Macro Technical Paper
A UK-HANK Model*

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Abstract

We develop a medium-scale HANK model tailored to the UK, including modelling rich fiscal, housing and international sectors. The model generates realistic wealth and income distributions as well as marginal propensities to consume consistent with UK evidence. We quantify and decompose monetary transmission in the model into key transmission channels to GDP that include: direct interest rate channels (55%), the exchange rate (15%), the housing market (15%), and further general equilibrium channels (15%). We demonstrate the model's versatility through several applications, including examining how house price changes affect consumption across housing tenure groups and analysing the effect of currency invoicing of exports on monetary transmission.

Keywords: Monetary policy, Housing, Heterogeneous agents
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1 Introduction

This document presents UK-HANK, a UK-focused Heterogenous Agent New Keynesian (HANK) model developed by Bank of England staff for scenario analysis of household sector dynamics and monetary policy counterfactuals.

The model's primary focus is the household sector. The labour income process is calibrated to closely match the historical labour income risk faced by UK households, and tax and benefit schedules replicate the degree of progressivity in place in the UK. The resulting income risk, combined with borrowing constraints for unsecured and secured debt, delivers a model with significant and realistic wealth inequality and intertemporal Marginal Propensities to Consume (iMPCs). A distinctive feature of UK-HANK is its treatment of secured borrowing against housing, which creates substantial negative financial wealth positions for some households. This generates heterogeneous exposure to interest rate changes across the wealth distribution, with important implications for aggregate consumption dynamics. We use the model to analyse monetary transmission and find that, at the peak response of GDP to a monetary policy shock, around 55% is explained by direct interest rate channels (cash-flow channel, intertemporal substitution and cost of capital), 15% by exchange rate channels, 15% by housing channels and a further 15% by broader general equilibrium channels.

To illustrate the model's wider applications, we perform four experiments connected to some of its key mechanisms. First, we demonstrate that declines in house prices produce heterogeneous consumption responses by tenure type: renters and mortgagors reduce spending both to climb the housing ladder and for precautionary savings reasons, while outright owners maintain stable consumption. Second, we find that the significant decline in sterling invoicing of UK exports since 2016 has only slightly weakened exchange rate pass-through, reducing the cumulative GDP impact of a sterling depreciation by approximately 7% and the cumulative inflation effect by 3% over three years. Third, monetary-fiscal interactions are quantitatively significant across fiscal policy rules, 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 households' balance-sheet developments since the Global Financial Crisis 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.

HANK models augment the established New Keynesian framework used to study monetary policy with a realistic distribution of agents over income and wealth. This wealth distribution arises endogenously because of idiosyncratic income risk and limits to risk sharing, such as borrowing constraints. Their distinct advantage lies in micro-foundations and assumptions that more closely resemble the real world, while still maintaining the broader macroeconomic features of previous modelling classes that successfully replicate business cycle dynamics. This proves particularly valuable when conducting counterfactual scenarios where there is a lack of data to externally validate the scenario. For example, the model has informed scenario simulations at the Bank of England, as discussed in the Monetary Policy Report (November 2025).

UK-HANK builds on the broader heterogeneous agent literature in general equilibrium, which started with Imrohoroğlu (1989) and Huggett (1993). During the 1990s, important advances include Aiyagari (1994), which combined heterogeneous agent models with the neoclassical supply side, and Krusell and Smith (1998), which introduced aggregate risk. 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—a result of realistic wealth distributions, borrowing constraints and uninsurable risk—fundamentally alters the transmission channel 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 (Auclert et al., 2021a; Bayer et al., 2024). As a result, HANK models are gaining traction as a policy tool among central banks globally (e.g., Bardóczy et al., 2024; Kase and Rigato, 2025).

Technically, UK-HANK follows the tradition of two-account HANK models (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 main decomposition, these elements jointly account for approximately 30% 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 labour income shocks, which leads to distributions for both labour income and wealth. Households' liquid savings are deposits at a financial intermediary, which pay a nominal interest. 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, including housing consumption services and secured borrowing subject to LTV and LTI constraints. In their housing tenure choice, households decide whether to be renters, flat owners or house owners, 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 as not to include individual private landlords. We also include deviations from rational expectations for both households and firms by incorporating sticky expectations (Auclert et al., 2020) and cognitive discounting (Gabaix, 2020; Pfäuti and Seyrich, 2022), as detailed below.

The financial intermediary uses the deposits from households to buy government debt and Central Bank reserves. Government debt is composed of a long-maturity nominal bond (modelled as in Andreolli, 2021), which matches the average maturity of UK government debt, and another one-period nominal bond that matches the value of National Savings and Investments (NS&I)

holdings. The government levies progressive taxes that are matched to the UK tax system and uses the taxes to fund government expenditures and transfers, and any deficit (surplus) is made up by increasing (reducing) the government debt. Furthermore, the Central Bank sets the interest rate and issues reserves to buy long-term government debt, effectively reducing its maturity.

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 Local Currency Pricing and Producer Currency Pricing.

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

Finally, we use P_t, the price level associated with non-housing aggregate consumption C_t, as the numeraire and all real prices, denoted by a tilde, are 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

Household $i \in [0, 1]$ chooses consumption $c_{i,t}$, savings $a_{i,t+1}$, and housing transition $h_{i,t+1}$. The household problem can be divided in two stages. In the first stage, idiosyncratic and aggregate shocks are realised, and households choose their housing tenure transition.[1] Households can be renters, owners of a flat or owners of a house, where houses have a bigger size than flats: $H_H > H_F$. 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 or save. 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.[2] Section 2.4 provides more details on the problem of the commercial rental sector.

Stage 1 At the beginning of Stage 1 in a given period households learn the 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 $\eta(h')$ and $V^{(2)}$ is the value function at the end of Stage 2, not including the utility costs $\varepsilon(h), \eta(h)$.

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

[1] Given budget and borrowing constraints are specific to each transition, it is more convenient to track the transition than the housing tenure. For example, households transition from a 'rent-rent' state in the prior period to 'rent-own flat' state in the current period as opposed to transitioning from a 'rent' state to an 'own flat' state.

[2] 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.

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 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 consume and save based on the budget and borrowing constraints dictated by that transition. Their problem is:

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

subject to

$$a_{i,t} + c_{i,t} + C_h(\tilde{P}_{O,t},\tilde{P}_{R,t},h') = \frac{1+i_{A,t-1}}{1+\pi_t}a_{i,t-1} + z(e_{i,t},\widetilde{W}_t,N_t,\tau_t,\tilde{B}_{G,t},div_t)$$

$$a_{i,t+1} \geqslant \underline{\text{a}}(h',\tilde{P}_{O,t},z_t(e_{i,t}))$$

where $i_{A,t}$ denotes the nominal interest rate promised from period t to period $t+1$, π_t is inflation, z_t denotes after-tax income (defined in more detail below) and labour productivity $e_{i,t} = e^P_{i,t} + e^T_{i,t}$ is composed of transitory and persistent terms. We denote labour disutility costs by $v(n)$, consumption of non-housing goods by $c_{i,t}$ and total expenditure on housing services by C_h. The borrowing limit is given by $\underline{\text{a}}(\cdot)$, 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 $\kappa_h\tilde{P}_O H$ and $\kappa_y z(\cdot)$, respectively, where $\tilde{P}_{O,t}$ is the price per size of housing. These limits only bind on a change of tenure, so in that sense mortgages are long term contracts.

The costs associated with each housing transition $C_h(\tilde{P}_{O,t},\tilde{P}_{R,t},h')$ (remember that $\tilde{P}_{R,t}$ are real rents) are shown in detail in Table 1, including the borrowing limit and the housing costs 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.

Table 1: Budget and borrowing constraints for each housing transition

Transition $h_- \to h$	$C_h(\cdot)$	$\underline{\text{a}}(\cdot)$
Own House - Own House	$-\delta_h H_H$	$\min\left[a_-, \max\left[-\kappa_h\tilde{P}_{O,t}H_H, -\kappa_y z_t(e)\right]\right]$
Own Flat - Rent	$\tilde{P}_{O,t}H_F - F - \tilde{P}_{R,t}H_F$	0
Rent - Own Flat	$-\tilde{P}_{O,t}H_F - F - \delta_h H_F$	$\max\left[-\kappa_h\tilde{P}_{O,t}H_F, -\kappa_y z_t(e))\right]$
Rent - Rent	$-\tilde{P}_{R,t}H_F$	0
Own House - Own Flat	$\tilde{P}_{O,t}(H_H - H_F) - 2F - \delta_h H_F$	$\max\left[-\kappa_h\tilde{P}_{O,t}H_F, -\kappa_y z_t(e)\right]$
Own Flat - Own House	$\tilde{P}_{O,t}(H_F - H_H) - 2F - \delta_h H_H$	$\max\left[-\kappa_h\tilde{P}_{O,t}H_H, -\kappa_y z_t(e)\right]$
Own Flat - Own Flat	$-\delta_h H_F$	$\min\left[a_-, \max\left[-\kappa_h\tilde{P}_{O,t}H_F, -\kappa_y z_t(e)\right]\right]$
Own House - Rent	$\tilde{P}_{O,t}H_H - F - \tilde{P}_{R,t}H_F$	0

We assume the utility function to be of the form

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

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 that the household is living in and if they are 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 above is a bundle on goods produced at home and abroad. In aggregate, let $C_{H,t}$ denote domestically produced goods consumed in the Home country, and $C_{F,t}$ denote goods produced abroad that are consumed domestically. We assume a CES aggregator

$$C_t = \left[\alpha_c^{1/\eta_c} C_{F,t}^{(\eta_c-1)/\eta_c} + (1-\alpha_c)^{1/\eta_c} C_{H,t}^{(\eta_c-1)/\eta_c}\right]^{\eta_c/(\eta_c-1)},$$

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

$$C_{H,t} = (1-\alpha_c)\left(\frac{P_{H,t}}{P_t}\right)^{-\eta_c} C_t,$$

$$C_{F,t} = \alpha_c \left(\frac{P_{F,t}}{P_t}\right)^{-\eta_c} C_t,$$

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

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

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). Household labour productivity $e_{i,t} = e_{i,t}^P + e_{i,t}^T$ is made of persistent ($e_{i,t}^P$) and transitory ($e_{i,t}^T$) components. The log of each of these components is a mean-reverting process that is subject to jump-shocks that arrive infrequently:

$$\log(e_{i,t}^P) = (1 - J_{i,t}^P)\rho^P \log(e_{i,t-1}^P) + J_{i,t}^P \epsilon_{i,t}^P,$$
$$\log(e_{i,t}^T) = (1 - J_{i,t}^T)\rho^T \log(e_{i,t-1}^T) + J_{i,t}^T \epsilon_{i,t}^T,$$

where $J_{i,t}^P = 1$ and $J_{i,t}^T = 1$ with probabilities λ^P and λ^T, respectively, and zero otherwise. The shocks $\epsilon_{i,t}^P, \epsilon_{i,t}^T$ are drawn from normal distributions with mean zero and variance σ_P^2 and σ_T^2.

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 ($J_{i,t}^s = 0$) the process reverts back to zero. But it can jump ($J_{i,t}^s = 1$) to a new value with probability λ^s. In our estimation, we have $\rho^P > \rho^T$ and find that permanent shocks arrive less frequently, or $\lambda^P < \lambda^T$. This specification allows us to match the overall distribution of annual labour earnings for the UK, and also moments of the changes in labour income for a given individual over time, such as volatility and kurtosis.

The cdf of the resulting distribution of $e_{i,t}$ is denoted by $\Phi_{i,t}$. 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:

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

which is able to match the progressivity of the tax and benefit system in the UK, and depends on a tax rate τ, aggregate benefit spend by the government G_B, the progressivity of the income tax λ, and the progressivity of the government benefit schedule $\lambda_{B,0}, \lambda_{B,1}$. 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 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" of shocks 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 is scaled down by a factor M^{CD}:

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

The adoption of this cognitive discounting helps to generate dampening of future shocks and offers a solution to the forward guidance puzzle (see Figure B.5 in Appendix B, with little evidence of such a powerful effect of forward guidance from the empirical literature).

Secondly, we 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:[3]

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

We implement these departures from rational expectations by manipulating the relevant Jacobians following Auclert et al. (2020).

2.3 Labour Unions

To allow for sticky wages we follow the literature (Auclert et al., 2021a) and introduce labour unions, who determine the labour supply from households and set the wages. There are $k \in [0,1]$

[3]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.

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 supply 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

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

We assume there are quadratic utility adjustment costs for adjusting 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.2) 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 $\pi_t^w = W_t / W_{t-1}$ 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, notice that 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 share of households that are renters, owners of flats and owners of houses, respectively. Equilibrium in the housing market is given by[4]

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

[4]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.

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.[5] This setup gives rise to a familiar Philips Curve type equation for rental inflation (see Appendix A.1 for details):

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

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

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

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

2.5 Firms

2.5.1 Final Good

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

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

where η_y is the elasticity of substitution between the two inputs and α_y is the steady-state share of foreign inputs. Let $P_{H,t}^X$ 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 $P_{H,t}$ are given by:

$$\begin{aligned} X_{H,t} &= (1 - \alpha_y) \left(\frac{P_{H,t}^X}{P_{H,t}}\right)^{-\eta_y} Y_t, \\ X_{F,t} &= \alpha_y \left(\frac{P_{F,t}^X}{P_{H,t}}\right)^{-\eta_y} Y_t, \\ P_{H,t} &= \left[\alpha_y \left(P_{F,t}^X\right)^{1-\eta_y} + (1 - \alpha_y) \left(P_{H,t}^X\right)^{1-\eta_y}\right]^{1/(1-\eta_y)}. \end{aligned}$$

[5] 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.

2.5.2 Intermediate Goods

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

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

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

$$x_{k,t} = X_t \left(\frac{P^X_{H,k,t}}{P^X_{H,t}} \right)^{-\eta_x} \tag{6}$$

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 then yields the familiar Phillips Curve (see appendix A.2) for intermediate goods inflation:

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

with real marginal cost defined by:

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

Total profits $t_{x,t}$ from the intermediate goods sector, including those from selling home intermediate goods abroad, is given by

$$\begin{aligned} P_t t_{x,t} &= P^X_{H,t} X_t - W_t N_t - P_t r_t^k K_{t-1} - (\varphi_x/2)(\pi^X_{H,t} - \overline{\pi})^2 X_t P_t + \left(\mathcal{E}_t P^{X,*}_{H,t} - P^X_{H,t} \right) X^*_{H,t} \\ &= X_t \left(P^X_{H,t} - MC_t - (\varphi_x/2)(\pi^X_{H,t} - \overline{\pi})^2 P_t \right) + \left(\mathcal{E}_t P^{X,*}_{H,t} - P^X_{H,t} \right) X^*_{H,t} \end{aligned} \tag{9}$$

where $X^*_{H,t}$ are home-produced intermediate goods used abroad, and $P^{X,*}_{H,t}$ is their price. The equality follows from PCP and from the solution to the $x(j)$ firms' problem.

