average interest rate $i_{av,t}$ on government debt B_t and the interest rate $i_{L,t}$ on new issuance of long-term debt L_t:

$$q_{av,t} = \frac{i_{av,t} + \delta}{i_{L,t} + \delta}. \tag{44}$$

A.4.1 Central Bank

The Central Bank (CB) issues new reserves $\widehat{M}t$ every period to buy a share κ of the new issuance of long-term debt: $\widehat{M}t = \kappa L_t$. It also buys back a share δ of past reserves, so that the law of motion for total reserves M_t is exactly the same as the one for government bonds, and it is given by:

$$M_t = (1-\delta) \frac{M_{t-1}}{1+\pi_t} + \widehat{M}t. \tag{45}$$

The CB does not buy or sell government bonds otherwise. We can then re-write it budget constraint in Equation (14) as

$$\begin{aligned} t_{cb,t} &= M_t + \frac{(i_{av,t-1}+\delta)}{1+\pi_t}\kappa B_{t-1} - \frac{(1+i_{t-1})}{1+\pi_t}M_{t-1} - \kappa L_t \\ &= \widehat{M}_t + \frac{(i_{av,t-1}+\delta)}{1+\pi_t}\kappa B_{t-1} - \frac{(\delta+i_{t-1})}{1+\pi_t}M_{t-1} - \kappa L_t \\ &= \frac{(i_{av,t-1}+\delta)}{1+\pi_t}\kappa B_{t-1} - \frac{(\delta+i_{t-1})}{1+\pi_t}M_{t-1} \\ &= \frac{i_{av,t-1}-i_{t-1}}{1+\pi_t}\kappa B_{t-1}, \end{aligned}$$

where we have used: the law of motion in Equation (45); $\widetilde{M}_t = \kappa L_t$; the fact that the law of motion for reserves and government debt are the same, then $M_t = \kappa B_t$ respectively, to go from the 1st to the 2nd, 3rd and 4th lines above.

A.5 Prices Under Local Currency Pricing

Under Local Currency Pricing, the domestic intermediate goods producers (indexed k) choose prices to maximise the present discounted value of profits subject to price adjustment costs and the CES demand function.

$$\max_{\left\{P^{X,*}_{D,k,t+j}\right\}_{j=0}^{\infty}} \hat{\mathbb{E}}^f_t \left[\sum_{j=0}^{\infty} \prod_{\tau=0}^{j} \frac{1}{1+r^{ante}_{t+\tau-1}} \left\{ x^*_{k,t+j} \frac{\mathcal{E}_{t+j} P^{X,*}_{D,k,t+j} - MC_{t+j}}{P_{t+j}} - \frac{\varphi^*_x}{2} \left(\frac{P^{X,*}_{D,k,t+j}}{P^{X,*}_{D,k,t+j-1}} - (1+\pi^*) \right)^2 X^*_{D,t} \right\} \right]$$

subject to

$$x^*_{k,t} = X^*_{D,t} \left(\frac{P^{X,*}_{D,k,t}}{P^{X,*}_{D,t}} \right)^{-\eta^*_x}$$

where real marginal costs are defined as in Equation (39).

The FOC of the profit-maximisation problem yields a Phillips curve for intermediate exports prices under LCP:

$$\begin{aligned} \left(\pi^{X,*,LCP}_{D,t} - \pi^*\right)(1+\pi^{X,*,LCP}_{D,t}) &= \frac{(1-\eta^*_x)}{\varphi_x} Q_t \tilde{P}^{X,*,LCP}_{D,t} + \frac{\eta^*_x}{\varphi_x}\widetilde{MC}_t \\ &+ \hat{\mathbb{E}}^f_t \left[\frac{\left(\pi^{X,*,LCP}_{D,t+1} - \pi^*\right)(1+\pi^{X,*,LCP}_{D,t+1})}{1+r^{ante}_t} \frac{X^{*,LCP}_{D,t+1}}{X^{*,LCP}_{D,t}} \right] \end{aligned}$$

where we can express the inflation rate for intermediate exports under LCP as:

$$1+\pi^{X,*,LCP}_{D,t} = \frac{\tilde{P}^{X,*,LCP}_{D,t}}{\tilde{P}^{X,*,LCP}_{D,t-1}}(1+\pi^*)$$

and the volume of intermediate goods exports under LCP is given by:

$$X_{D,t}^{*,LCP} = \alpha_y \left(\tilde{P}_{D,t}^{X,*,LCP}\right)^{-\eta_y^*} Y^*.$$

Finally, the other prices under LCP are simpler, by assumption. For the final output firms, we assume that their LCP pricing grows in line with their domestic price $P_{D,t}$, thus ignoring any exchange-rate movements. For the exporters from the rest of the world, because of the Small Open Economy assumption the economy abroad is always at its steady-state and we have $P_{F,t}^{*,LCP} = P_{F,t}^{X,*,LCP} = 1$.

