Lighting the Shadows: Central Bank Policy Transmission through Banks and Non-Banks*

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Abstract

Non-bank financial intermediaries (NBFIs) account for an increasingly large share of credit provision and play a central role in quantitative easing (QE) and tightening (QT). We develop a DSGE model with banks, NBFIs and a central bank interacting through wholesale deposits, bonds and reserve markets to study how monetary transmission changes as the size of NBFIs expands. We estimate the model on UK data to evaluate key parameters in the financial sector. We find that the transmission of conventional interest rate policy to output and inflation is essentially unaffected by the size of the NBFI sector. Conversely, the transmission of QE/QT is strongly altered by the size of the NBFI sector and the source of its expansion. When the NBFI sector expands due to firm funding preferences, this *amplifies* QE and QT. When it expands due to an increased cost of obtaining bank finance, this *weakens* them. The results underscore that monetary policymakers retain rate control regardless of financial structure, but that the effectiveness of balance-sheet policies depends crucially on the composition and behaviour of the non-bank sector.

Keywords: Monetary Policy Tools, QE/QT, Reserves, NBFIs, DSGE Estimation.

JEL classification: C13, E51, E52, E58, G23.

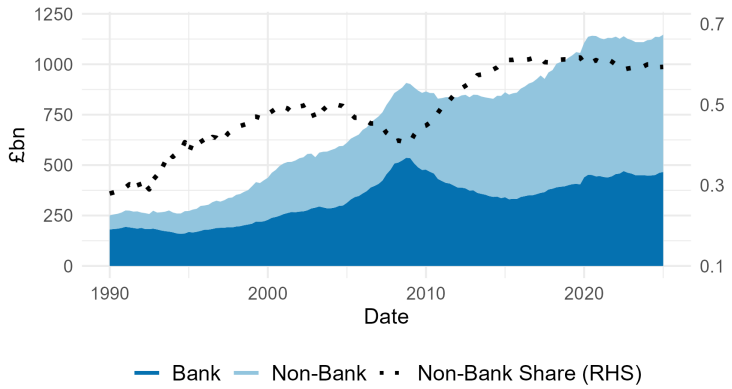
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1 Introduction

Non-bank financial intermediaries (NBFIs) have become the largest global financial intermediaries, eclipsing traditional banks (FSB, 2025). Their growth has been rapid and wide ranging: since the Global Financial Crisis, NBFIs recorded higher participation in government bond markets, tighter funding links with banks and larger financing to non-financial firms (Figure 1). These dynamics mirror the increasing role of debt securities in the financing structure of firms and the predominance of sovereign bonds over private sector credit (Shin, 2025). In the meantime, traditional banking has retreated. In the UK, only 40% of corporate debt takes the form of traditional bank lending (Figure 1), compared with 60% in 2008. Globally, the banking sector owns 38% of of total global financial assets, down from 46% in 2008 (FSB, 2025). A new financing structure of the economy has emerged, with NBFIs playing a prominent role (ECB, 2021).

This evolution of the financial landscape has introduced significant uncertainty into the transmission of monetary policy (BIS, 2025b). The uncertainty stems from the lack of a workhorse model: to date, only a nascent theoretical literature has attempted to model this new financing structure and its monetary policy consequences. A fast-growing empirical literature has provided more insights, but without reaching a consensus. Concerned over this knowledge gap, central banks have called for more research on the topic (Bailey, 2025; Schnabel, 2021; Yellen, 2014).

Figure 1: UK Corporate Debt by Lender



Sources: Association of British Insurers, Bayes CRE Lending Report, Deloitte, Eikon from Refinitiv, Financing & Leasing Association, firm public disclosures, Integer Advisors estimates, S&P Global Market Intelligence, London Stock Exchange, ONS, Peer-to-Peer Finance Association, and Bank of England.