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

$$K_t = K_{t-1}(1-\delta_K) + I_t\left(1 - S\left(\frac{I_t}{I_{t-1}}\right)\right) \tag{10}$$

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 (10). The FOCs for the problem are

$$q_t^K = \hat{\mathbb{E}}_t^f \left[\frac{r_{t+1}^K + q_{t+1}^K(1-\delta_K)}{1 + r_t^{ante}}\right] \tag{11}$$

$$1 = q_t^K\left(1 - S\left(\frac{I_t}{I_{t-1}}\right) - \frac{I_t}{I_{t-1}}S'\left(\frac{I_t}{I_{t-1}}\right)\right) + \hat{\mathbb{E}}_t^f\left[\frac{q_{t+1}^K}{1 + r_t^{ante}}\left(\frac{I_{t+1}}{I_t}\right)^2 S'\left(\frac{I_{t+1}}{I_t}\right)\right] \tag{12}$$

where q_t^K is the Lagrange multiplier associated with the constraint in Equation (10), i.e., it is the shadow value of capital. Equations (11) and (12) 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 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 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 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 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 coupon 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 (notice that we are not taking into account mark-to-market losses here) of the government as:

$$T_t + T_{cb,t} + L_t + \hat{L}_t = G_t + G_{B,t} + F_t, \tag{13}$$

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 is also an analogous $G_{H,t}$ and $G_{F,t}$, with government expenditures having the same price index P_t. The tax rate τ is defined by aggregate revenue requirements and the progressivity of the tax code λ:

$$\tau_t = \frac{\widetilde{W}_t N_t + div_t - T_t}{(\widetilde{W}_t N_t + div_t) \int e_{i,t}^{1-\lambda} di} \tag{14}$$

2.6.1 Fiscal Rules

We assume that in response to fluctuations the government responds by keeping constant the ratio of taxes to non-housing GDP and keeping constant aggregate benefits, while slowly adjusting consumption to stabilise government debt. This yields the following fiscal rules:

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

Overall this results in debt to GDP 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 (13) is always satisfied.

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: $\hat{M}_t = \kappa L_t$. 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).[6]

The CB's budget constraint is then:

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

[6]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.

In Appendix A.3.2 we show that this equation reduces to

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

which means that in the steady state $T_{cb} = 0$ since $i_{av} = i$. However, if a shock hits the economy, $T_{cb,t}$ can deviate from zero for many periods, while $i_{av,t} \neq i_{t-1}$.[7]

Finally, the central bank sets the short-term nominal rate according to a Taylor rule that responds smoothly to both inflation and output:

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

and allows for deviations from this rule through monetary policy socks $\epsilon_{r,t}$. The inflation rate that the Bank of England targets includes rental costs paid by renters, but not imputed costs to homeowners. 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 $\omega_{rent} = (P_R s_r H_F)/(P_C c + P_R s_r H_F)$ 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 $C_{H,t}^*$ with elasticity given by η_c^*:

$$C_{H,t}^* = \alpha_c \left(\frac{P_{H,t}^*}{P_t^*}\right)^{-\eta_c^*} C^*,$$

where $P_{H,t}^*$ 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 $X_{H,t}^*$ are given by:

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

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 steady-state level of domestic interest rates, $i_t^* = \bar{i}$, and that this is consistent with prices growing at the same rate of steady-state domestic inflation $\pi_t^* = \overline{\pi}^* = \overline{\pi}$. We assume that the home economy is small relative to the Rest of the World. Thus, foreign variables are independent of those from the home economy. For example, that was already reflected in the assumptions that

[7] 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 $t > \tau$.

foreign consumption C^* and output Y^* are constant. But that also means that CPI abroad is not affected by the price of home-produced goods: $P^*_{F,t} = P^*_t$.

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:

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

where $P^{*,LCP}_{F,t}$, $P^{X,*,LCP}_{F,t}$, 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.

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

$$P^*_{H,t} = \rho^X \frac{1}{\mathcal{E}_t} P_{H,t} + \left(1 - \rho^X\right) P^{LCP}_{H,t} \tag{16}$$
$$P^{X,*}_{H,t} = \rho^X \frac{1}{\mathcal{E}_t} P^X_{H,t} + \left(1 - \rho^X\right) P^{X,LCP}_{H,t}. \tag{17}$$

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.[8]

The rest of the world buys a constant share κ^* of the domestic long-term government debt on the secondary market. In any period, the rest of the world holds

$$\sum_{j=0}^{\infty} q^j_t B^{j,*}_{F,t} = \sum_{j=0}^{\infty} q^j_t \kappa^* B^j_t = \kappa^* q_{av,t} B_t$$

Given its portfolio, and similarly to domestic financial intermediaries, the rest of the world's profits/losses on the domestic government debt portfolio is (in units of the domestic final good)

$$T^*_\tau = \frac{\kappa^* q_{av,\tau-1} B_{\tau-1}}{1+\pi_\tau} \left(\frac{i_{L,\tau}+1}{i_{L,\tau}+\delta} - \frac{i_{\tau-1}+1}{i_{L,\tau-1}+\delta} \right) (i_{L,\tau-1}+\delta)$$

Finally, the rest of the world issues 1-period foreign bonds B^*_t (denominated in real terms, with the foreign consumption good as a numeraire) that pay a nominal interest rate i^*_t in the foreign

[8]See Appendix A.9 for the profit-maximisation problem of intermediate goods exporters under LCP, and the corresponding LCP intermediates export price Phillips curve.

currency. They can be negative, which would mean the home country borrowing 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).

2.8 Financial Intermediaries

Intermediaries buy short $\hat{L}_{m,t}$ and long government debt $\{B^j_{m,t}\}_{j=0}^{\infty}$ in the secondary market as well as M_t reserves from the Central Bank. They sell deposits A_t to the households and also pay dividends $T_{m,t}$ to them. Moreover, they can buy foreign bonds B^*_t.

Recall that q^j_t is the price of a bond at time t if it was issued j periods ago, with $q^0_t = 1$. Let $B^j_{m,t}$ denote the holdings by financial intermediaries at time t of long-term bonds issued j periods ago. The budget constraint is:

$$T_{m,t} + \sum_{j=0}^{\infty} q^j_t B^j_{m,t} + \frac{1+i_{A,t-1}}{1+\pi_t} A_{t-1} + M_t + \hat{L}_{m,t} + Q_t B^*_t = \tag{18}$$

$$\sum_{j=1}^{\infty}[(1-\delta)q^j_t + i_{L,t-j} + \delta]\frac{B^j_{m,t-1}}{1+\pi_t} + A_t + \frac{1+i_{t-1}}{1+\pi_t} M_{t-1} + \frac{1+i_{t-1}}{1+\pi_t}\hat{L}_{m,t-1} + \frac{1+i^*_{t-1}}{1+\pi^*_t} Q_t B^*_{t-1}$$

The intermediaries maximise:

$$\max \sum_{t=0}^{\infty}\left(\prod_{k=0}^{t}\frac{1}{1+r^{ante}_{k-1}}\right) T_{t,m}$$

subject to the flow budget constraint and the law of motion for capital in Equations (18) and (10), discounting dividends at the real expected rate (and $r^{ante}_{-1} = 0$). The FOCs with respect to M_t, A_t, $B^j_{m,t}$ and B^*_t are:

$$\begin{aligned}
1 + i_t &= \hat{\mathbb{E}}^f_t\left[(1+\pi_{t+1})(1+r^{ante}_t)\right] \\
i_t &= i_{A,t}, \\
q^j_t &= \frac{(1-\delta)q^j_{t+1} + i_{L,t-j} + \delta}{1+i_t} \\
1 + i_t &= (1+i^*_t)\hat{\mathbb{E}}^f_t\left[\frac{\mathcal{E}_{t+1}}{\mathcal{E}_t}\right]
\end{aligned} \tag{19}$$

where we had already imposed from the beginning that the return on short term bonds must equal to i_t in equilibrium. The 3$^{\text{rd}}$ equation in (19) is the Uncovered Interest Rate Parity (UIP) condition.

We assume that the private banks 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:

$$\sum_{j=0}^{\infty} q^j_t B^j_{m,t} + M_t + \hat{L}_{m,t} + Q_t B^*_t = A_t. \tag{20}$$

and profits/losses are defined as:

$$T_m = \frac{1}{1+\pi_t}\left(\frac{i_{L,t}+1}{i_{L,t}+\delta} - \hat{\mathbb{E}}^f_{t-1}\left[\frac{i_{L,t}+1}{i_{L,t}+\delta}\right]\right)(i_{L,t-1}+\delta)(1-\kappa-\kappa^*)q_{av,t-1}B_{t-1} \quad (21)$$
$$+ B^*_{t-1}\frac{(1+i^*_{t-1})}{1+\pi_t}\left(Q_t\frac{(1+\pi_t)}{1+\pi^*_t} - \hat{\mathbb{E}}^f_{t-1}\left[Q_t\frac{(1+\pi_t)}{1+\pi^*_t}\right]\right).$$

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 pounds depreciates) the intermediary makes unexpected profits if the home country is a net creditor ($B^*_t > 0$).

2.9 Market Clearing

In equilibrium the endogenous demand for assets, goods and housing must equal the supply of those objects. Net financial wealth demand must equal asset supply composed of long and short term government debt, central bank reserves and foreign assets. Demand and supply for final goods and intermediate goods must balance. And the GDP identity must hold.

Assets

$$A_t = \sum_{j=0}^{\infty} q^j_t B^j_{m,t} + M_t + \hat{L}_t + Q_t B^*_t \quad (22)$$
$$= (1-\kappa-\kappa^*)q_{av,t}B_t + \kappa B_t + \hat{L}_t + Q_t B^*_t.$$

Short term government debt

$$\hat{L}_t = \hat{L}_{m,t}. \quad (23)$$

Long term government debt

$$(1-\delta)^j L_{t-j} = B^j_{m,t} + \kappa(1-\delta)^j L_{t-j} + \kappa^*(1-\delta)^j L_{t-j}. \quad (24)$$

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

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

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

$$Y_t = C_{H,t} + G_{H,t} + C^*_{H,t} + DWL_{H,t} + I_{H,t}. \quad (25)$$

Intermediate goods

$$X_t = X_{H,t} + X^*_{H,t}. \quad (26)$$

Housing and rental markets As in Equations (3) and (4).

Resource Constraint

$$X_t\widetilde{P}^X_{H,t} = C_t + G_t + I_t + (exports_t - imports_t) + DWL_t \tag{27}$$

where

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

We can also express the trade balance in terms of net foreign income and saving.

$$\begin{aligned} imports_t - exports_t = \Big[(1+r^*_t)B^*_{t-1}Q_t - Q_tB^*_t\Big] + \Big[\kappa^*B_t - \frac{\kappa^*B_{t-1}}{1+\pi_t}(1+i_{av,t-1})\Big] \\ + \Big[\Big(Q_t\widetilde{P}^{X,*}_{H,t} - \widetilde{P}^X_{H,t}\Big)X^*_{H,t}\Big] \end{aligned} \tag{28}$$

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 the imputed rent method by calculating housing consumption according to the following formula:

$$C_{housing,t} = \overline{H}\tilde{P}_{R,t} \tag{29}$$

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

$$C_{tot,t} = C_t + C_{housing,t} \tag{30}$$

$$GDP_t = X_t + \frac{C_{housing,t}}{\widetilde{P}^X_{H,t}} \tag{31}$$

3 Model Calibration and Solution Method

Our model solution strategy follows Auclert et al. (2021a) by representing the model in the sequence space and solving for the models dynamics as a local approximation around the model's non-linear steady state. We calibrate the model's 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 the change 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). 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 to 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 imports 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. 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. Mortgage 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 steady state interest rate. 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. 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	7.281	Labour disutility scale	Normalised labour supply = 1/3
T_{ss}	23.4%	Steady-state tax to GDP ratio	Income tax rate (ONS, 2001-2023)
G_B	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	
η_x	5.45	Goods demand elasticity	Pure profit share = 18%
α_k	0.16	Capital elasticity	Labour share = 68%
		Financial Markets and Wealth	
π^*	0.5%	Steady-state inflation target	Annual inflation target = 2%
B_{ss}	158%	Steady-state government debt relative to *quarterly* GDP	Together with $\hat{L}_{ss}$, ratio of net liquid wealth to avg. *annual* labour income = 34% (WAS & ONS)
$\hat{L}_{ss}$	22%	Steady-state NS&I holdings relative to *quarterly* GDP	See B_{ss}
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 (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
$\bar{r}$	1.25%	Mortgage spread	2y 75% LTV mortgage minus 2y gilt (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	Annual $r = 1.76\%$ (Davis et al., 2024)
P_O	20.24	House price	Housing wealth-to-income ratio = 6.3 (ONS, 1997-2023)
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	0.26	Utility cost of moving	Own-to-rent transition probability = 1% (EHS)

Note: This table presents the calibration of the parameters that affect the steady state of the model. 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

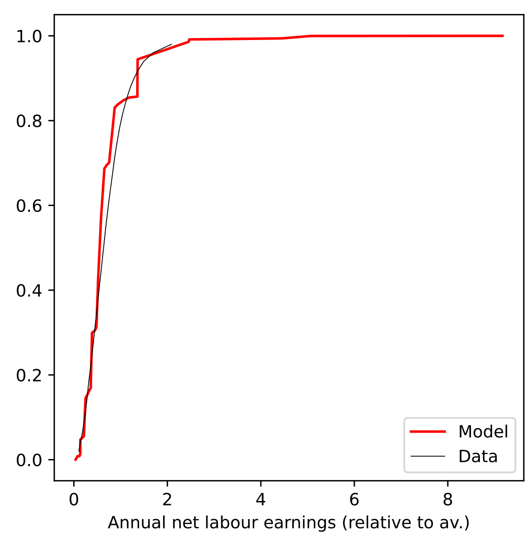
The household income process is estimated using data from the Annual Survey of Hours and Earnings (ASHE), which underpins many official UK wage statistics. ASHE is a 1% sample of all UK employees structured as a panel dataset. Following Kaplan et al. (2018), we set the earnings process parameters listed 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.[9]

Table 3: Income process

Parameter	Value	Description
		Estimated externally
p_T	14%	Arrival rate of transitory shock
ρ_T	0.495	Persistence of transitory shock
σ_T	0.464	Standard deviation of transitory shock
p_P	1.1%	Arrival rate 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.

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 that 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

[9]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.

the distribution for labour income is less unequal than that of wealth, but it is well known that Aiygari-type models struggle to generate a distribution for 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 shr.	12%	18%
Financial Wealth < 0	50%	50%
Bottom 50 Shr.	15%	6%
Top 10 Shr.	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
		IRF matching
$1-\gamma$	12%	Household's probability of updating
$1-\gamma_f$	15%	Firm's probability of updating
ϕ_T	0.027	Fiscal adjustment speed
φ_x	59.6	Scale of price adjustment cost
φ_r	163.82	Scale of rental price adjustment cost
φ_w	386	Scale of wage adjustment cost
ρ_i	0.97	Inertia coefficient on the Taylor rule
ϕ_π	1.33	Inflation coefficient on the Taylor rule
ϕ_y	0.06	Output gap coefficient on the Taylor rule
ρ_m	0.50	Final goods price pass through
ρ_x	0.56	Foreign goods price pass through
φ_i	19.92	Scale of investment adjustment cost

Notes: These parameters are estimated to minimise the inverse variance weighted distance from the models 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.