A.6 Financial Intermediaries

A.6.1 Re-writing the FOC for long-term bonds

Remember the FOC with respect to $B_{m,t}^j$ for financial intermediaries was:

$$q_t^j = \frac{(1-\delta)q_{t+1}^j + i_{L,t-j} + \delta}{1+i_t}$$

We want to show that using the equation above the following two equations hold:

$$q_t^j = \frac{i_{L,t-j} + \delta}{i_{L,t} + \delta} \tag{46}$$

$$\frac{1}{i_{L,t}+\delta} = \frac{1}{1+i_t}\left(1 + \frac{1-\delta}{i_{L,t+1}+\delta}\right) \tag{47}$$

which we use in Appendices A.6.2 and A.6.3 below.

To show the second equation above holds, start by evaluating the FOc at $j = 0$

$$q_t^0 = \frac{i_{L,t}+\delta}{1+i_t} + \frac{(1-\delta)q_{t+1}^0}{1+i_t},$$

which can be written recursively as:

$$q_t^0 = \sum_{j=0}^{\infty}\left(\prod_{k=0}^{j}\frac{1}{1+i_{t+k}}\right)(i_{L,t}+\delta)(1-\delta)^j.$$

The above implies that

$$\frac{q_t^0}{i_{L,t}+\delta} = \sum_{j=0}^{\infty}\left(\prod_{k=0}^{j}\frac{1}{1+i_{t+k}}\right)(1-\delta)^j = \frac{1}{1+i_t} + \frac{1-\delta}{1+i_t}\sum_{j=0}^{\infty}\left(\prod_{k=0}^{j}\frac{1}{1+i_{t+1+k}}\right)(1-\delta)^j,$$

and shifting 1 period forward

$$\frac{q_{t+1}^{-1}}{i_{L,t+1}+\delta} = \sum_{j=0}^{\infty}\left(\prod_{k=0}^{j}\frac{1}{1+i_{t+1+k}}\right)(1-\delta)^j.$$

Combining the last 2 equations yields

$$\frac{q_t^0}{i_{L,t}+\delta} = \frac{1}{1+i_t} + \frac{1-\delta}{1+i_t}\frac{q_{t+1}^{-1}}{i_{L,t+1}+\delta}$$

Since $q_t^0 = q_{t+1}^{-1} = 1$,[30]

$$\frac{1}{i_{L,t} + \delta} = \frac{1}{1 + i_t}\left(1 + \frac{1 - \delta}{i_{L,t+1} + \delta}\right).$$

Now taking the equation for q_t^j in Equation (19) for $j > 0$ we have the analogous recursion:

$$\frac{q_t^j}{i_{L,t-j} + \delta} = \sum_{j=0}^{\infty}\left(\prod_{k=0}^{j}\frac{1}{1 + i_{t+k}}\right)(1 - \delta)^j$$

thus we can equate

$$\frac{q_t^j}{i_{L,t-j} + \delta} = \frac{q_t^0}{i_{L,t} + \delta} = \frac{1}{i_{L,t} + \delta} \implies q_t^j = \frac{i_{L,t-j} + \delta}{i_{L,t} + \delta}.$$

A.6.2 Average price of debt

From our definition

$$\begin{aligned} q_{av,t}B_t &= \sum_{j=0}^{\infty}(1 - \delta)^j \tilde{L}_{t-j} q_t^j \\ &= \sum_{j=0}^{\infty}(1 - \delta)^j \tilde{L}_{t-j}\frac{i_{L,t-j} + \delta}{i_{L,t} + \delta}, \end{aligned}$$

where we used Equation (46).

From the equation for the average coupon rate, we have

$$B_t(i_{av,t} + \delta) = (i_{L,t} + \delta)L_t + (i_{av,t-1} + \delta)(B_t - L_t),$$

i.e.

$$\tilde{B}_t(i_{av,t} + \delta) = (i_{L,t} + \delta)\tilde{L}_t + (i_{av,t-1} + \delta)(\tilde{B}_t - \tilde{L}_t) = (i_{L,t} + \delta)\tilde{L}_t + (i_{av,t-1} + \delta)(1 - \delta)\tilde{B}_{t-1},$$

using the law of motion of total government debt in Equation (43) in nominal terms. Then, iterating backwards

$$\tilde{B}_t(i_{av,t} + \delta) = \sum_{j=0}^{\infty}(1 - \delta)^j(i_{L,t-j} + \delta)\tilde{L}_{t-j}$$

which allows us to write

$$q_{av,t}\tilde{B}_t = \sum_{j=0}^{\infty}(1 - \delta)^j \tilde{L}_{t-j}\frac{i_{L,t-j} + \delta}{i_{L,t} + \delta} = \tilde{B}_t\frac{i_{av,t} + \delta}{i_{L,t} + \delta}$$

i.e.

$$q_{av,t} = \frac{i_{av,t} + \delta}{i_{L,t} + \delta}, \tag{48}$$

which is Equation (44).