This paper aims to fill the gap by developing a Dynamic Stochastic General Equilibrium (DSGE) model featuring banks and NBFIs. In our model, banks face several frictions capturing the banking environment in advanced economies after the Global Financial Crisis, namely macroprudential regulation and the abundant supply of central banks' reserves (Gerali et al., 2010; Vissing-Jørgensen, 2023). NBFIs, reflecting their greater role over the past two decades, are modelled as entities trading across three asset classes seeking duration *and* liquidity benefits. In our framework as in reality, NBFIs do not have access to central bank's reserves (Adrian et al., 2010). However, they are the central bank's counterparty during the implementation of Quantitative Easing (QE) and Tightening (QT), inspired by Cui and Sterk (2021) and reflecting the experience of major central banks.[1] Within the financial block, banks and non-banks interact *directly* via wholesale deposits and reserve markets, and *indirectly* through competition to acquire household savings and supply loans to firms. This structure shapes the transmission of monetary policy, that hinges on three elements: i) the funding mix of corporates between bank loans and bonds; ii) the NBFI's duration and liquidity choices between wholesale deposits and long term government and corporate bonds; and iii) banks's liquidity benefits of holding reserves. Against this backdrop, we address the following question: how does monetary transmission change when NBFIs play a larger role in the provision of credit to the economy?

Our model structure is designed to be flexible and initially leaves open the effects of NBFIs on the monetary transmission. This follows from the lack of consensus in the existing literature. As demonstrated in Section 6 on robustness checks, our findings depend on the specific parameter values. To bring empirical validity to the model, we estimate the key parameters on UK data using standard Bayesian methods. By doing so, we are the first to estimate key financial market frictions, making an empirical contribution as well as a theoretical one.

We find that the transmission of conventional interest-rate policy to output and inflation is essentially unaffected by the size of the NBFI sector.[2] Differently from the policy rate, we find that

[1] NBFIs were large counterparties to the the Bank of England, Federal Reserve, and indirectly Eurosystem's asset purchases programmes. For more details see Avdjiev et al. (2019); Carpenter et al. (2015); Joyce et al. (2012); Kaminska et al. (2025).

[2] This contrasts with macroprudential policy, where the risk of "leakage" from the banking to non-banking sectors weakens the effectiveness of policy, as in Gebauer and Mazelis (2023).

the transmission of QE and QT is significantly altered by the size of the NBFI sector and the source of its expansion. When the NBFI sector expands due to firm funding preferences, this *amplifies* QE and QT. When it expands due to an increased cost of obtaining bank finance, this *weakens* them. Further simulations show that the smooth transmission of QE depends on a well-functioning wholesale deposits market linking NBFIs to banks, and to a lesser extent the existing volume of central bank reserves.

Our paper makes several contributions. First, we develop a novel DSGE model with a comprehensive, state-of-the-art financial sector capturing the new financing structure of the economy. This allows for an in-depth assessment of monetary policy, including QE and QT. We estimate the model and quantify the effect of NBFIs on monetary policy transmission. Second, we provide a novel approach to modelling the heterogenous universe of NBFIs. Previous frameworks assume NBFIs carry out either very specialised activities or provide an identical credit product to banks', only subject to different regulation and market structure.[3] These specifications struggle to encompass the varied activities of NBFIs, limiting their applicability to monetary policy analysis. Differently, we introduce an aggregate NBFI sector whose activity is driven entirely by duration and liquidity benefits. By imposing NBFIs to oscillate between these two motives while intermediating three different assets, we capture realistically a wide range of non-banks, from hedge funds to money market funds, enhancing the validity of the model for monetary policy exercises.