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

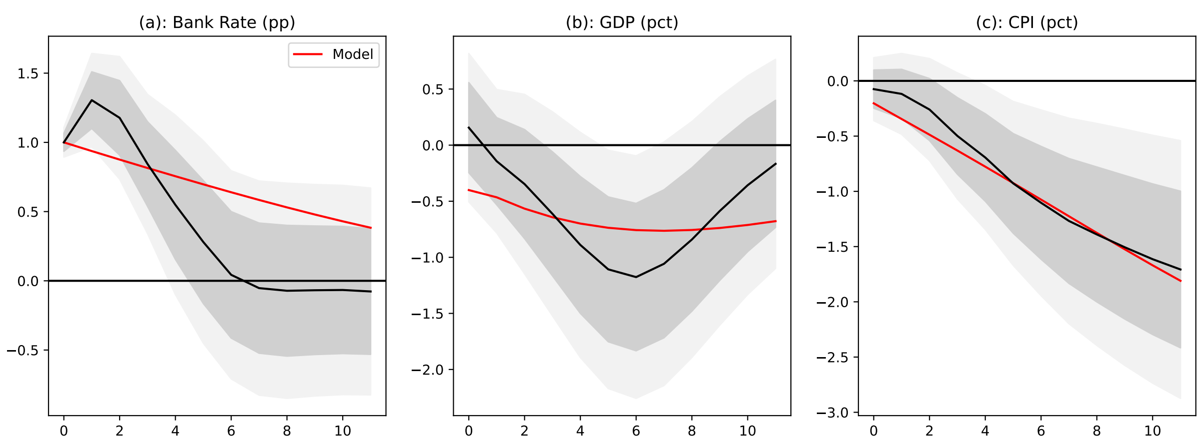
$$MIN_{\theta_{IRF}}(Y(\theta_{IRF})-\dot{Y})^T W(Y(\theta_{IRF})-\dot{Y})$$

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 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 it 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 hump-shaped responses of many IRFs, 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 update probabilities for households vs non-households agents. The model calls for a high degree of stickiness for households in line with that of Auclert et al. (2020), and also for firms. Firms being only slightly more attentive than households which is surprising at face value but 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 1p.p. 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: 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. 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 it to a broader selection of estimates published in the academic literature. Table 6 reports a selection of estimates and the simple average over those estimates relative to the UK-HANK model. We see the GDP responses for the UK HANK model are quite close to the average over these studies. The CPI response, while in line with the numbers from Albuquerque et al. (2025b), are around 50 percent higher than the average from the literature.

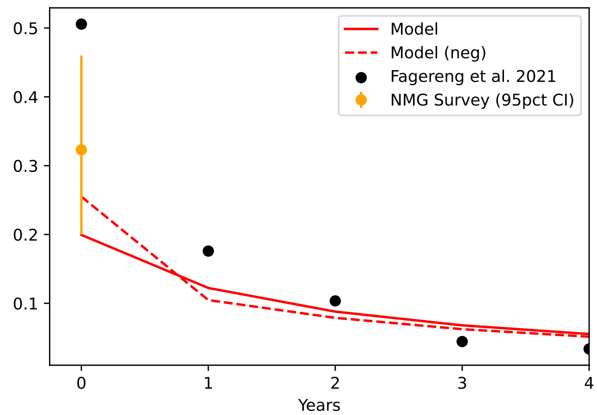
Table 6: Empirical evidence on the effect of monetary policy

Source	GDP Effect		CPI Effect	
	(pp, 4th qtr)	(pp, peak)	(pp, 4th qtr)	(pp, peak)
Albuquerque et al. (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	-0.67	-0.93	-0.37	-1.0
UK-HANK	-0.64	-0.76	-0.63	-1.66

Note: Results from Cloyne and Hürtgen (2016) based on quarterly VAR. 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.

Finally, we assess how the marginal propensities to consume in the model look relative 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. We are comfortable with this particularly in light of recent work that pushes back on the plausibility of such high MPC estimates in the broader literature (e.g., see Borusyak et al., 2024; Orchard et al., 2025).

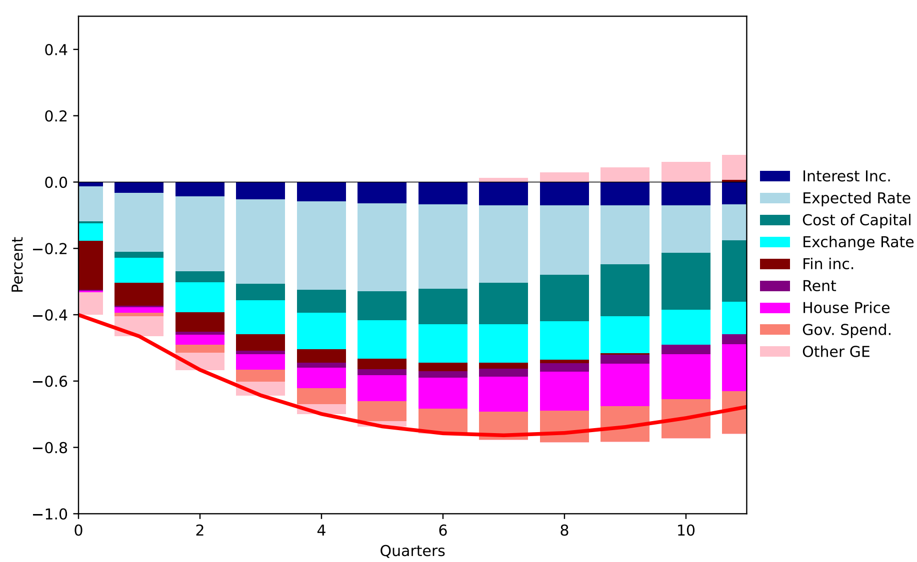
Figure 3: iMPCs



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 the values reported in the Household NMG 2012-2014 survey waves based on responses to questions on temporary income surprises experienced by households also used by Bunn et al. (2018). In addition, we plot the corresponding response in the model to a negative income shock of the same magnitude.

4 Monetary Transmission Mechanism

Figure 4: Transmission Channels



Notes: this figure decomposes the impact of an unanticipated monetary policy shock on GDP into partial equilibrium channels and a general equilibrium effect.

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 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.

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. For example, the house price effect (pink) captures how consumption responds to the house price decline induced by the rate rise, abstracting from all other price adjustments.

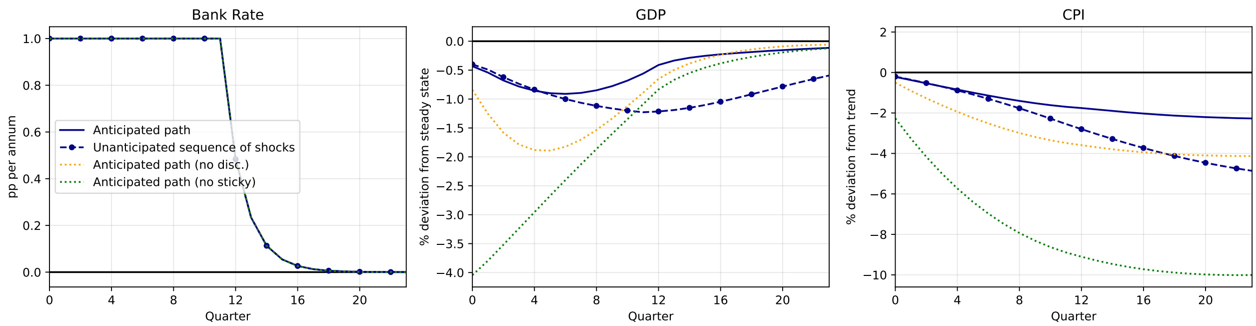
Starting with the direct channels, one can see that the expected rate channel, which captures intertemporal substitution (higher rates incentivize saving and debt reduction), remains the largest single channel. However, in this HANK setting it is far from the dominant force it would be in a representative 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 effect on debtors and savers almost cancels out – indebted households have higher marginal propensities to consume and end up depressing spending.

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. Fourth, government spending falls according to our fiscal rules, which has an important effect specially in the later part of the response. Finally, other GE effects from lower wages, hours worked, reduce GDP initially, but increase it in the longer run. Interestingly, wage effects have a smaller impact in our setting than in Kaplan et al. (2018).

At the peak GDP decline (quarter 6), the direct channels (interest income, expected rate, and cost of capital) account for 55% of transmission; the exchange rate contributes 15%; housing channels 15%; and other channels 15%. This breakdown aligns well with bottom-up quantitative decompositions such as Slacalek et al. (2020). Since prices are deep general equilibrium objects, we 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 1pp 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 where as discounting shortens the planning window of agents.[10]

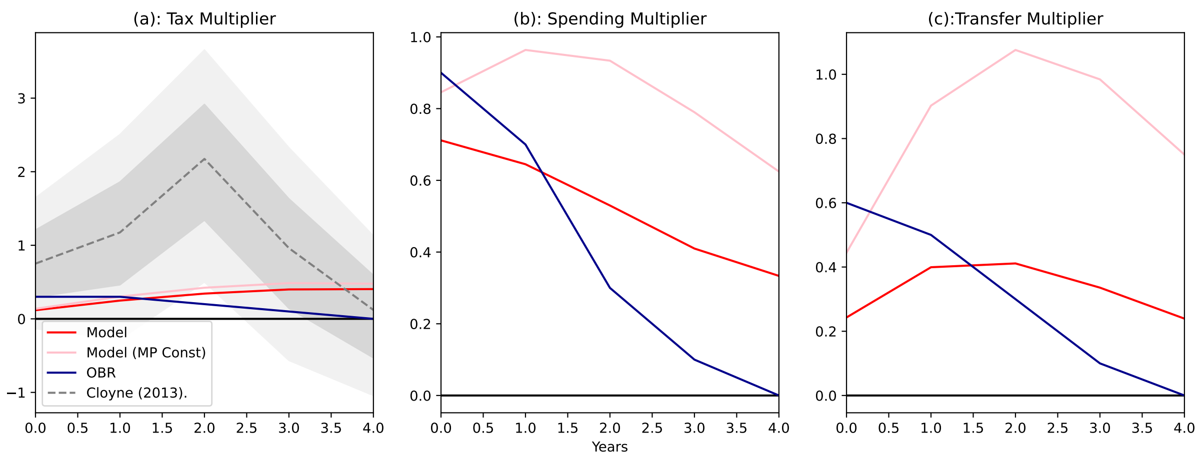
Figure 5 illustrates this by plotting the response of GDP and the CPI price level to an interest rate path that raises the policy rate by 1 percentage point for three years before returning it quickly and smoothly to zero. The solid line depicts the response when this interest rate sequence is pre-announced 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 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

[10]Figure B.5 illustrates these different effects.

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.[11]

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 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 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. The model responses in red are compared against the standard multipliers embedded in the Office of Budget Responsibilities (OBR) forecasts, and 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. 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. The model responses are similar in magnitude to the OBR multipliers, which also include the endogenous effects of monetary policy.

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

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.[12] 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.

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 question is then to examine the cross-sectional consumption impact of house price changes 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 1% at their peak, which leads to a peak fall in consumption of around 0.3%, or a 0.3 elasticity. But what are the drivers? To help us investigate that, Panel (b) shows the breaks down the response of consumption for different groups of households.

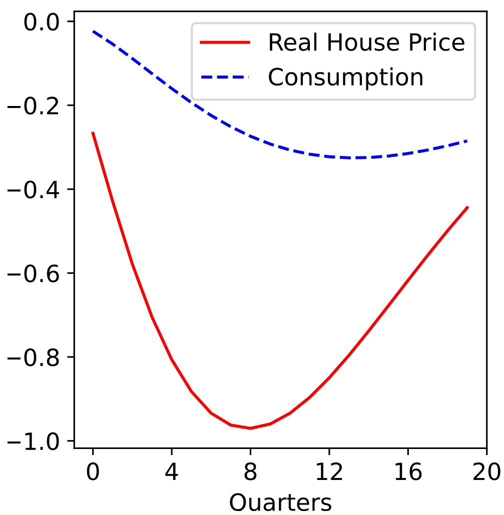
We define groups based on the combination of housing and net financial wealth: *renters* (no housing wealth), *mortgagors* (positive housing wealth and negative net financial wealth), and *outright owners* (positive housing wealth and positive net financial wealth). Given all households' policy functions along the house price path, we can show the consumption response of a panel of households conditional on their group as of $t = 0$ and relative to the counterfactual where their consumption would have evolved according to the steady-state policies.

As panel (b) shows, consumption responses differ markedly across household types. Renters (green) reduce consumption to get on the housing ladder now that properties are cheaper, though they must save more to accumulate the required down payment. 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 LTVs tighten. Outright owners (cyan), generally wealthy and positioned at the top of the housing ladder, can ride out the temporary price decline with negligible consumption adjustment.[13]

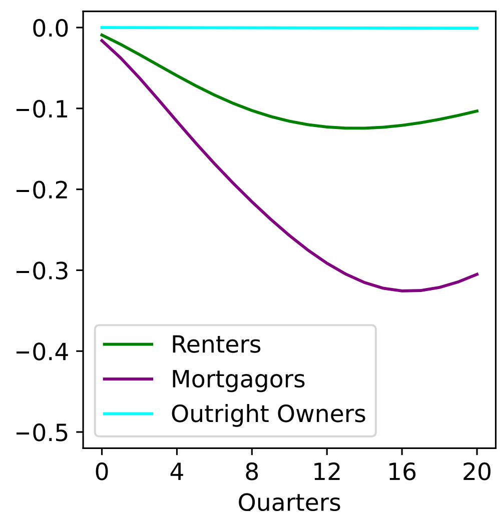
[12] This is consistent with evidence in the US from documented by Bouscasse and Hong (2023).