[30] Notice that q_t^0 is the price today of a bond issued today, and q_{t+1}^{-1} is the price tomorrow of a bond issued -1 periods ago, i.e., issued tomorrow.

A.6.3 Private bank transfers

Using the balance sheet in Equation (20) we can start from:

$$
\begin{aligned}
&(1+\pi_t)t_{m,t} = \\
&\sum_{j=1}^{\infty}[(1-\delta)q_t^j + i_{L,t-j} + \delta]B_{m,t-1}^j - (1+i_{t-1})(A_{t-1} - M_{t-1} - \hat{L}_{t-1}) + (1+\pi_t)\frac{(1+i_{t-1}^*)}{1+\pi_t^*}Q_t B_{t-1}^* \\
&= \sum_{j=1}^{\infty}\left[(1-\delta)\frac{q_t^j}{q_{t-1}^j} + \frac{i_{L,t-j}+\delta}{q_{t-1}^j}\right] q_{t-1}^j B_{m,t-1}^j \\
&\qquad - (1+i_{t-1})(A_{t-1} - M_{t-1} - \hat{L}_{t-1}) + (1+\pi_t)\frac{(1+i_{t-1}^*)}{1+\pi_t^*}Q_t B_{t-1}^* \\
&= \sum_{j=1}^{\infty}\left[(1-\delta)\frac{i_{L,t-1}+\delta}{i_{L,t}+\delta} + i_{L,t-1} + \delta\right] q_{t-1}^j B_{m,t-1}^j \\
&\qquad - (1+i_{t-1})(A_{t-1} - M_{t-1} - \hat{L}_{t-1}) + (1+\pi_t)\frac{(1+i_{t-1}^*)}{1+\pi_t^*}Q_t B_{t-1}^* \\
&= \left[(1-\delta)\frac{i_{L,t-1}+\delta}{i_{L,t}+\delta} + i_{L,t-1} + \delta\right] \sum_{j=1}^{\infty} q_{t-1}^j B_{m,t-1}^j \\
&\qquad - (1+i_{t-1})(A_{t-1} - M_{t-1} - \hat{L}_{t-1}) + (1+\pi_t)\frac{(1+i_{t-1}^*)}{1+\pi_t^*}Q_t B_{t-1}^* \\
&= \left[(1-\delta)\frac{i_{L,t-1}+\delta}{i_{L,t}+\delta} + i_{L,t-1} + \delta\right] (A_{t-1} - M_{t-1} - \hat{L}_{t-1} - Q_{t-1}B_{t-1}^*) \\
&\qquad - (1+i_{t-1})(A_{t-1} - M_{t-1} - \hat{L}_{t-1}) + (1+\pi_t)\frac{(1+i_{t-1}^*)}{1+\pi_t^*}Q_t B_{t-1}^* \\
&= \left[(1-\delta)\frac{i_{L,t-1}+\delta}{i_{L,t}+\delta} + i_{L,t-1} + \delta - (1+i_{t-1})\right] (A_{t-1} - M_{t-1} - \hat{L}_{t-1} - Q_{t-1}B_{t-1}^*) \\
&\qquad - (1+i_{t-1})Q_{t-1}B_{t-1}^* + (1+\pi_t)\frac{(1+i_{t-1}^*)}{1+\pi_t^*}Q_t B_{t-1}^*
\end{aligned}
$$

From the market clearing for long bonds and for assets in Equations (23) and (22), together with the definition for $q_{av,t}$ in Equation (44) we have:

$$A_t = (1-\kappa-\kappa^*)q_{av,t}B_t + M_t + \hat{L}_t + Q_t B_t^*. \tag{49}$$

Substituting the above in our derivation we get:

$$
\begin{aligned}
t_m = &\left[\frac{i_{L,t}+1}{i_{L,t}+\delta} - \frac{1+i_{t-1}}{i_{L,t-1}+\delta}\right](i_{L,t-1}+\delta)(1-\kappa-\kappa^*)\frac{q_{av,t-1}}{1+\pi_t}B_{t-1} \\
&- B_{t-1}^*\left(\frac{(1+i_{t-1})}{1+\pi_t}Q_{t-1} - \frac{(1+i_{t-1}^*)}{1+\pi_t^*}Q_t\right).
\end{aligned}
$$

Notice that we can also write the above as:

$$t_m = \frac{1}{1+\pi_t}\left(\frac{i_{L,t}+1}{i_{L,t}+\delta} - \hat{\mathbb{E}}^f_{t-1}\left[\frac{i_{L,t}+1}{i_{L,t}+\delta}\right]\right)(i_{L,t-1}+\delta)(1-\kappa-\kappa^*)q_{av,t-1}B_{t-1}$$
$$+ B^*_{t-1}\frac{(1+i^*_{t-1})}{1+\pi_t}\left(Q_t\frac{(1+\pi_t)}{1+\pi^*_t} - \hat{\mathbb{E}}^f_{t-1}\left[Q_t\frac{(1+\pi_t)}{1+\pi^*_t}\right]\right).$$