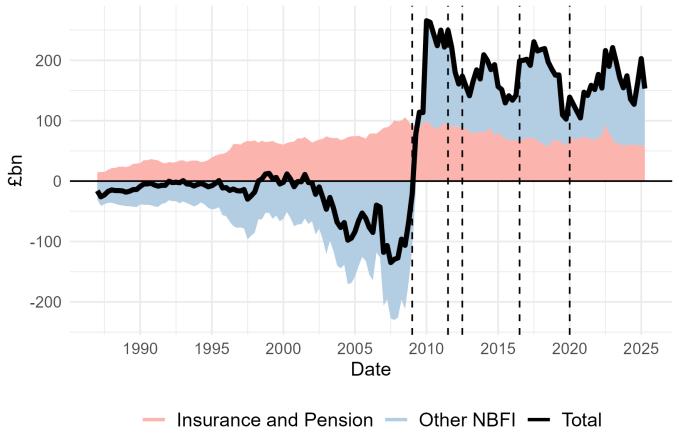
Third, we introduce NBFIs as net lenders to banks. Relative to previous theoretical literature (Gloria and Punzo, 2025), we are able to capture NBFIs funding linkages to banks through one of the most common instrument, NBFIs' wholesale deposits (BIS, 2025a).[4] Importantly, the rate on these deposits is different from other short rates in standard New Keynesian models (e.g. retail deposits) because it is highly sensitive to market conditions. As shown in the 2020 "Dash for Cash", it is the main vehicle to transmit liquidity shocks (Franceschi et al., 2023). Hence, building in this funding relationship adds a crucial channel to the determination of short rates and to the

[3]Examples of the former are: Liabilities driven Investment (LDI) funds providing liabilities-hedging to pension funds in Bandera and Stevens (2024) and securitisation in Fève et al. (2019). Examples of the latter are Gebauer and Mazelis (2023); Gloria and Punzo (2025).

[4]Non-banks are net lenders to banks in the Euro Area and United Kingdom (a) but net borrowers in the United states (Acharya, Cetorelli, et al., 2024).

transmission of the policy rate. The inclusion of NBFIs funding also adds an important channel to the transmission of QE, that empirical research has shown to work through NBFIs' unsecured deposits (Acharya and Rajan, 2024; Darst et al., 2025). While not perfectly correlated, Figure 2 shows in the United Kingdom QE programmes by the Bank of England (dashed lines) corresponded with NBFIs' short-term funding to banks exceeding banks' short-term claims on NBFIs.

Figure 2: Non-Banks net short-term financing to Banks in the UK



Source: ONS, UK Economic Accounts. Dashed lines indicate QE announcements. Insurance and Pension: ESA codes S.128 and S.129. Other NBFIs: all ESA codes S.124-S.127. The net value is calculated as Deposits with UK MFIs (AF.22N1) and short-term debt securities issued by UK MFIs (AF.31N5) net of short-term loans owed to UK MFIs (AF.41N1).

Fourth, we propose a new modelling of the firms' funding choice between bank and non-bank financing. The NBFI literature assumes that only regulatory coverage breaks the otherwise perfect substitutability between the two options (Gebauer and Mazelis, 2023). This gives rise to a funding pecking order: firms turn to banks first and then, after having exhausted the credit permitted by regulations, acquire NBFIs funding. We take a different perspective; we observe that large corporates tend to rely on market finance while small and medium sized enterprises access funding primarily through bank lending (Bank of England, 2021). We replicate this financing mix by allowing the marginal firm to borrow either through the bond market or the banking sector but, critically, this is subject to a low elasticity of substitution between the two options. This approach leads to a more realistic rate pass-through, again benefitting the model's application to monetary policy analysis.

The reminder of the paper is organised as follows. After presenting a review of the relevant literature in Section 2, Section 3 explains the main features of the model, focusing on the rich financial sector. Sections 4 shows the the estimation and calibration of the model. Section 5 simulates an interest rate shock, a QE shock and a QT shock to assess the transmission through banks and non-banks. Critically, we evaluate the consequences of a larger NBFI sector in the transmission of monetary policy. Counterfactuals with larger reserves and a wholesale market shutdown provide more insights on transmission channels and non-linearities. Section 6 checks that our results are robust to a range of parameter values. Finally, Section 7 concludes.