[13] 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 (the largest property size in the model), with the remaining share downsizing to flats or transitioning to renting due to taste and income shocks. This share will tend to shrink as house prices fall, since households would incur

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) decomposes the consumption response across household types: 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 specification the parameter ρ^X in Equation (16) can be thought of as the share of sterling-denominated exports. 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.[14]

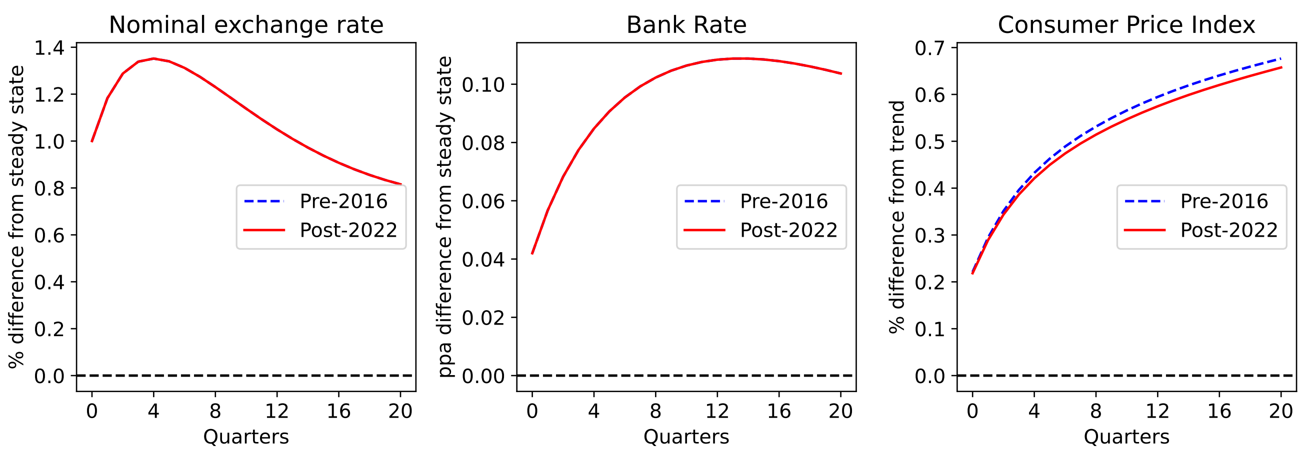
Figure 8 presents the dynamic responses to a 1% sterling depreciation in the pre-2016 economy — modelled as a wedge in the UIP condition with mean reversion at rate 0.9. To ensure comparability, we impose the same exchange rate and Bank Rate paths from the pre-2016 economy onto the post-2022 economy using anticipated shocks. Panel (a) shows the paths for nominal variables,

losses on such transactions. 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.

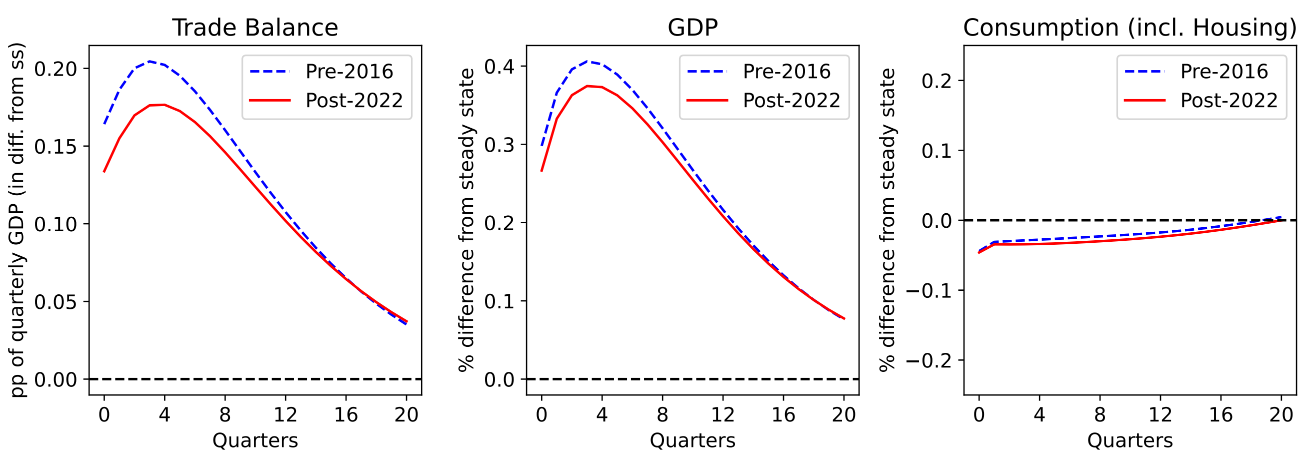
[14]We construct these economies by rescaling the baseline value of ρ^X (0.56, estimated by IRF matching) using the ratio of sterling-denominated export shares of goods for 2015 and 2022 relative to the full sample average (1993-2023). This yields $\rho^X = 0.56 \times 1.03 = 0.57$ for the pre-2016 economy 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.

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 7% lower than in the pre-2016 economy. The cumulative inflation effect is reduced by approximately 3% at the three-year mark. 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.[15]

Figure 8: Impulse Responses to a 1% Sterling Depreciation



(a) Nominal variables



(b) Real variables

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.

[15]The response of non-durable consumption to the depreciation is negligible over the simulation period. The small decline in total consumption visible in Figure 8 reflects the fall in real imputed rents.

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: incomplete markets, which effectively shortens the planning horizon of households close to the borrowing constraint, and 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 the fiscal policy between taxes and debt movements. Moreover, government spending policies can have a bigger impact since households do not fully take into account future tax movements needed to balance it. However, as shown in Figure 3, 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 rules following an unanticipated monetary policy shock.

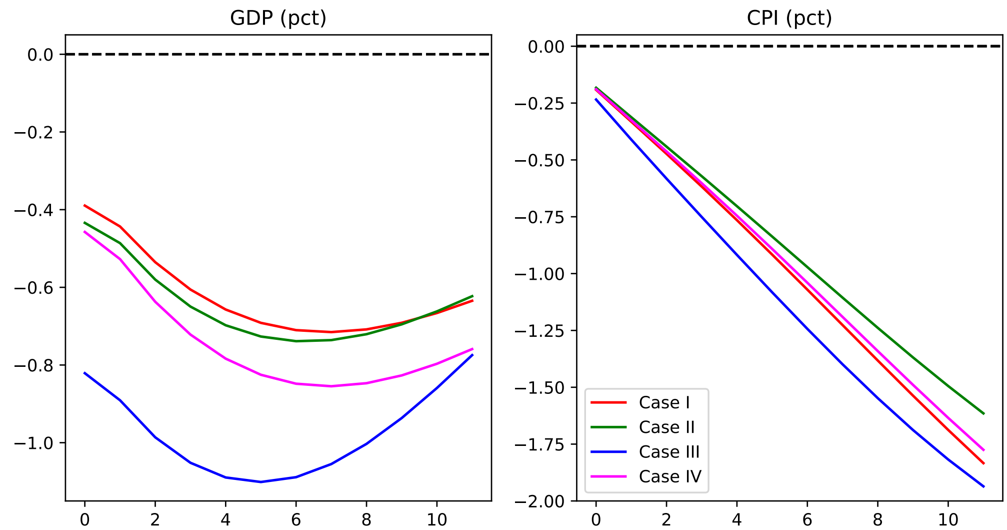
The baseline fiscal block (Section 2.6.1) assumes that the government keeps the tax ratio to (non-housing) GDP and aggregate benefit spending constant while gradually adjusting consumption expenditure to stabilise government debt:

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

For this experiment, we define four cases, noting that outside of the fiscal block the model and parametrisation remain the same. **Case I** uses the baseline rules above. **Case II** reverses the roles of T and G, that is, the government keeps the spending-to-GDP ratio fixed. Cases III and IV hold real debt constant (balanced budget) at B_{ss} by instantly adjusting G in **Case III** (holding the tax ratio constant) or T in **Case IV** (holding the G-to-GDP ratio constant). Therefore, for Cases III and IV

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

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



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 rules 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, Case I here) onto the other cases using anticipated shocks.

Case III shows the largest GDP response: when government spending adjusts fully to satisfy the budget constraint, the same monetary contraction generates a cumulative impact on GDP that is 57% larger and a cumulative inflation response that is 6% 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 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 Case III across the remaining fiscal rules, but divergences between cases remain substantial: over the first three years, the cumulative impact on GDP in Case IV is 20% larger, and the cumulative inflation response for Case II 12% lower, than Case I (the base case).

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

5.4 Balance-Sheet Composition: Long-run Changes to the Monetary Transmission Mechanism Pre- and Post-GFC

The UK economy experienced significant changes in household and public sector balance sheets around the 2008 Global Financial Crisis. Before the GFC, households held low net liquid wealth and housing wealth relative to labour income, government debt-to-GDP was low, and central bank reserves were small in the absence of large-scale asset purchases. Instead, Post-GFC, net liquid wealth-to-income, housing wealth-to-income, debt-to-GDP and central bank reserves all increased substantially.

We use the model to examine changes in the monetary transmission mechanism (MTM) between two steady states representing the pre- and post-GFC UK economy. The pre-GFC steady state uses averages over 1993–2007, while the post-GFC steady state uses averages over 2016–2019, the period in-between considered 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 Appendix C.[16]

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 26% smaller. Various mechanisms drive the inflation effect. 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. Additionally, overall higher rental price inflation and weaker sterling appreciation in the post-GFC case partially offset deflationary pressures, reducing the overall inflation response.[17] 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.

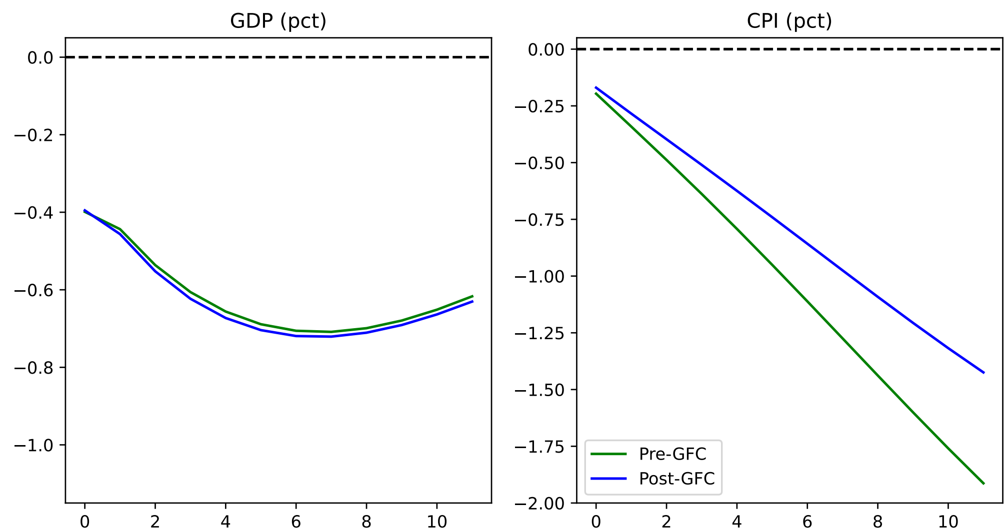
Panel (b) of Figure 10 decomposes the difference in GDP responses between the two periods, revealing that the small aggregate difference masks substantial offsetting forces, whose magnitude ranges up to about 9% of the total GDP response. Intertemporal consumption substitution generates the largest positive 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.

[16] 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.

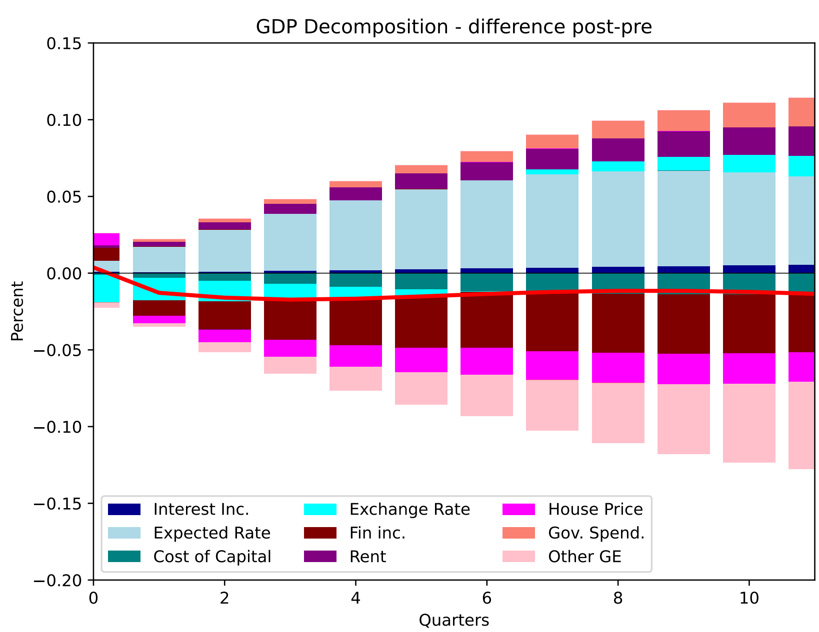
[17] The CPI includes nominal rental costs. As Figure C.8 (Appendix C) shows, the post-GFC period exhibits a larger initial rise in nominal rents and a smaller subsequent decline. These rent dynamics, combined with the exchange rate response, also contribute to the more muted price level decline in the 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. The black line and shaded areas are the paths from the SVAR estimates averaged to a quarterly frequency, as in the base case, to guide the eye. See Appendix C Figure C.8 for further variables.

(a) Impulse Responses to a Monetary Policy Shock in the Pre- and Post-GFC States



(b) Decomposition of GDP Response Difference: Post-GFC vs. Pre-GFC

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 conducting Bayesian estimation to provide a fuller description of the business cycle and assess parameter uncertainty, 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.

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A Detailed calculations

A.1 Commerical 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.[18] 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

$$H_{R,k,t} = H_{R,t} \left(\frac{P_{R,k,t}}{P_{R,t}} \right)^{-\eta_r} \tag{32}$$

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

$$\max_{\{P_{R,k,t+j}\}_{j=0}^{\infty}} \hat{\mathbb{E}}_t^f \left[\sum_{j=0}^{\infty} \prod_{\tau=0}^{j} \frac{1}{1+r_{t+\tau-1}^{ante}} \left\{ H_{R,k,t+j} \left(\frac{P_{R,k,t}}{P_{t+j}} - \delta_H \right) - \frac{\varphi_r}{2} \left(\frac{P_{R,k,t+j}}{P_{R,k,t+j-1}} - (1+\overline{\pi}) \right)^2 \mathbb{Y}_{t+j} \right.\right. \tag{33}$$

$$\left.\left. - F_R + \frac{P_{O,t+j}}{P_{t+j}} \left(H_{R,k,t+j-1} - H_{R,k,t+j} \right) \right\} \right], \text{ subject to Equation (32)}$$

where $r_{-1}^{ante} = 0$ and F_R are fixed costs to running a commercial firm.[19] 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

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

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

$$\begin{aligned}
\tilde{P}_{O,t} =& \left(\frac{\eta_r - 1}{\eta_r} \right) \tilde{P}_{R,t} - \delta_H + \hat{\mathbb{E}}_t^f \left[\frac{\tilde{P}_{O,t+1}}{1+r_t^{ante}} \right] \\
&+ \frac{\varphi_r}{\eta_r} \left((\pi_{R,t} - \overline{\pi})(1+\pi_{R,t}) - \hat{\mathbb{E}}_t^f \left[\frac{(\pi_{R,t+1} - \overline{\pi})(1+\pi_{R,t+1})}{1+r_t^{ante}} \frac{H_{R,t+1}}{H_{R,t}} \right] \right)
\end{aligned} \tag{34}$$

[18] 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.