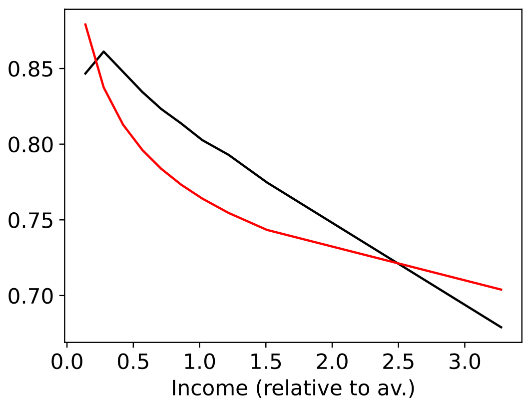
In either case, with Equation (47) at $t-1$ the first term in the equation above is equal to zero; and with the UIP condition at $t-1$ in Equation (19) the second term is equal to zero. We then have $t_m = 0$ without shocks (i.e., no difference between expected values in the FOCs from the last period to their realised values at t).

B Calibration: Further Details

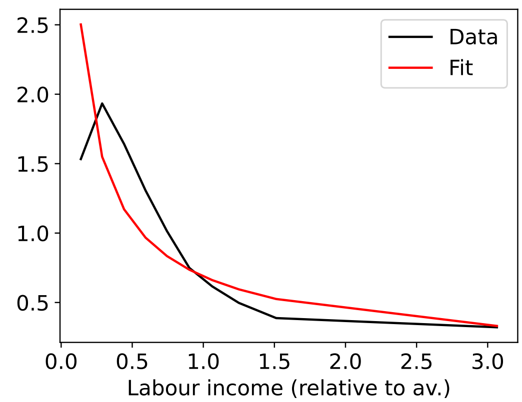
Table B.1: Earnings process estimation: moments comparison

Moment	UK data	US data	Continuous process	Discretized process
Std log earnings	0.70	0.84	0.62	0.65
Std 1-year change log earnings	0.28	0.48	0.25	0.26
Std 5-year change log earnings	0.42	0.68	0.48	0.49
Kurtosis 1-year change	24.8	17.8	24.8	24.8
Share |1-year change| $<$ 10%	0.60	0.54	0.56	0.53
Share |1-year change| $<$ 20%	0.78	0.71	0.76	0.78
Share |1-year change| $<$ 50%	0.94	0.86	0.95	0.96
Kurtosis 5-year change	11.5	11.6	12.0	11.8

Figure B.1: Tax and benefit schedules



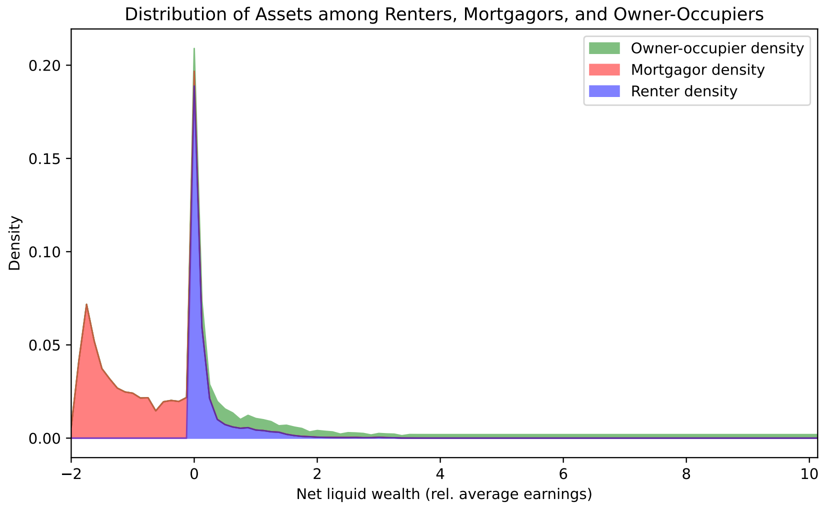
(a) Income tax retention



(b) Benefit relativity

Notes: Figure compares the income tax retention and benefit relativity functional forms to the data as implied by the ONS's "Effects of taxes and benefits on UK household income". The data is based on the average over the period 2001-2023 for non-retired households. Income tax includes payroll taxes. The benefit relativity is relative to the average spend across all households.