2 Related literature

Our paper is part of a nascent body of macro-finance research studying the growth of NBFIs - and the corresponding new financial landscape - in a general equilibrium framework. While most of this literature assesses the rise of NBFIs from a financial stability perspective (Dempsey, 2025; Fève et al., 2019), we take a fundamentally different stance: we study the role of a larger NBFI sector in the transmission of monetary policy.

There is a thin theoretical literature studying the role of NBFIs in the transmission of monetary policy. An important contribution comes from (Gebauer and Mazelis, 2023), who develop a DSGE model featuring banks and non-banks with different regulatory coverage and market structure to assess the effects of tighter capital requirements. Following a negative monetary policy shock, they observe a decline in bank lending that is partly counteracted by higher NBFIs' credit supply. This is confirmed by (Xiao, 2019): in his structural model of bank competition, NBFIs weaken contractionary monetary policy due to their superior ability to attract deposits. The opposite result is found by (Gloria and Punzo, 2025): in their DSGE model NBFIs amplify the contractionary effects of monetary policy through the asset price channel.

We depart from these contributions along several dimensions. First, we model NBFIs reflecting the heterogeneity of the sector. Previous theoretical literature on financial crises modelled NBFIs as entities engaging in securitisation (Fève et al., 2019; Meeks et al., 2017) or providing liability-hedging to the pension sector (Bandera and Stevens, 2024). These very specialised entities fail to represent the varied business models of current NBFIs. Gebauer and Mazelis (2023); Salgado-

Moreno (2023) and Gloria and Punzo (2025) provide more general frameworks in which non-banks supply a credit product like banks, only subject to different regulation and market structure. We develop their set-up further, moving away from regulatory constraints. To capture the heterogeneity in the NBFI sector we allow non-banks to hold three different assets - wholesale deposits and long-term corporate and government bonds – motivated by duration and liquidity benefits.

Second, we introduce NBFIs funding to banks. Most of the existing DSGE models with NBFIs have prevented any funding interlinkages between NBFIs and banks (Dempsey, 2025; Gebauer and Mazelis, 2023). This is not consistent with the banks' significant exposure to NBFIs (BIS, 2025a). Other papers have allowed only very specific funding relationships; for instance, Liability Driven Investment funds obtaining banks' repo loans (Bandera and Stevens, 2024). However, focusing on such specific relationships does not account for the large number of activities connecting banks and NBFIs (BIS, 2025a). Allowing NBFIs to fund banks brings us closer to Kumhof and Salgado-Moreno (2024), who model a money market fund holding wholesale deposits. However, in their approach only banks interact with the real economy, while in our frameworks both banks and NBFIs provide finance to firms and collect deposits from households.

Third, we model NBFIs as counterparties to the central bank during Quantitative Easing and Tightening programmes. Our model of QE is inspired by Kumhof and Salgado-Moreno (2024) and Cui and Sterk (2021). The central bank implements QE by purchases government bonds directly from NBFIs, who receive newly create wholesale deposits. Commercial banks intermediate this transaction by expanding its balance sheet and creating these new wholesale deposits, in exchange for newly created central bank reserves. This rationalises the empirical findings on QE mechanics across several jurisdictions (Carpenter et al., 2015; Darst et al., 2025; Fisher, 2010; Goldstein et al., 2018; Joyce et al., 2012; Kaminska et al., 2025; Saito and Hogen, 2014). This framework sets us apart from previous DSGE models of QE, in which typically the central bank purchases bonds from banks (Sims and Wu, 2021) or households (Alpanda and Kabaca, 2020). In terms of transmission mechanism, QE in our model operates through a portfolio balance channel (; Harrison, 2017) and a liquidity channel (Del Negro et al., 2017; Gertler and Karadi, 2011; Gertler and Kiyotaki, 2010). However, the distinctive role of NBFIs in the transmission mechanism allows

us to innovate on the existing literature. Since we simulate asset purchases as well as asset sales, our paper also relates to theoretical models of QT (Airaudo, 2025; Arazi, 2025; G. Benigno and P. Benigno, 2022; Cantore and Meichtry, 2024; Harrison, 2024). However, while these papers focus on the optimal sequencing of tools during a tightening cycle, we are interested in the role played by NBFI in the transmission of QT.