[19] Above, we assumed that the depreciation cost grows in line with the the price index P_t. Adjustment costs are usually assumed to grow in line with total output but above we have kept it still general as $\mathbb{Y}_t$. Assuming that $\mathbb{Y}_t = H_{R,t}$, i.e., that adjustment costs move in line with total rental sector output, simplifies the calculations.

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 $\tilde{P}_{O,t} - \hat{\mathbb{E}}_t^f[\tilde{P}_{O,t+1}/(1 + r_t^{ante})]$ also appears because housing is a durable good. The firm uses the r_t^{ante} real interest rate to discount future profits, which is given by the Fisher equation (and derived as an optimality condition of the Financial Intermediaries in Equation (19))

$$1 + r_t^{ante} = \hat{\mathbb{E}}_t^f \left[\frac{1 + i_t}{1 + \pi_{t+1}} \right] \tag{35}$$

Notice that we made it explicit that the real interest-rate is an ex-ante, expected rate. However, assets in the economy promise nominal returns, so if shocks hit the economy and inflation is different than expected, then the ex-post real interest rate can differ from the ex-ante one, which leads to Fisher effects.

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

$$t_{R,t} = H_{R,t}(\tilde{P}_{R,t} - \delta_H) - (\varphi_r/2)(\pi_{R,t} - \bar{\pi})^2 H_{R,t} + \tilde{P}_{O,t}(H_{R,t-1} - H_{R,t}) - F_R \tag{36}$$

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.2 Phillips Curves

A.2.1 Wages

To allow for sticky wages we follow the literature (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 supply. The labour supply from unions then gets packaged into total labour supply N_t, which is hired by firms:

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

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

$$N_{k,t} = N_t \left(\frac{W_{k,t}}{W_t} \right)^{-\eta_w} \tag{37}$$

We assume there are quadratic utility adjustment costs for adjusting 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

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

subject to the demand in Equation (1), and where $v(n)$ denotes the disutility from labour.[20] Auclert et al. (2024b) show that:

$$\frac{\partial c_{i,t}}{\partial W_{k,t}} = \frac{\partial z_{i,t}}{\partial W_{k,t}} \text{ , and } \frac{\partial n_{i,t}}{\partial W_{k,t}} = -\eta_w \frac{\partial N_{k,t}}{\partial W_{k,t}}, \tag{38}$$

where

$$\frac{\partial z_{i,t}}{\partial W_{k,t}} = (1-\lambda)\tau_t \left(\frac{W_{k,t}}{P_t} e_{i,t} N_{k,t}\right)^{-\lambda} \frac{e_{i,t}}{P_t} N_{k,t}(1-\eta_w) \tag{39}$$

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

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

where Z_t is the aggregate after-tax labour income

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

Noting that $n_{i,t} = N_t$ and rearranging the FOC we get the wage Phillips curve

$$(\pi_t^w - \overline{\pi})(1+\pi_t^w) = \frac{\eta_w}{\varphi_w} \left\{ v'(N_t)N_t - (1-\lambda) Z_t \frac{(\eta_w - 1)}{\eta_w} u'(C_t^*) \right\} + \beta \hat{\mathbb{E}}_t^f \left[(\pi_{t+1}^w - \overline{\pi})(1+\pi_{t+1}^w) \right] \tag{40}$$

where

$$u'(C_t^*) = \int_0^1 u'(c_{i,t}, h_{i,t}) \frac{e_{i,t}^{1-\lambda}}{\int e_{i,t}^{1-\lambda} di} di$$

Finally, we define

$$v(N) = \zeta \frac{N^{1+\nu}}{1+\nu} \tag{41}$$

A.2.2 Intermediate goods prices

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.

[20] 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 costs here is an utility cost.

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

$$\frac{\widetilde{W} n}{r^k k} = \frac{1-\alpha_k}{\alpha_k} \tag{42}$$

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

$$\widetilde{MC} = \frac{1}{\Omega} \left(\frac{r^k}{\alpha_k} \right)^{\alpha_k} \left(\frac{\widetilde{W}}{1-\alpha_k} \right)^{1-\alpha_k} \tag{43}$$

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

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

subject to Equations (6) and (43). Noting that $x_{k,t} = X_{H,t}$ and $P^X_{H,k,t} = P^X_{H,t}$ in equilibrium, the FOC of the problem above can be re-arranged into the price Phillips Curve

$$(\pi^X_{H,t} - \overline{\pi})(1+\pi^X_{H,t}) = \frac{(1-\eta_x)}{\varphi_x} \tilde{P}^X_{H,t} + \frac{\eta_x}{\varphi_x} \widetilde{MC}_t + \hat{\mathbb{E}}^f_t \left[\frac{(\pi^X_{H,t+1} - \overline{\pi})(1+\pi^X_{H,t+1})}{1+r^{ante}_t} \frac{X_{t+1}}{X_t} \right] \tag{44}$$

where $\pi^X_{H,t} = P^X_{H,t} / P^X_{H,t-1}$ 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: $\int k_{k,t} dk = K_{t-1}$.[21] Total output is then

$$X_t = \Omega_t K^{\alpha_k}_{t-1} N^{1-\alpha_k}_t \tag{45}$$

Total profits $t_{x,t}$ from the intermediate goods sector, including those from selling home intermediate goods abroad, is given by

$$\begin{aligned} P_t t_{x,t} &= P^X_{H,t} X_t - W_t N_t - P_t r^k_t K_{t-1} - (\varphi_x/2)(\pi^X_{H,t} - \overline{\pi})^2 X_t P_t + \left(\mathcal{E}_t P^{X,*}_{H,t} - P^X_{H,t} \right) X^*_{H,t} \\ &= X_t \left(P^X_{H,t} - MC_t - (\varphi_x/2)(\pi^X_{H,t} - \overline{\pi})^2 P_t \right) + \left(\mathcal{E}_t P^{X,*}_{H,t} - P^X_{H,t} \right) X^*_{H,t} \end{aligned} \tag{46}$$

where $X^*_{H,t}$ are home-produced intermediate goods used abroad, and $P^{X,*}_{H,t}$ is their price. The equality follows from PCP and from the solution to the $x(j)$ firms' problem. In Equation (46), the

[21] Notice that Equation (42) in aggregate is $r^k_t = \widetilde{W}_t N_t \alpha_K / (K_{t-1}(1-\alpha_K))$

term $X_t(P^H_{X,t} - \widetilde{MC}_t)$ is the aggregate over the profits of the (j) firms, which we assume that only sell into domestic markets at price $P^X_{H,t}$, and do not take into account the share of intermediate goods that ends up abroad. We then implicitly assume that there is an aggregator which splits X_t between $X_{H,t}$ and $X^*_{H,t}$ and sells each share to the domestic/foreign markets. They sell $X_{H,t}$ at price $P^H_{X,t}$ under fully flexible prices and then make no profits, and the term $\left(\mathcal{E}_t P^{X,*}_{H,t} - P^X_{H,t}\right) X^*_{H,t}$ represents profits with respect to selling a share to foreign markets.

A.3 Government

The government issues nominal bonds each period, both long and short-term ones. 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 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 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 $(i_{L,t}+\delta)(1-\delta)^{k-1}$. The law of motion for real long-term government debt B_t is then given by:

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

Given the geometric structure of the debt, these government bonds carry an average net coupon rate that evolves slowly over time:

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

Notice that in steady-state we have $i_{av} = i_L$. It is useful to define the average market price of government debt as well: $q_{av,t}\tilde{B}_t = \sum_{j=0}^{\infty}(1-\delta)^j \tilde{L}_{t-j} q^j_t$, where $\tilde{B}_t$ and $\tilde{L}_t$ are the nominal counterparts of B_t, L_t, and q^j_t is the price of a bond issued j periods ago. Then one can show that (details in Appendix A.7):

$$q_{av,t} = \frac{i_{av,t}+\delta}{i_{L,t}+\delta}. \tag{47}$$

Let $T_{cb,t}$ denote net transfers from the Central Bank to the treasury. Then the interest and coupon payments on all bonds that are due at time t are given by

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

Then we can express the flow budget constraint (notice that we are not taking into account mark-to-market losses here) of the government as:

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

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

$$\tau_t = \frac{\widetilde{W}_t N_t + div_t - T_t}{(\widetilde{W}_t N_t + div_t)\int e^{1-\lambda}_{i,t} di} \tag{48}$$

A.3.1 Fiscal Rules

We assume that in response to fluctuations the government responds by keeping the tax ratio to non-housing GDP constant, aggregate benefit spending constant, while slowly adjusting consumption to stabilise debt to GDP. This yields the following fiscal rule:

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

Overall this results in debt to GDP 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 A.3 is always satisfied.

A.3.2 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:

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

The CB does not buy or sell government bonds otherwise. Its budget constraint is:

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

where we have used the fact that the CB will always hold a fraction κ of all the bonds issued by the government, and with the same duration of the government debt, so it gets $i_{av,t}$ in net coupon payments. Notice that because the law of motion for reserves and government debt are the same and we have $\widehat{M}t = \kappa L_t$, then $M_t = \kappa B_t$. Also, in the steady-state we have $i = i_{av}$. Then:

$$
\begin{aligned}
T_{cb}(1+\pi) + (i+\delta)\kappa B &= (i+\delta)\kappa B \\
&\rightarrow T_{cb} = 0.
\end{aligned}
$$

However, outside of the steady state we have:

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

so that if a shock hits the economy, $T_{cb,t}$ can deviate from zero for many periods, while $i_{av,t} \neq i_{t-1}$.[22]

[22] 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 $t > \tau$.

Finally, the central bank sets the short-rate nominal rate according to a Taylor rule that smoohtly responds to both inflation and output gap. The Central Bank does not target inflation π_t as defined by P_t. The CPI for the inflation rate that the Bank of England targets includes rents cost paid by renters (although it does not include imputed costs to homeowners, which is given by the separate index CPIH in the UK). Let $\pi_t^{cpi} = P_t^{cpi}/P_{t-1}^{cpi} - 1$ be the inflation rate that the central bank targets, and the price level be given by

$$P_t^{cpi} = P_t(1 - \omega_{rent}) + P_{R,t}\omega_{rent}, \tag{49}$$

where $\omega_{rent} = \frac{P_R s_r H_F}{P_C c + P_R s_r H_F}$ is the share of total consumption spent on rental services in the steady state. Thus, the Taylor rule is given by

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

and allows for deviations from this rule through monetary policy socks $\epsilon_{r,t}$.

A.4 Rest of the World

The rest of the world imports and exports goods from the home country, issues foreign bonds (or debt) and buys domestic long-term government debt, but with the assumption that the home economy is small relative to the rest of the world. The rest of the world imports goods produced in the home country $C_{H,t}^*$ with elasticity given by η_c^*:

$$C_{H,t}^* = \alpha_c \left(\frac{P_{H,t}^*}{P_t^*} \right)^{-\eta_c^*} C^*,$$

where $P_{H,t}^*$ 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 $X_{H,t}^*$ are given by:

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

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 steady-state level of domestic interest rates, $i_t^* = \bar{i}$, and that this is consistent with prices growing at the same rate of steady-state domestic inflation $\pi_t^* = \overline{\pi}^* = \overline{\pi}$:

$$P_t^* = (1+\overline{\pi})P_{t-1}^*.$$

The assumption that the home economy is small is reflected in the fact that CPI abroad is not affected by the price of home-produced goods: $P_{F,t}^* = P_t^*$.

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 (e.g. Forbes et al. (2018)) we adopt the following rules for the pricing of the home economy's imported final and intermediate goods:

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

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.

The prices of UK final and intermediate goods exports to the rest of the world follow similar rules:

$$P_{H,t}^* = \rho^X \frac{1}{\mathcal{E}_t} P_{H,t}^{PCP} + \left(1-\rho^X\right) P_{H,t}^{LCP} \tag{50}$$
$$P_{H,t}^{X,*} = \rho^X \frac{1}{\mathcal{E}_t} P_{H,t}^{X,PCP} + \left(1-\rho^X\right) P_{H,t}^{X,LCP}. \tag{51}$$

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.[23]

The rest of the world buys a constant share κ^* of the domestic long-term government debt on the secondary market. In any period, the rest of the world holds

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

Given its portfolio, and similarly to domestic financial intermediaries, the rest of the world's profits/losses on the domestic government debt portfolio is (in units of the domestic final good)

$$T_\tau^* = \frac{\kappa^* q_{av,\tau-1} B_{\tau-1}}{1+\pi_\tau} \left(\frac{i_{L,\tau}+1}{i_{L,\tau}+\delta} - \frac{i_{\tau-1}+1}{i_{L,\tau-1}+\delta} \right) \left(i_{L,\tau-1}+\delta\right)$$

For convenience of notation we define

$$T_{cg,\tau} = T_{m,\tau} + T_\tau^*$$

where $T_{cg,\tau}$ are total capital gains/losses on the assets of the economy.

Finally, the rest of the world issues 1-period foreign bonds B_t^* (denominated in real terms, with the foreign consumption good as a numeraire) that pay a nominal interest rate i_t^* in the foreign currency. They can be negative, which would mean the home country borrowing 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).

[23]See Appendix A.9 for the profit-maximisation problem of intermediate goods exporters under LCP, and the corresponding LCP intermediates export price Phillips curve.

A.5 Financial Intermediaries

Intermediaries buy short $\hat{L}_{m,t}$ and long government debt $\{B^j_{m,t}\}_{j=0}^{\infty}$ in the secondary market as well as M_t reserves from the Central Bank. They sell deposits A_t to the households and also pay dividends $T_{m,t}$ to them. Moreover, they can buy foreign bonds B^*_t.