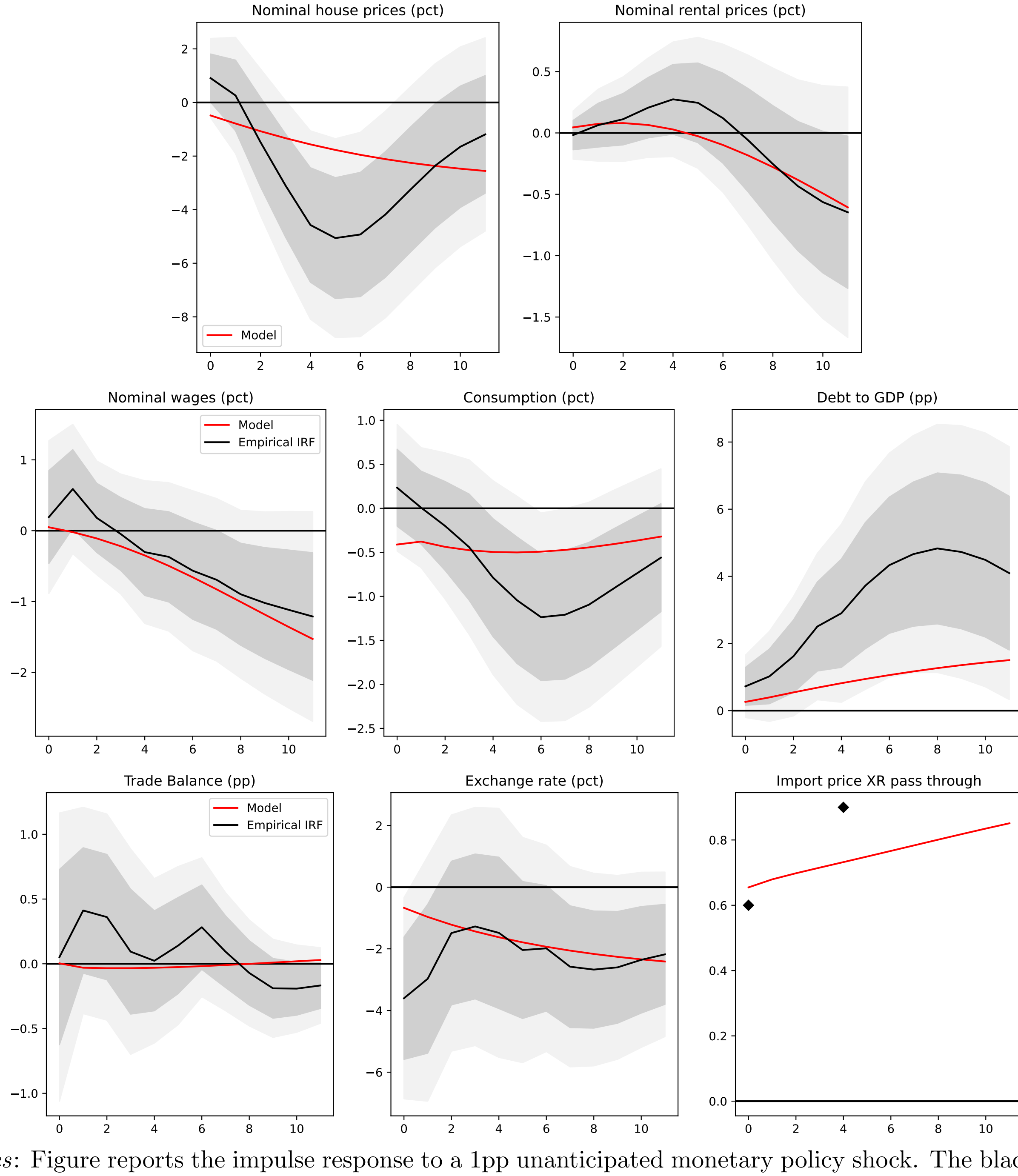
Figure B.2: Asset distribution



Notes: Figure reports the distribution of liquid assets in the model.