Finally, our treatment of the firm's funding mix places our paper within a long literature studying the imperfect substitutability between corporate bonds and loans and the implications of this for monetary policy. Bernanke and Blinder (1988) were the first to study this, from the perspective of bank's credit supply and using this imperfect substitutability to develop the popular "IS-LM-CC" framework. Recent papers have taken the firms' perspective and showed that interest rate policy (QE) is weakened (strengthened) when corporate bonds represent a larger share of firms financing (Alder et al., 2023; Holm-Hadulla and Thurwachter, 2021). Our model rationalise these empirical results.

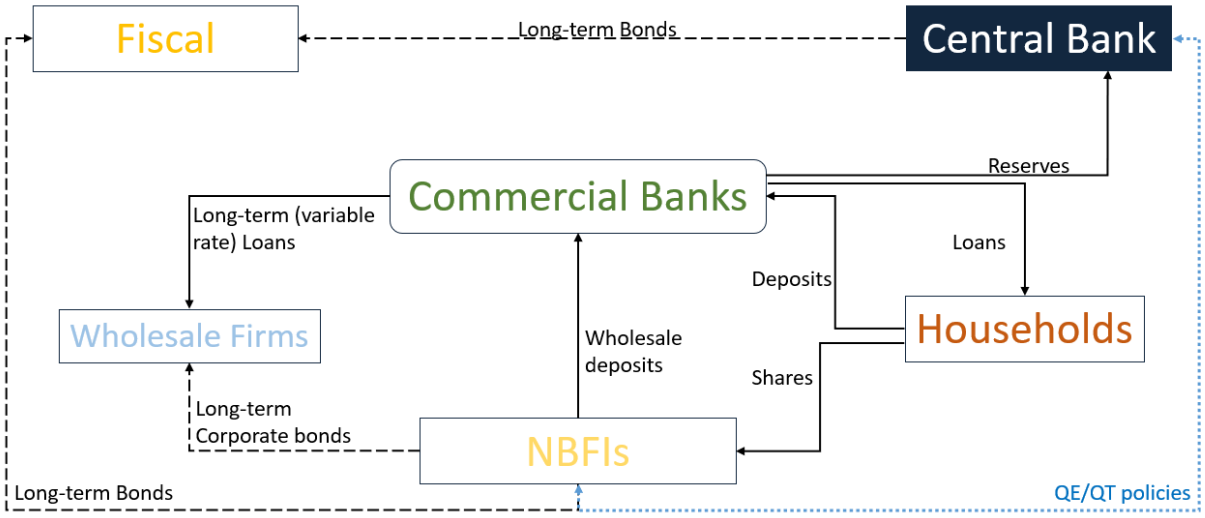
3 Model

We develop a novel medium-scale DSGE model with a sophisticated financial sector at its core accurately reflecting financial interlinkages in advanced economies. Figure 3 below illustrates the interlinkages between the different financial actors in the model. Banks are monopolistically competitive and provide loans to both households and firms at a markup following Gerali et al. (2010). They issue retail deposits to households and wholesale deposits to NBFIs, both at a markdown. They additionally hold reserves from the central bank and face related "reserve scarcity costs" as in Kumhof and Salgado-Moreno (2024). This cost motivates banks to hold reserves even when the policy rate is below their marginal funding cost.