Recalling q^j_t as the price of a bond at time t if it was issued j periods ago, with $q^0_t = 1$. Let $B^j_{m,t}$ denote the holdings by financial intermediaries at time t of long-term bonds issued j periods ago. The budget constraint is:

$$
\begin{aligned}
&T_{m,t} + \sum_{j=0}^{\infty} q^j_t B^j_{m,t} + \frac{1+i_{A,t-1}}{1+\pi_t} A_{t-1} + M_t + \hat{L}_{m,t} + Q_t B^*_t = \\
&\sum_{j=1}^{\infty} [(1-\delta) q^j_t + i_{L,t-j} + \delta] \frac{B^j_{m,t-1}}{1+\pi_t} + A_t + \frac{1+i_{t-1}}{1+\pi_t} M_{t-1} + \frac{1+i_{t-1}}{1+\pi_t} \hat{L}_{m,t-1} + \frac{1+i^*_{t-1}}{1+\pi^*_t} Q_t B^*_{t-1}
\end{aligned}
\tag{52}
$$

The intermediaries maximise:

$$
\max \sum_{t=0}^{\infty} \left(\prod_{k=0}^{t} \frac{1}{1+r^{ante}_{k-1}} \right) T_{t,m}
$$

subject to the flow budget constraint and the law of motion for capital in Equations (52) and (10), discounting dividends at the real expected rate (and $r^{ante}_{-1} = 0$). The FOCs with respect to M_t, A_t, $B^j_{m,t}$ and B^*_t are:

$$
\begin{aligned}
1 + i_t &= \hat{\mathbb{E}}^f_t \left[(1+\pi_{t+1})(1+r^{ante}_t) \right] \\
i_t &= i_{A,t}, \\
q^j_t &= \frac{(1-\delta) q^j_{t+1} + i_{L,t-j} + \delta}{1+i_t} \\
1 + i_t &= (1+i^*_t) \hat{\mathbb{E}}^f_t \left[\frac{\mathcal{E}_{t+1}}{\mathcal{E}_t} \right]
\end{aligned}
\tag{53}
$$

where we had already imposed from the beginning that the return on short term bonds must equal to i_t in equilibrium. The 3$^{\text{rd}}$ equation in (53) is the Uncovered Interest Rate Parity (UIP) condition.[24] The equation for q^j_t in Equation (19) be written in terms of interest rates only (details in Appendix A.6):

$$
\frac{1+i_t}{1+i_{L,t+1}} = \frac{i_{L,t} + \delta}{i_{L,t+1} + \delta},
\tag{54}
$$

We assume that the private banks 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:

$$
\sum_{j=0}^{\infty} q^j_t B^j_{m,t} + M_t + \hat{L}_{m,t} + Q_t B^*_t = A_t.
\tag{55}
$$

and profits/losses are defined as :

[24] Which is equal to $1 + r^{ante}_t = (1 + r^{ante,*}_t) \mathbb{E}_t [Q_{t+1}/Q_t]$ in real terms.

$$T_m = \frac{1}{1+\pi_t}\left(\frac{i_{L,t}+1}{i_{L,t}+\delta} - \hat{\mathbb{E}}^f_{t-1}\left[\frac{i_{L,t}+1}{i_{L,t}+\delta}\right]\right)(i_{L,t-1}+\delta)(1-\kappa-\kappa^*)q_{av,t-1}B_{t-1} \tag{56}$$
$$+ B^*_{t-1}\frac{(1+i^*_{t-1})}{1+\pi_t}\left(Q_t\frac{(1+\pi_t)}{1+\pi^*_t} - \hat{\mathbb{E}}^f_{t-1}\left[Q_t\frac{(1+\pi_t)}{1+\pi^*_t}\right]\right).$$

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 pounds depreciates) the intermediary makes unexpected profits if the home country is a net creditor ($B^*_t > 0$).

A.6 Private banks' FOC

Taking the equation for q^j_t in Equation (53) for $j = 0$ we have:

$$q^0_t = \frac{i_{L,t}+\delta}{1+i_t} + \frac{(1-\delta)q^0_{t+1}}{1+i_t},$$

which can be written recursively as:

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

The above implies that

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

and shifting 1 period forward

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

Combining the last 2 equations yields

$$\frac{q^0_t}{i_{L,t}+\delta} = \frac{1}{1+i_t} + \frac{1-\delta}{1+i_t}\frac{q^{-1}_{t+1}}{i_{L,t+1}+\delta}$$

Since $q^0_t = q^{-1}_{t+1} = 1$,[25]

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

which is Equation 54.

Now taking the equation for q^j_t in Equation (53) for $j > 0$ we have the analogous recursion:

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

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

thus we can equate

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

which we will use in Appendix A.8.

A.7 Average price of debt

From our definition

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

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 nominal terms. 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.

$$q_{av,t} = \frac{i_{av,t}+\delta}{i_{L,t}+\delta}, \tag{57}$$

which is Equation (47).

A.8 Private bank transfers

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

$$
\begin{aligned}
&(1+\pi_t)T_{m,t} = \\
&\sum_{j=1}^{\infty}[(1-\delta)q_t^j + i_{L,t-j}+\delta]B^j_{m,t-1} - (1+i_{t-1})(A_{t-1}-M_{t-1}-\hat{L}_{t-1}) + (1+\pi_t)\frac{(1+i^*_{t-1})}{1+\pi^*_t}Q_t B^*_{t-1} \\
&= \sum_{j=1}^{\infty}\left[(1-\delta)\frac{q_t^j}{q^j_{t-1}} + \frac{i_{L,t-j}+\delta}{q^j_{t-1}}\right] q^j_{t-1}B^j_{m,t-1} \\
&\qquad - (1+i_{t-1})(A_{t-1}-M_{t-1}-\hat{L}_{t-1}) + (1+\pi_t)\frac{(1+i^*_{t-1})}{1+\pi^*_t}Q_t B^*_{t-1} \\
&= \sum_{j=1}^{\infty}\left[(1-\delta)\frac{i_{L,t-1}+\delta}{i_{L,t}+\delta} + i_{L,t-1}+\delta\right] q^j_{t-1}B^j_{m,t-1} \\
&\qquad - (1+i_{t-1})(A_{t-1}-M_{t-1}-\hat{L}_{t-1}) + (1+\pi_t)\frac{(1+i^*_{t-1})}{1+\pi^*_t}Q_t B^*_{t-1} \\
&= \left[(1-\delta)\frac{i_{L,t-1}+\delta}{i_{L,t}+\delta} + i_{L,t-1}+\delta\right] \sum_{j=1}^{\infty} q^j_{t-1}B^j_{m,t-1} \\
&\qquad - (1+i_{t-1})(A_{t-1}-M_{t-1}-\hat{L}_{t-1}) + (1+\pi_t)\frac{(1+i^*_{t-1})}{1+\pi^*_t}Q_t B^*_{t-1} \\
&= \left[(1-\delta)\frac{i_{L,t-1}+\delta}{i_{L,t}+\delta} + i_{L,t-1}+\delta\right] (A_{t-1}-M_{t-1}-\hat{L}_{t-1}-Q_{t-1}B^*_{t-1}) \\
&\qquad - (1+i_{t-1})(A_{t-1}-M_{t-1}-\hat{L}_{t-1}) + (1+\pi_t)\frac{(1+i^*_{t-1})}{1+\pi^*_t}Q_t B^*_{t-1} \\
&= \left[(1-\delta)\frac{i_{L,t-1}+\delta}{i_{L,t}+\delta} + i_{L,t-1}+\delta - (1+i_{t-1})\right] (A_{t-1}-M_{t-1}-\hat{L}_{t-1}-Q_{t-1}B^*_{t-1}) \\
&\qquad - (1+i_{t-1})Q_{t-1}B^*_{t-1} + (1+\pi_t)\frac{(1+i^*_{t-1})}{1+\pi^*_t}Q_t B^*_{t-1}
\end{aligned}
$$

From the market clearing for long bonds and for assets in Equations (24) and (22), together with the definition for $q_{av,t}$ in Equation (47) we have:

$$
A_t = (1-\kappa-\kappa^*)q_{av,t}B_t + M_t + \hat{L}_t + Q_t B^*_t. \tag{58}
$$

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:

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

In either case, with Equation (54) 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).

A.9 Intermediate Export 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.

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

subject to

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

where real marginal costs are defined as in Equation (43).

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

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

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

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

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

$$X^{*,LCP}_{H,t} = \alpha_y \left(\tilde{P}^{X,*,LCP}_{H,t} \right)^{-\eta^*_y} Y^*.$$

A.10 Equilibrium Equations

The equilibrium of the model is defined by 70 equations in 70 endogenous aggregate variables.

$$C_{H,t} = (1-\alpha_c)\tilde{P}_{H,t}^{-\eta_c} C_t, \tag{E.1}$$
$$C_{F,t} = \alpha_c \tilde{P}_{F,t}^{-\eta_c} C_t, \tag{E.2}$$
$$C_{H,t}^{*} = \alpha_c \left(\tilde{P}_{H,t}^{*}\right)^{-\eta_c^{*}} C^{*}, \tag{E.3}$$
$$\tilde{P}_{H,t} = \left(\frac{1-\alpha_c \tilde{P}_{F,t}^{1-\eta_c}}{1-\alpha_c}\right)^{1/(1-\eta_c)}, \tag{E.4}$$
$$G_{F,t} = \alpha_c \tilde{P}_{F,t}^{-\eta_c} G_t, \tag{E.5}$$
$$G_{H,t} = (1-\alpha_c)\tilde{P}_{H,t}^{-\eta_c} G_t, \tag{E.6}$$
$$\tilde{P}_{F,t} = \rho^{M} Q_t \tilde{P}_{F,t}^{*} + (1-\rho^{M})\tilde{P}_{F,t}^{*}, \tag{E.7}$$
$$\tilde{P}_{F,t}^{*} = 1, \tag{E.8}$$
$$\tilde{P}_{H,t}^{*} = \rho^{X} \tilde{P}_{H,t}/Q_t + (1-\rho^{X})\tilde{P}_{H,t}, \tag{E.9}$$
$$\tilde{P}_{F,t}^{X,*} = 1, \tag{E.10}$$
$$\tilde{P}_{F,t}^{X} = \rho^{M} Q_t \tilde{P}_{F,t}^{X,*} + (1-\rho^{M})\tilde{P}_{F,t}^{X,*}, \tag{E.11}$$
$$\tilde{P}_{H,t}^{X,*} = \rho^{X} \tilde{P}_{H,t}^{X}/Q_t + (1-\rho^{X})\tilde{P}_{H,t}^{X,LCP}, \tag{E.12}$$
$$\tilde{P}_{H,t}^{X} = \left(\frac{\tilde{P}_{H,t} - \alpha_y (\tilde{P}_{F,t}^{X})^{1-\eta_y}}{1-\alpha_y}\right)^{1/(1-\eta_y)}, \tag{E.13}$$
$$\pi_{H,t}^{X} = (1+\pi_t)\frac{\tilde{P}_{H,t}^{X}}{\tilde{P}_{H,t-1}^{X}} \tag{E.14}$$
$$\begin{aligned}\left(\pi_{H,t}^{X,*,LCP} - \pi^{*}\right)(1+\pi_{H,t}^{X,*,LCP}) &= \frac{(1-\eta_x^{*})}{\varphi_x} Q_t \tilde{P}_{H,t}^{X,*,LCP} + \frac{\eta_x^{*}}{\varphi_x}\widetilde{MC}_t \\ &+ \hat{\mathbb{E}}_t^{f}\left[\frac{\left(\pi_{H,t+1}^{X,*,LCP} - \pi^{*}\right)(1+\pi_{H,t+1}^{X,*,LCP})}{1+r_t^{ante}}\frac{X_{H,t+1}^{*,LCP}}{X_{H,t}^{*,LCP}}\right],\end{aligned} \tag{E.15}$$
$$1+\pi_{H,t}^{X,*,LCP} = \frac{\tilde{P}_{H,t}^{X,*,LCP}}{\tilde{P}_{H,t-1}^{X,*,LCP}}(1+\pi^{*}), \tag{E.16}$$
$$X_{H,t}^{*,LCP} = \alpha_y \left(\tilde{P}_{H,t}^{X,*,LCP}\right)^{-\eta_y^{*}} Y^{*}, \tag{E.17}$$
$$X_t = \Omega K_t^{\alpha_k} N_t^{1-\alpha_k}, \tag{E.18}$$
$$X_{H,t} = (1-\alpha_y)(\tilde{P}_{H,t}^{X}/\tilde{P}_{H,t})^{-\eta_y} Y_t, \tag{E.19}$$
$$X_{H,t}^{*} = \alpha_y (\tilde{P}_{H,t}^{X,*}/\tilde{P}_{F,t}^{*})^{-\eta_y^{*}} Y^{*}, \tag{E.20}$$
$$X_{F,t} = \alpha_y (\tilde{P}_{F,t}^{X}/\tilde{P}_{H,t})^{-\eta_y} Y_t, \tag{E.21}$$
$$T_{X,t} = X_t\left(P_{H,t}^{X} - MC_t - (\varphi_x/2)(\pi_{H,t}^{X} - \overline{\pi})^2 P_t\right) + \left(Q_t \tilde{P}_{H,t}^{X,*} - \tilde{P}_{H,t}^{X}\right) X_{H,t}^{*}, \tag{E.22}$$
$$\tilde{W}_t = (1-\alpha_k)\tilde{MC}_t \Omega_t \left(\frac{K_t}{N_t}\right)^{\alpha_k}, \tag{E.23}$$
$$\pi_t = (1+\pi_t^{w})\frac{\tilde{W}_{t-1}}{\tilde{W}_t} - 1, \tag{E.24}$$
$$r_t^{k} = \alpha_k \tilde{MC}_t \Omega_t \left(\frac{N_t}{K_t}\right)^{1-\alpha_k}, \tag{E.25}$$
$$(\pi_{H,t}^{X} - \overline{\pi})(1+\pi_{H,t}^{X}) = \frac{(1-\eta_x)}{\varphi_x}\tilde{P}_{H,t}^{X} + \frac{\eta_x}{\varphi_x}\widetilde{MC}_t + \hat{\mathbb{E}}_t^{f}\left[\frac{(\pi_{H,t+1}^{X} - \overline{\pi})(1+\pi_{H,t+1}^{X})}{1+r_t^{ante}}\frac{X_{t+1}}{X_t}\right], \tag{E.26}$$

$$(\pi_t^w - \overline{\pi})(1+\pi_t^w) = \frac{\eta_w}{\varphi_w}\left\{v'(N_t)N_t - (1-\lambda)Z_t\frac{(\eta_w-1)}{\eta_w}u'(C_t^*)\right\} + \beta\hat{\mathbb{E}}_t^f\left[(\pi_{t+1}^w-\overline{\pi})(1+\pi_{t+1}^w)\right], \tag{E.27}$$

$$q_t^K = \frac{r_{t+1}^K + (1-\delta_K)q_{t+1}^K}{1+r_t^{ante}}, \tag{E.28}$$

$$1 = q_t^K\left(1 - S\left(\frac{I_t}{I_{t-1}}\right) - \frac{I_t}{I_{t-1}}S'\left(\frac{I_t}{I_{t-1}}\right)\right) + \hat{\mathbb{E}}_t^f\left[\frac{q_{t+1}^K}{1+r_t^{ante}}\left(\frac{I_{t+1}}{I_t}\right)^2 S'\left(\frac{I_{t+1}}{I_t}\right)\right], \tag{E.29}$$

$$K_t = K_{t-1}(1-\delta_K) + I_t\left(1 - S\left(\frac{I_t}{I_{t-1}}\right)\right), \tag{E.30}$$

$$t_{K,t} = r_t^K K_t - I_t, \tag{E.31}$$

$$I_{F,t} = \alpha_c\tilde{P}_{F,t}^{-\eta_c}I_t, \tag{E.32}$$

$$I_{H,t} = (1-\alpha_c)\tilde{P}_{H,t}^{-\eta_c}I_t, \tag{E.33}$$

$$\begin{aligned} T_m = &\frac{1}{1+\pi_t}\left(\frac{i_{L,t}+1}{i_{L,t}+\delta} - \hat{\mathbb{E}}_{t-1}^f\left[\frac{i_{L,t}+1}{i_{L,t}+\delta}\right]\right)(i_{L,t-1}+\delta)(1-\kappa-\kappa^*)q_{av,t-1}B_{t-1} \\ &+ B_{t-1}^*\frac{(1+i_{t-1}^*)}{1+\pi_t}\left(Q_t\frac{(1+\pi_t)}{1+\pi_t^*} - \hat{\mathbb{E}}_{t-1}^f\left[Q_t\frac{(1+\pi_t)}{1+\pi_t^*}\right]\right), \end{aligned} \tag{E.34}$$