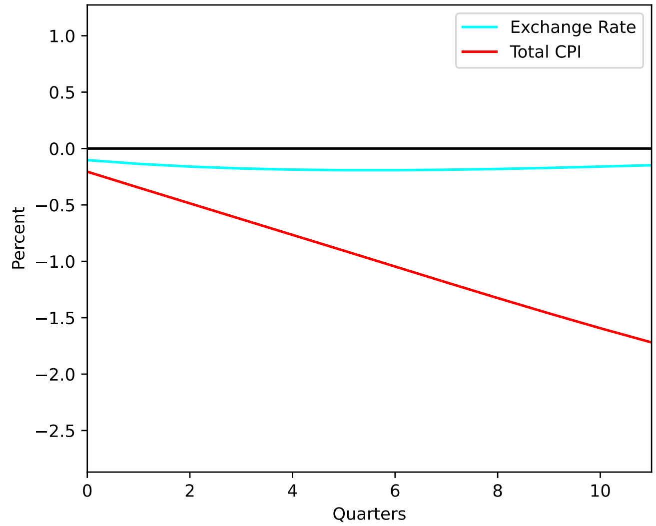
B.1 Model dynamics

Figure B.3: Impulse response to a monetary policy shock



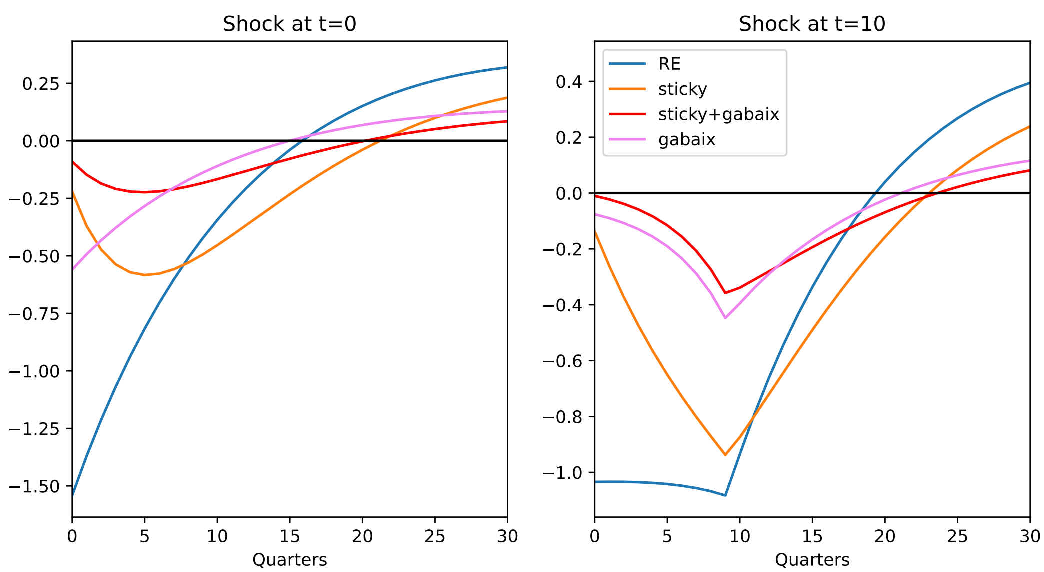
Notes: Figure reports the impulse response to a 1pp unanticipated monetary policy shock. The black line and shaded areas are the paths from the SVAR estimates averaged to a quarterly frequency. The shaded areas represent the 68% and 90% confidence intervals for the empirical responses.Import price exchange rate pass through is benchmarked against the evidence of Forbes et al. (2018) in black diamonds with 1.0 being full pass through from the exchange rate to import prices.

Figure B.4: Exchange rate channel in the CPI



Notes: Figure decomposes the impact of an unanticipated monetary policy shock on CPI into exchange rate and other channels.

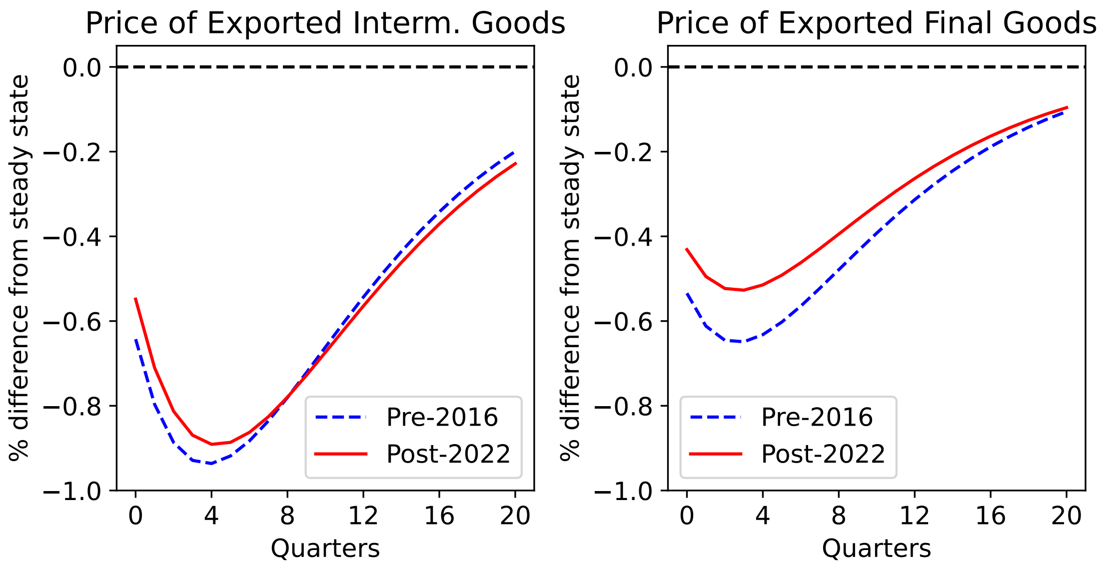
Figure B.5: Sticky expectations and cognitive discounting



Notes: Figure reports the consumption response to interest rate shocks under rational expectations, sticky expectations and sticky expectations augmented with a cognitive discount factor of 0.85. Impulse responses plotted for a shock at t=0 and a shock announced 20 quarters ahead.