NBFIs are competitive, but face liquidity and duration management costs inspired by the "portfolio balance" frictions of Alpanda and Kabaca (2020). They fund themselves exclusively by issuing deposit-like shares to households and use them to acquire long-term corporate and government bonds, and wholesale deposits held at banks. Long-term bonds are based on Woodford (2001) and calibrated to correspond with a ten-year bond. Bank deposits and government bonds both provide liquidity benefits, while both government and corporate bonds carry duration costs. Capital invest-

ment by firms is funded through a mixture of retained profits and corporate borrowing following Carlstrom et al. (2017). Firms may borrow from either banks or NBFIs, but a CES cost function ensures they cannot substitute perfectly between the two types of financing. Conceptually, small firms borrow from banks, large firms sell bonds to NBFIs, and a group of medium firms have limited capacity to do either. The central bank sets the policy rate following a standard Taylor rule and runs QE/QT. For this, the central bank purchases (sells) government bonds held exclusively by NBFIs and commercial banks settle the transaction by issuing more (less) deposits backed by the newly created (destroyed) central bank reserves.

Figure 3: Financial Sector Overview



3.1 Households

A representative household maximises lifetime utility with respect to consumption C_t, labour supply L_t and a portfolio allocation problem. Households receive wage w_t^h from selling labour to unions, and may save using either commercial bank deposits, d_t^c or NBFI's shares, d_t^s. They may borrow ℓ_t^{hh} in loans from the commercial bank. They pay a lump sum tax τ_t to the central government.

This is characterised by the following problem:

$$\max_{\{C_t, L_t, d_t^c, d_t^s, \ell_t^{hh}\}_{t=0}^{\infty}} \quad \mathbb{E}_t^H \sum_{t=0}^{\infty} \beta^t \left[ln(C_t - bC_{t-1}) - \psi_{l,t} \chi \frac{L_t^{1+\eta}}{1+\eta} \right]$$

$$\text{s.t.} \quad C_t + d_t^c + d_t^s - \ell_t^{hh} \leq w_t^h L_t + F_t + \Omega_t^{hh} - \tau_t, \tag{1}$$

$$F_t \equiv \Pi_t^{-1} \left[R_{t-1}^{d,c} d_{t-1}^c + R_{t-1}^{d,s} d_{t-1}^s - R_{t-1}^{\ell,hh} \ell_{t-1}^{hh} \right] - \mathcal{A}_t, \tag{2}$$

$$\mathcal{A}_t \equiv 0.5 \kappa_{hh} \ell_t^{hh} \left(\ell_t^{hh} - \ell_{t-1}^{hh} \right)^2 + 0.5 \kappa_{nbfi} d_t^s \left(d_t^s - d_{t-1}^s \right)^2, \tag{3}$$

$$\text{and} \quad C_t \leq \nu_t^d d_t^c, \tag{4}$$

$$d_t^c = \left[\int_0^1 \left(d_t^c \left(j \right) \right)^{\frac{\xi_d - 1}{\xi_d}} dj \right]^{\frac{\xi_d}{\xi_d - 1}}, \tag{5}$$

$$\ell_t^{hh} = \left[\int_0^1 \left(\ell_t^{hh} \left(j \right) \right)^{\frac{\xi_t^\ell - 1}{\xi_t^\ell}} dj \right]^{\frac{\xi_t^\ell}{\xi_t^\ell - 1}}, \tag{6}$$

where $\beta \in (0,1)$ is a discount factor, $b \in [0,1)$ indicates internal habit formation, $\chi > 0$ is a scaling parameter used to normalise steady-state labour supply, and η is the inverse Frisch elasticity. All profits are transferred to households in a lump-sum manner though the term Ω_t^{hh}.[5] As in Gabaix (2020) household expectations of the future are not fully rational, and are denoted $\mathbb{E}_t^H$. This a realistic feature adopted to help the model align quantitatively with the data; details are set out in Appendix A.1.