$$i_{L,t} = (1+i_t)\frac{\delta + i_{L,t+1}}{1+i_{L,t+1}} - \delta, \tag{E.35}$$

$$i_{av,t} = i_{L,t}L_t/B_t + i_{av,t-1}(1-L_t/B_t), \tag{E.36}$$

$$q_{av,t} = \frac{i_{av,t}+\delta}{i_{L,t}+\delta}, \tag{E.37}$$

$$r_t^{ante} = \frac{1+i_t}{\hat{\mathbb{E}}_t^f[1+\pi_{t+1}]} - 1, \tag{E.38}$$

$$r_t = \frac{1+i_{t-1}}{1+\pi_t} - 1, \tag{E.39}$$

$$T_{cb,t} = \frac{i_{av,t-1} - i_{t-1}}{1+\pi_t}\kappa B_{t-1}, \tag{E.40}$$

$$L_t = B_t - (1-\delta)\frac{B_{t-1}}{1+\pi_t}, \tag{E.41}$$

$$T_t = T + \frac{T}{X}(X_t - X), \tag{E.42}$$

$$G_t = G - \phi^G(B_{t-1} - B_{ss}), \tag{E.43}$$

$$T_t + T_{cb,t} + L_t + \hat{L}_t + B_t = G_t + (1+i_{av,t-1})\frac{B_{t-1}}{1+\pi_t} + (1+i_{t-1})\frac{\hat{L}_{t-1}}{1+\pi_t}, \tag{E.44}$$

$$Z_t = \tau_t(\tilde{W}_tN_t + Div_t)^{1-\lambda}\mathbb{E}_t[e_i^{1-\lambda}], \tag{E.45}$$

$$T_t = N_t\tilde{W}_t + Div_t - Z_t \tag{E.46}$$

$$r_t^{ante} = (1+r_t^*)\hat{\mathbb{E}}_t^f\left[Q_{t+1}/Q_t\right] - 1, \tag{E.47}$$

$$\mathcal{E}_t = \mathcal{E}_{t-1}\frac{1+\pi_t}{1+\pi^*}\frac{Q_t}{Q_{t-1}}, \tag{E.48}$$

$$T_\tau^* = \frac{\kappa^* q_{av,\tau-1}B_{\tau-1}}{1+\pi_\tau}\left(\frac{i_{L,\tau}+1}{i_{L,\tau}+\delta} - \frac{i_{\tau-1}+1}{i_{L,\tau-1}+\delta}\right)(i_{L,\tau-1}+\delta), \tag{E.49}$$

$$t_{R,t} = H_{R,t}(\tilde{P}_{R,t} - \delta_H) - (\varphi_r/2)(\pi_{R,t} - \overline{\pi})^2 H_{R,t} + \tilde{P}_{O,t}(H_{R,t-1} - H_{R,t}) - F_R, \tag{E.50}$$

$$\tilde{P}_{O,t} = \left(\frac{\eta_r - 1}{\eta_r}\right) \tilde{P}_{R,t} - \delta_H + \hat{\mathbb{E}}_t^f \left[\frac{\tilde{P}_{O,t+1}}{1 + r_t^{ante}}\right] \tag{E.51}$$

$$+ \frac{\varphi_r}{\eta_r}\left((\pi_{R,t} - \overline{\pi})(1 + \pi_{R,t}) - \hat{\mathbb{E}}_t^f \left[\frac{(\pi_{R,t+1} - \overline{\pi})(1 + \pi_{R,t+1})}{1 + r_t^{ante}} \frac{H_{R,t+1}}{H_{R,t}}\right]\right),$$

$$\pi_{R,t} = P_{R,t}/P_{R,t-1} - 1, \tag{E.52}$$

$$P_t^{cpi} = P_t(1 - \omega_{rent}) + P_{R,t}\omega_{rent}, \tag{E.53}$$

$$\log(1 + i_t) = \rho_i \log(1 + i_{t-1}) + (1 - \rho_i)\Big\{ \log(1 + \overline{r}) + \log(1 + \overline{\pi}) + \phi_\pi \left[\log(1 + \pi_t^{cpi}) - \log(1 + \overline{\pi})\right] \tag{E.54}$$

$$+ \phi_y \left[\log(X_t) - \log(X)\right] \Big\} + \log(1 + \epsilon_{r,t}),$$

$$Div_t = T_{m,t} + T_{X,t} + t_{r,t} + t_{K,t}, \tag{E.55}$$

$$\overline{H} = H_F(s_{r,t} + s_{oF,t}) + H_H s_{oH,t}, \tag{E.56}$$

$$H_{R,t} = s_{r,t} H_F, \tag{E.57}$$

$$DWL_{O,t} = TRANS_t \times F + \bar{H}\delta_H + \frac{\varphi}{2}(\pi_{R,t} - \bar{\pi})^2 H_{R,t} \tag{E.58}$$

$$- BORROW_t \times \bar{r} + H_R(\tilde{P}_R - \delta_H), \tag{E.59}$$

$$DWL_t = DWL_{O,t} + X_t(\varphi_x/2)(\pi_{H,t}^X - \overline{\pi})^2, \tag{E.60}$$

$$DWL_{H,t} = (1 - \alpha_c)\tilde{P}_{H,t}^{-\eta_c} DWL_t, \tag{E.61}$$

$$DWL_{F,t} = \alpha_c \tilde{P}_{F,t}^{-\eta_c} DWL_t, \tag{E.62}$$

$$X_t = X_{H,t} + X_{H,t}^*, \tag{E.63}$$

$$C_t = \int c_t(a, e) d\Psi_t(a, e), \tag{E.64}$$

$$A_t = \int a_t(a, e) d\Psi_t(a, e), \tag{E.65}$$

$$A_t = (1 - \kappa - \kappa^*) q_{av,t} B_t + \kappa B_t + \hat{L}_t + Q_t B_t^*, \tag{E.66}$$

$$C_t + A_{t+1} = (1 + r_t)A_t + Z_t - t_{R,t} - DWL_{O,t}, \tag{E.67}$$

$$Y_t = C_{H,t} + G_{H,t} + C_{H,t}^* + DWL_{H,t} + I_{H,t}, \tag{E.68}$$

$$C_t + G_t + I_t + DWL_t = X_t \widetilde{P}_{H,t}^X + \left[\left(Q_t \widetilde{P}_{H,t}^{X,*} - \widetilde{P}_{H,t}^X\right) X_{H,t}^*\right] \tag{E.69}$$

$$+ \left[(1 + r_t^*) B_{t-1}^* Q_t - Q_t B_t^*\right] + \left[\kappa^* B_t - \frac{\kappa^* B_{t-1}}{1 + \pi_t}(1 + i_{av,t-1})\right]$$

$$\tilde{P}_{H,t} C_{H,t}^* + Q_t \widetilde{P}_{H,t}^{X,*} X_{H,t}^* - \tilde{P}_{F,t}\left(C_{F,t} + G_{F,t} + I_{F,t} + DWL_{F,t}\right) - \tilde{P}_{F,t}^X X_{F,t}, \tag{E.70}$$

$$= \left[\frac{\kappa^* B_{t-1}}{1 + \pi_t}(1 + i_{av,t-1}) - \kappa^* B_t\right] + \left[Q_t B_t^* - (1 + r_t^*) B_{t-1}^* Q_t\right]$$

The variables Y^*, C^*, π^*, i^*, r^*, Ω, and ϵ_r are exogenous. The endogenous aggregate variables are:

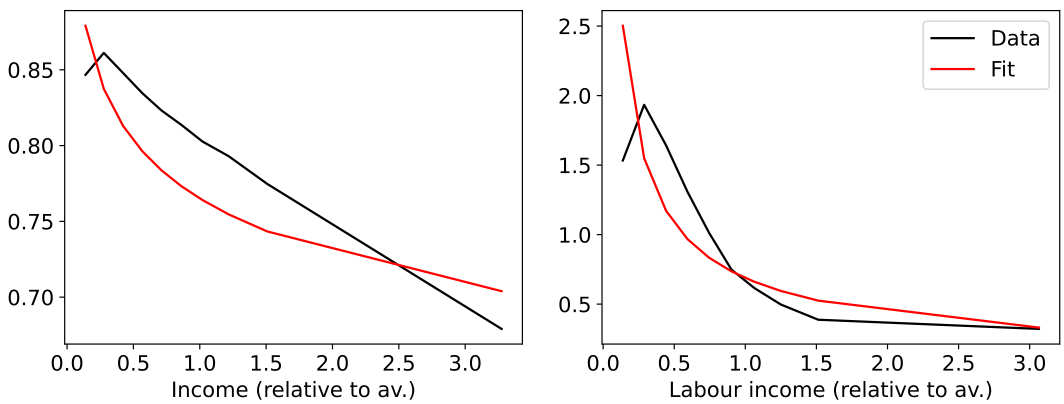
C_t	$C_{H,t}$	$C_{F,t}$	G_t	$G_{H,t}$	$G_{F,t}$	I_t	$I_{H,t}$	$I_{F,t}$	Y_t
X_t	$X_{H,t}$	$X_{F,t}$	K_t	L_t	$\hat{L}_t$	N_t	Z_t	Div_t	W_t
MC_t	P_t	P_t^{cpi}	$P_{H,t}$	$P_{H,t}^*$	$P_{F,t}^*$	$P_{H,t}^X$	$P_{F,t}^X$	$P_{H,t}^{X,*}$	$P_{F,t}^{X,*}$
$P_{H,t}^{X,*,LCP}$	π_t	π_t^w	π_t^{cpi}	$\pi_{H,t}$	$\pi_{H,t}^X$	$\pi_{H,t}^{X,*,LCP}$	r_t	r_t^{ante}	i_t
$i_{L,t}$	$i_{av,t}$	q_t^K	$q_{av,t}$	B_t	B_t^*	T_t	$T_{cb,t}$	$t_{K,t}$	$T_{X,t}$
$T_{m,t}$	$X_{H,t}^*$	$X_{H,t}^{*,LCP}$	T_t^*	$\mathcal{E}_t$	Q_t	$P_{R,t}$	$P_{O,t}$	$\pi_{R,t}$	$t_{R,t}$
$TRANS_t$	$BORROW_t$	DWL_t	$DWL_{H,t}$	$DWL_{F,t}$	$DWL_{O,t}$	$H_{R,t}$	$s_{r,t}$	$s_{oF,t}$	$s_{oH,t}$

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

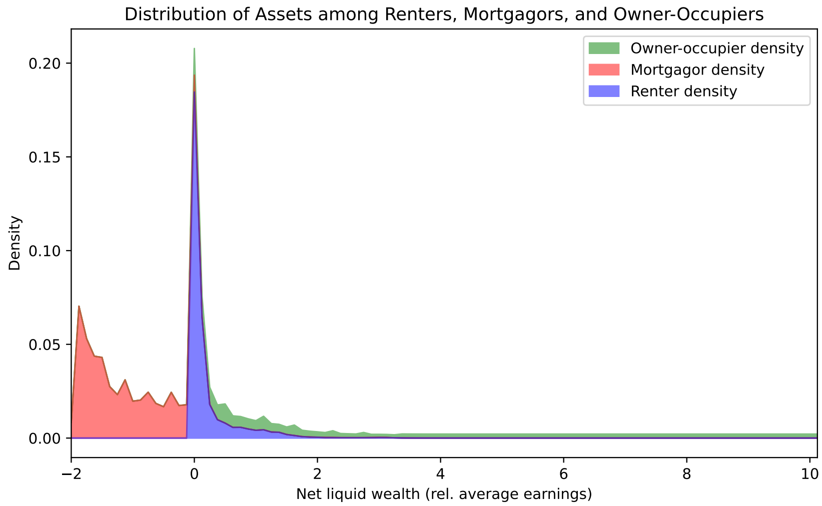
Figure B.1: Tax and Benefit Schedule



(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.