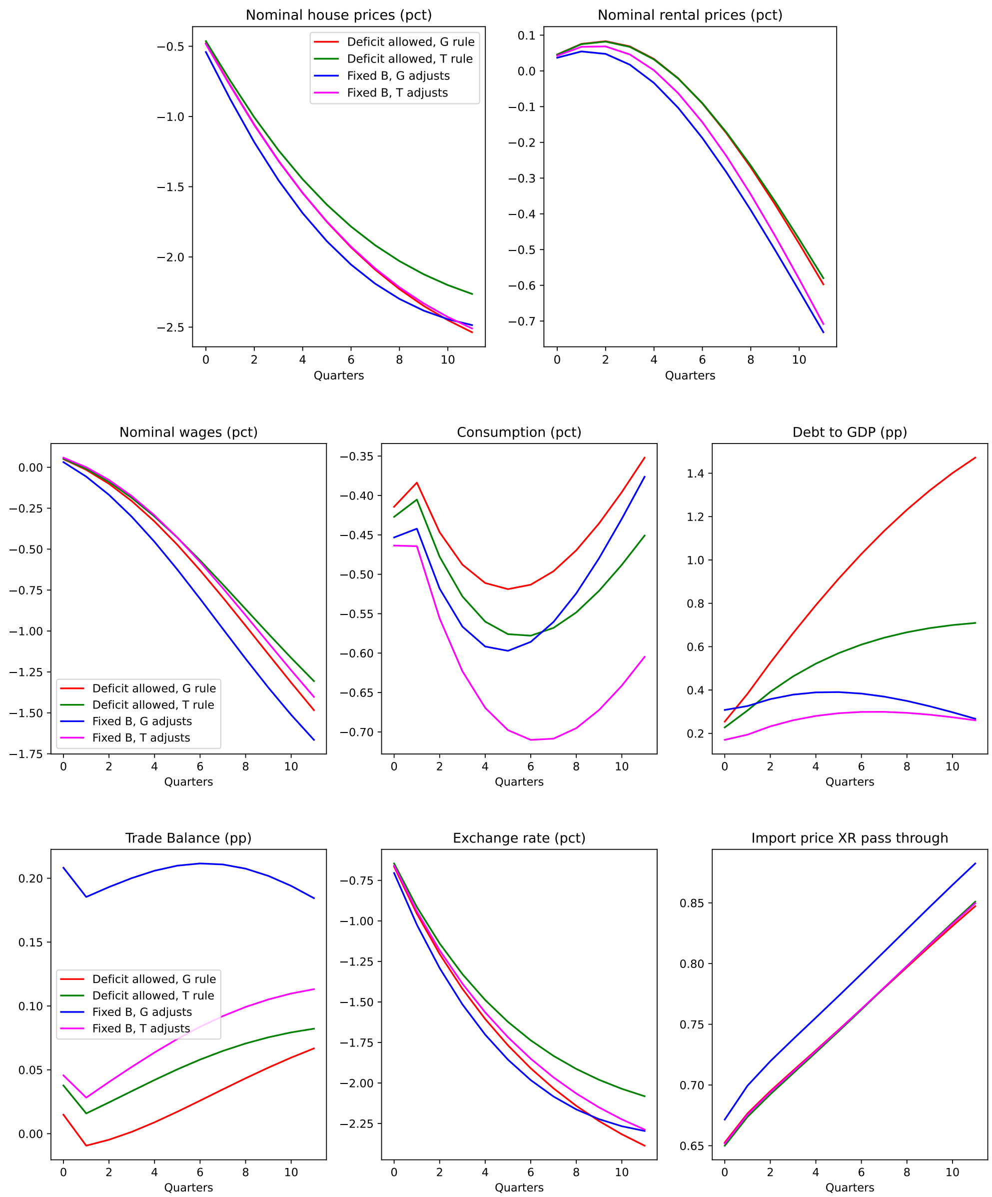
C Applications: Further Details

Figure C.6: International block application: export price responses



Notes: Impulse responses to a 1% sterling depreciation. Dashed blue lines represent the pre-2016 economy, solid red lines the post-2022 economy.

Figure C.7: Fiscal policy experiment: impulse responses of other variables



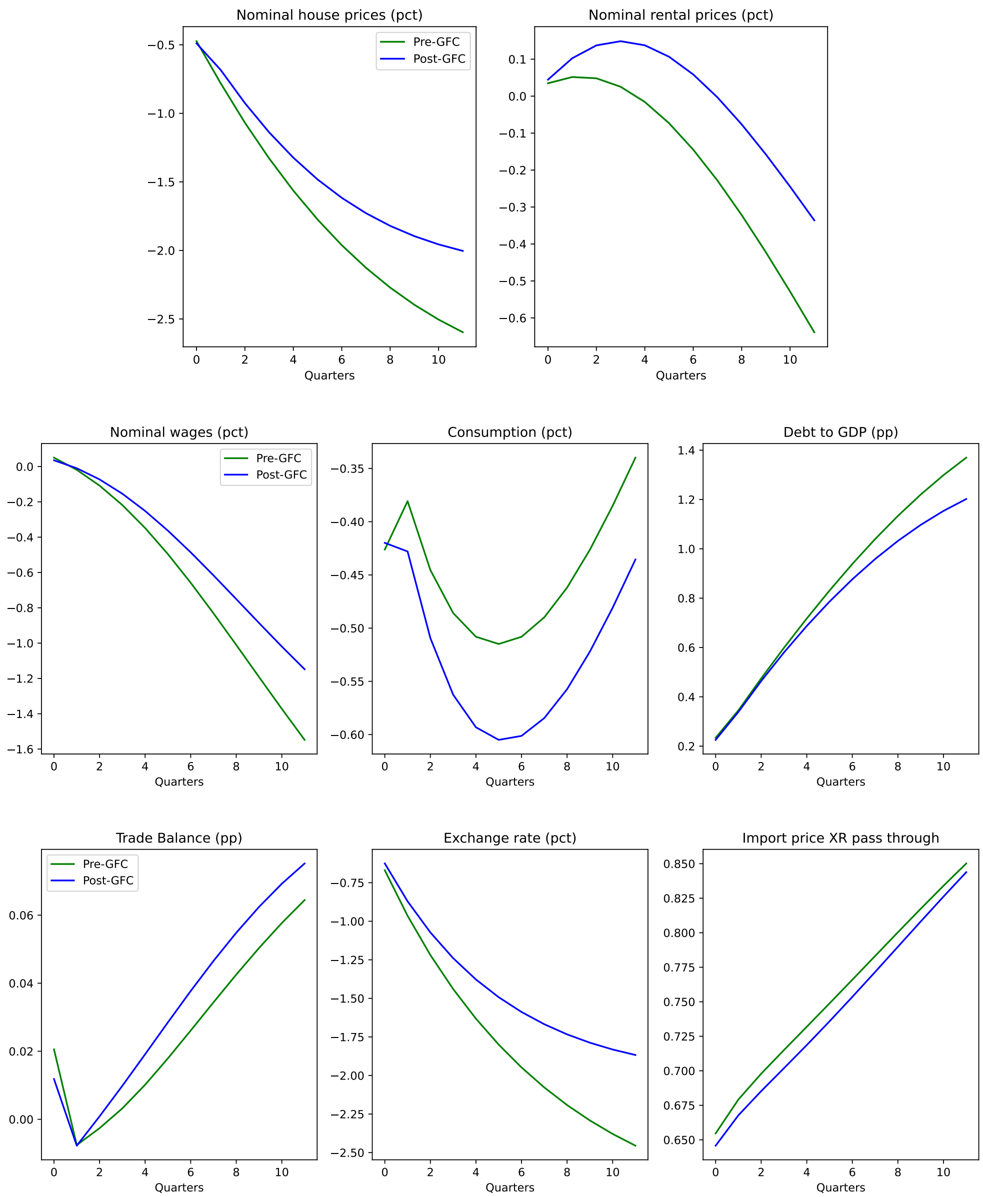
Notes: Figure reports the impulse response to a 1pp unanticipated monetary policy shock fixing the Bank Rate path to be the same as in Figure 2 across all cases using anticipated shocks.

Table C.2: Balance-sheet composition: calibrated parameters

Parameter	Description	Pre-GFC	Post-GFC	Base
	External calibration (when changed from base case)			
$\hat{L}_{ss}$	Steady-state NS&I holdings relative to quarterly GDP	29%	12%	24%
B^*_{ss}	Steady-state lending to RoW relative to quarterly GDP	-72%	2%	-54%
κ^*	Share of foreign ownership of B_{ss}	0.21	0.29	0.25
κ	Share of long-term debt swapped for reserves	0.00	0.22	0.13
δ	Share of long-term debt principal repaid quarterly	0.021	0.016	0.019
r^*	Steady-state real rate	2.82%	0.56%	1.76%
	Targets			
$A/4\widetilde{W}N$	Net liquid wealth-to-labour income	0.27	0.42	0.34
$\bar{H}P_H/4\widetilde{W}N$	Housing wealth-to-labour income	5.1	7.5	6.3
	Share of renters	0.30	0.37	0.33
	Share of homeowners with a mortgage	0.60	0.46	0.54
	Own to rent transition probability	1%	1%	1%
	Internal calibration (when changed from base case)			
β	Discount factor	0.987	0.993	0.990
P_H	House price	16.42	23.69	20.27
P_R	Rental price	0.17	0.08	0.15

Notes: We report the external calibration when it changes versus the baseline parameters reported in Table 2. While we only allow three parameters which are not related to abstract utility preferences to vary we can match the targets well, with the exception of the "Share of homeowners with a mortgage" which remains in the range $0.71 - 0.74$ as in the base case. The Pre-GFC and Base cases are seen to be closer in many parameters, which is reflected in the results of this experiment.

Figure C.8: Balance-sheet composition: impulse responses of other variables



Notes: Figure reports the impulse response to a 1pp unanticipated monetary policy shock.