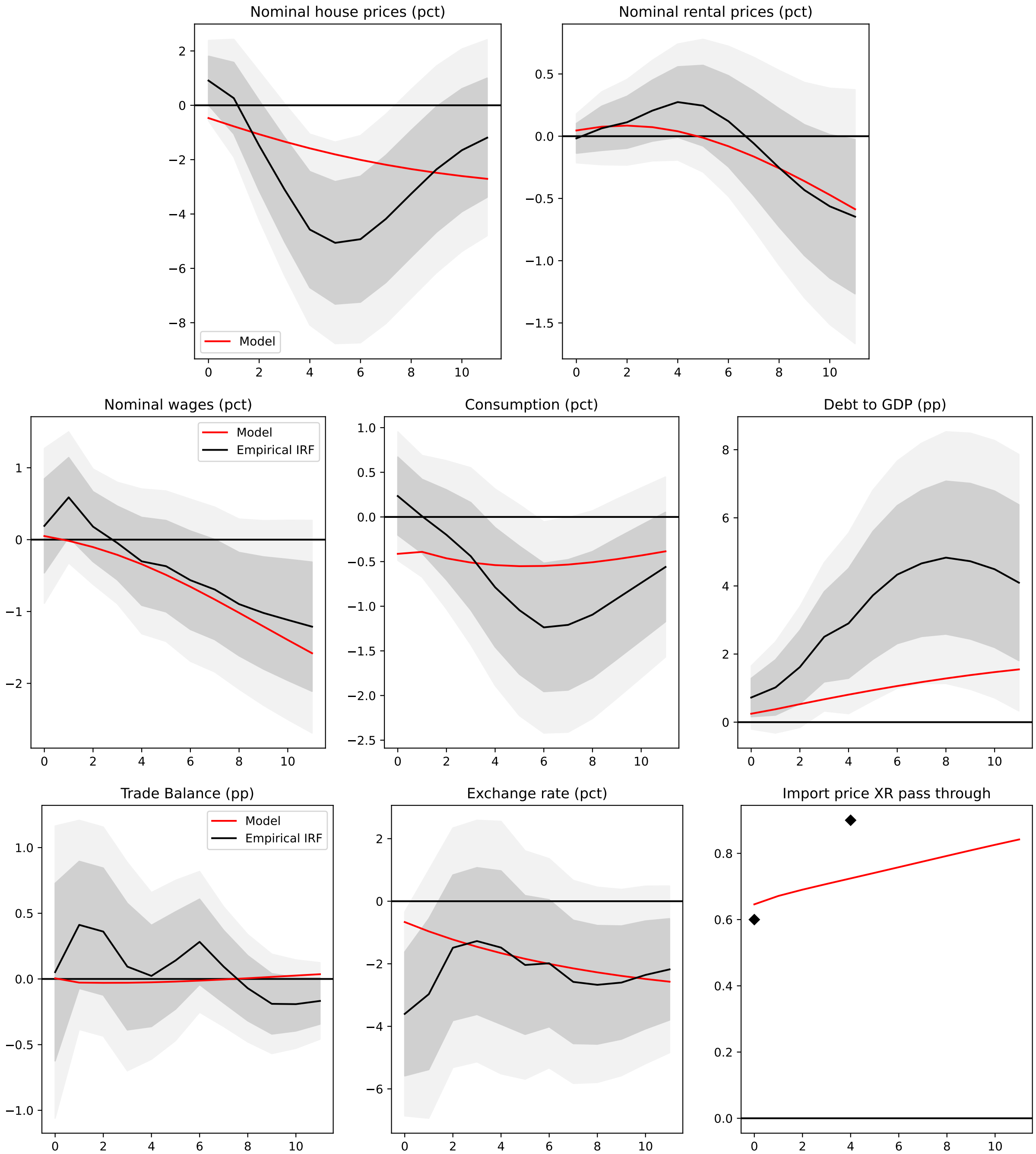
Figure B.2: Asset Distribution



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

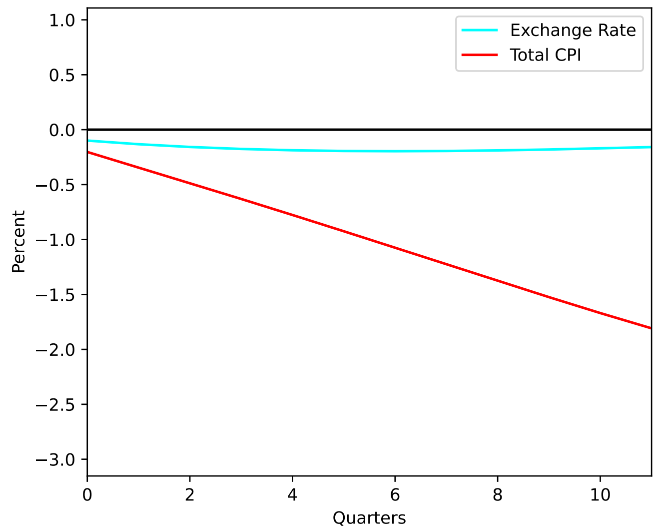
B.1 Model dynamics

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



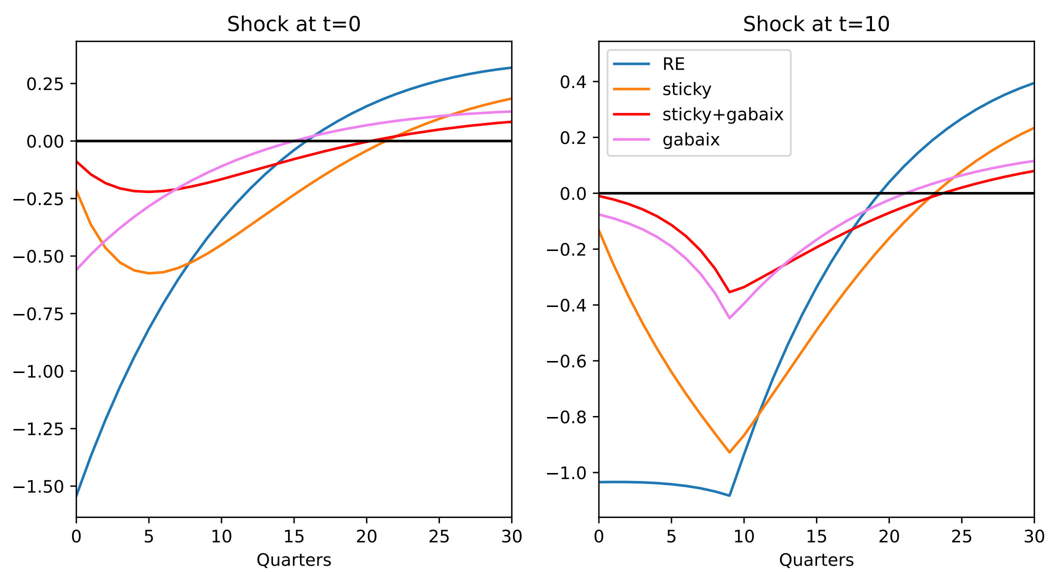
Notes: Figure reports the impulse response to a 1pp unanticipated monetary policy shock. The black line and shaded areas are the paths from the SVAR estimates averaged to a quarterly frequency. The shaded areas represent the 68% and 90% confidence intervals for the empirical responses.Import price exchange 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.

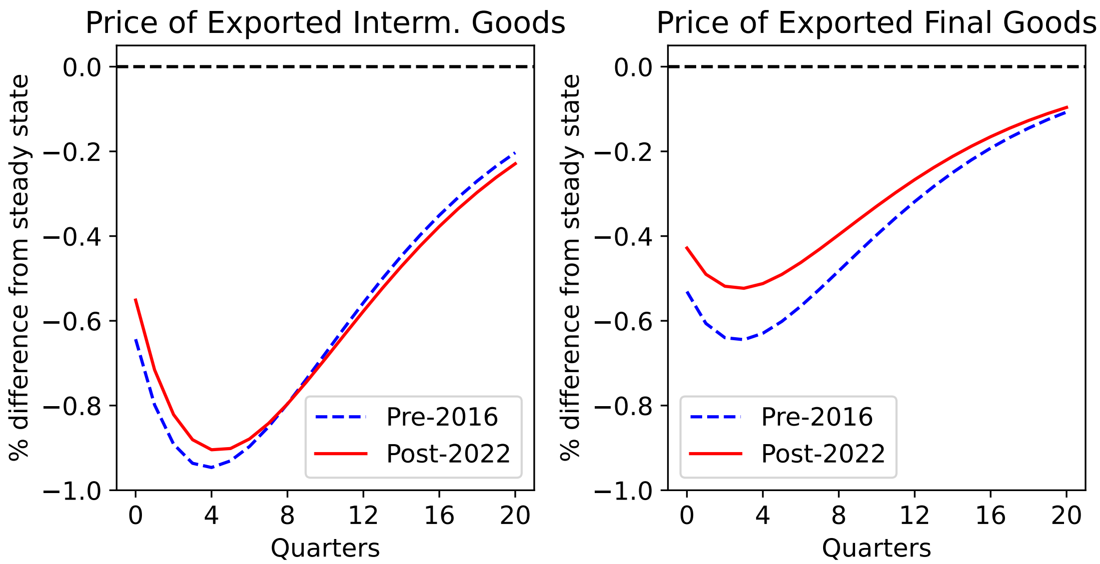
Figure B.5: Sticky expectations and cognitive discounting



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.

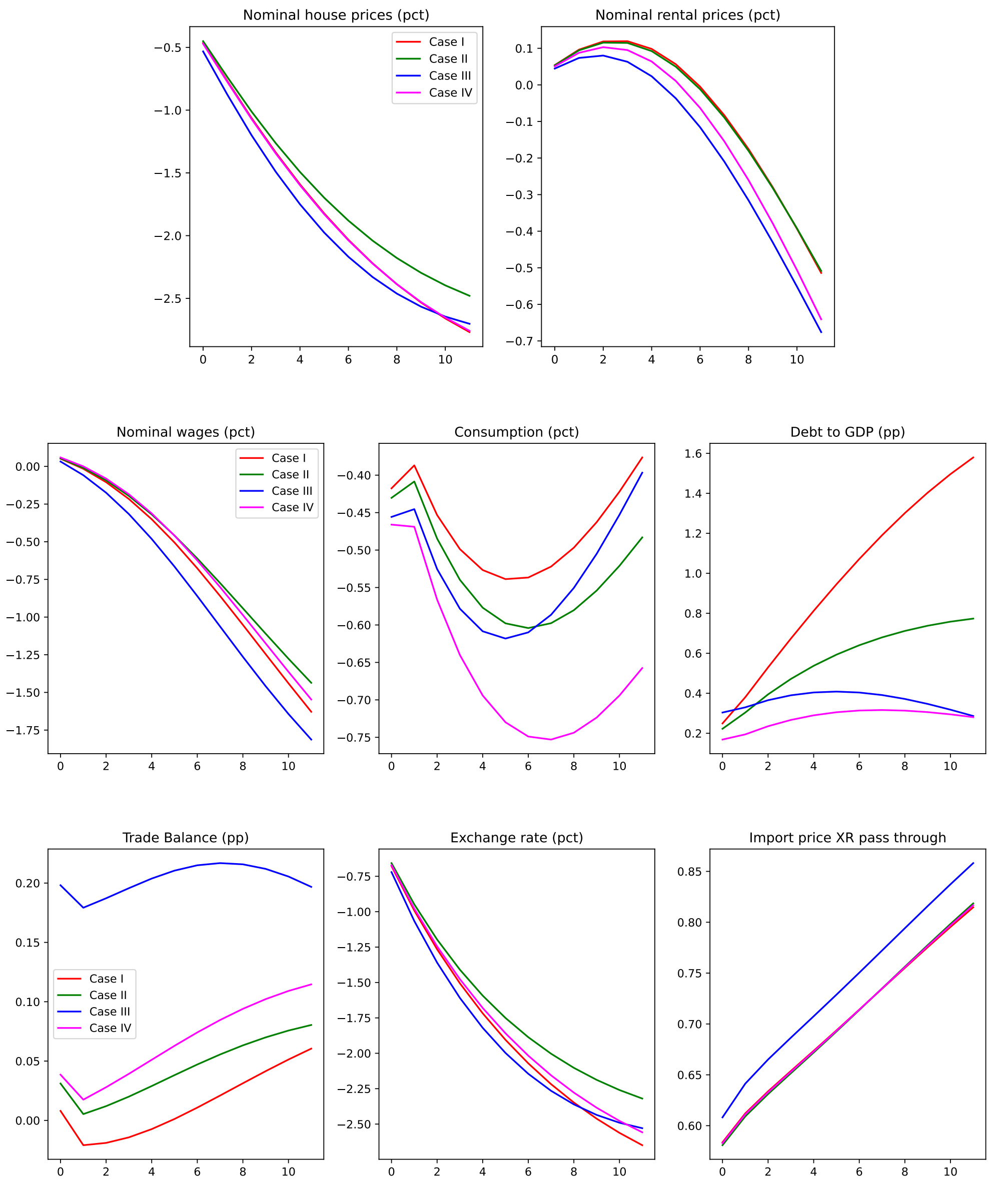
C Applications: Further Details

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



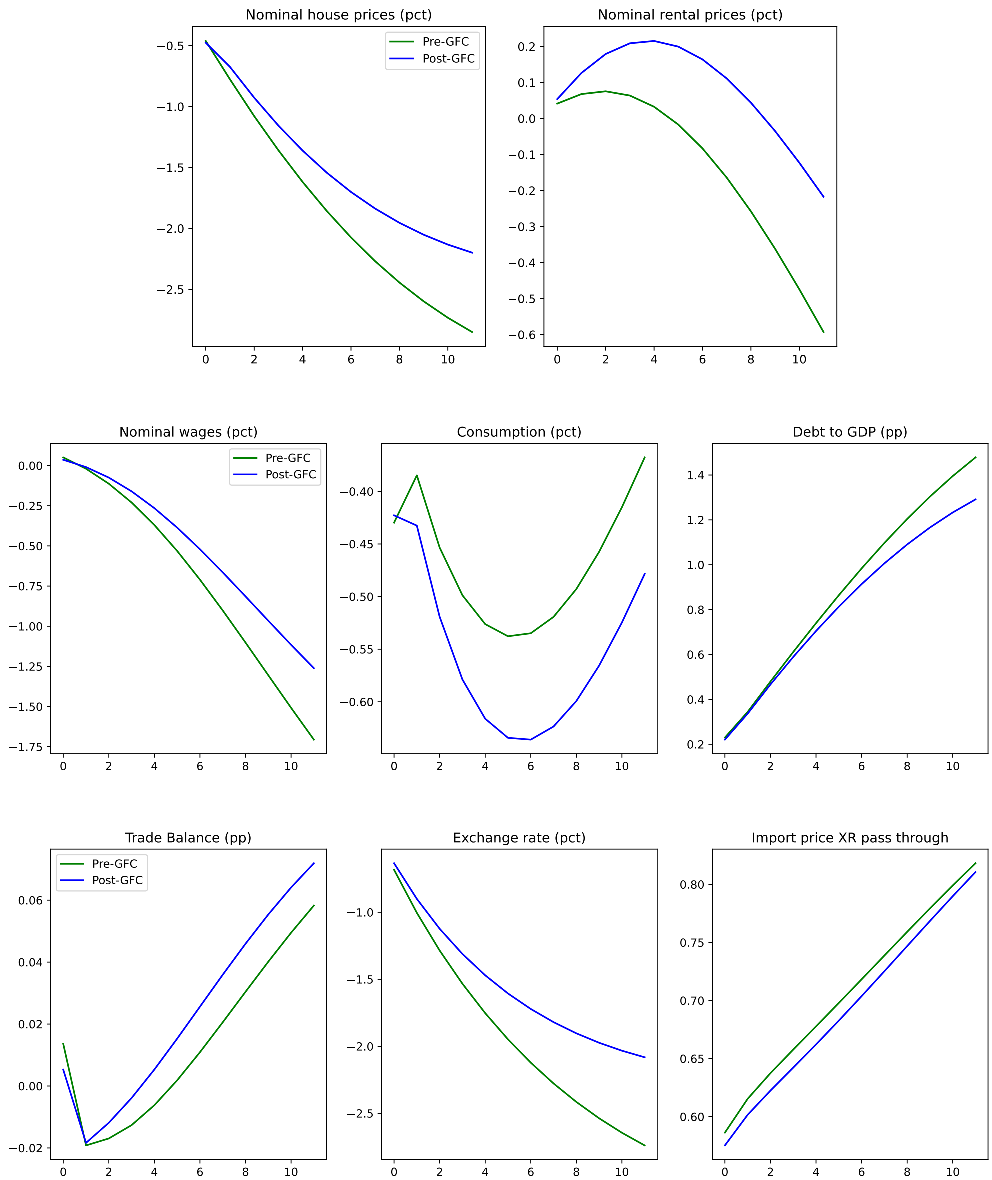
Notes: Figure reports the impulse response to a 1pp unanticipated monetary policy shock fixing the Bank Rate path to be the same as in Figure 2 across all cases using anticipated shocks.

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	20%	8%	22%
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	0.021	0.016	0.019
r^*	Long-run real rate	2.82%	0.56%	1.76%
	Targets			
$A/4\bar{W}_tN_t$	Net financial wealth-to-labour income	0.27	0.42	0.34
$\bar{H}p_O/4\bar{W}_tN_t$	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 trans. prob	1%	1%	1%
	Internal calibration (when changed from base case)			
β	Discount factor	0.987	0.993	0.990
p_O	House price	16.42	23.69	20.24
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. The black line and shaded areas are the paths from the SVAR estimates averaged to a quarterly frequency, as in the base case, to guide the eye.