As in Kumhof and Salgado-Moreno (2024), households are willing to hold liquid bank deposits d_t^c at a low rate of return due to the presence of a a deposit-in-advance constraint linking bank deposits to consumption. This specific implementation is not critical to our results, what is important is that households have a strong non-pecuniary motivation for holding bank deposits. Households are therefore willing to hold both bank deposits and bank loans ℓ_t^{hh}, and ultimately to acquire bank deposits via borrowing; they optimise over their gross financial position with respect to each asset type rather than just their net position. The potential illiquidity of bank loans and NBFI shares, and therefore the difficulty for households to change their exposure, is captured by an adjustment cost $\mathcal{A}_t$. Finally, as in Gerali et al. (2010), bank deposit holdings is itself a CES aggregate of individual bank deposits from each bank. This gives commercial banks monopolistic power and therefore in equilibrium it ensures a spread between the policy rate and the deposit rate.

[5] Ω_t^{hh} implicitly adjusts to clear $Y_t = C_t + I_t + G_t$

The first order conditions are (after defining $\Lambda_{t,t+1} \equiv \beta\psi_{c,t}\frac{\mu_{t+1}}{\mu_t}$):

$$\mu_t = \frac{1}{(C_t - bC_{t-1})} - \beta b \mathbb{E}_t^H \left\{ \frac{1}{(C_{t+1} - bC_t)} \right\} \tag{7}$$

$$\psi_{l,t}\chi L_t^\eta = \mu_t w_t^h \tag{8}$$

$$1 = \mathbb{E}_t^H \left\{ \Lambda_{t,t+1}\Pi_{t+1}^{-1} R_t^{d,c} \right\} + \mu_t^d \nu_t^d \tag{9}$$

$$1 = \mathbb{E}_t^H \left\{ \Lambda_{t,t+1}\Pi_{t+1}^{-1} R_t^{d,s} + \mathcal{A}_t^s \right\} \tag{10}$$

$$1 = \mathbb{E}_t^H \left\{ \Lambda_{t,t+1}\Pi_{t+1}^{-1} R_t^{\ell,hh} + \mathcal{A}_t^\ell \right\} \tag{11}$$

where μ_t and μ_t^d are the multipliers associated with the budget and deposit-in-advance constraints, respectively. Demand for the deposits and loans of a specific monopolistic bank can be obtained as a cost-minimisation exercise. Appendix A.6 sets this out, and defines the partial derivatives of the adjustment costs $\mathcal{A}^\ell$ and $\mathcal{A}^s$.

3.2 Goods production

There are four types of firms interacting in the model: i) a capital producer turns unconsumed final output into investment subject to an adjustment costs ii) a representative wholesale firm transforms capital and labour into wholesale output; iii) a continuum of monopolistic retail firms transforms wholesale output into differentiated retail output and iv) a representative final goods firm buys retail outputs and repackages them into a final good. The main difference from a standard framework as in Sims and Wu (2021) is the modelling of the representative wholesale firm, which must borrow from both banks and NBFIs.

The retail and final goods layers are present simply to generate a monopolistic friction and nominal price rigidity and are set up in standard fashion, details can be found in Appendices A.4 and A.5. Similarly, details of the capital producer are located in Appendix A.3.

As with households, non-financial firms do not have perfectly rational expectations of the future; we denote firm expectations by $\mathbb{E}_t^F$. This primarily affects capital producers (through the expected return on investment) and retail firms (through anticipated future inflation). Details are set out in Appendix A.1.

We turn now to the representative wholesale firm, which produces homogenous wholesale output following a Cobb-Douglas production function:

$$Y_{m,t} = A_t(u_t K_t)^{\alpha} L_{d,t}^{1-\alpha} \tag{12}$$

Where Y_m is output, $L_{d,t}$ is the labour factor of production, A_t is a productivity variable that follows an AR(1) process, K_t is the stock of firm's capital that is multiplied by u_t, the capital utilisation. $\hat{I}_t$ is new capital purchased from the capital producer at a price p_t^k. K_t is accumulated following the standard law of motion of physical capital, with time-varying depreciation rate $\delta_t(u_t)$:

$$K_{t+1} = \hat{I}_t + (1 - \delta(u_t))K_t \tag{13}$$

$$\delta(u_t) = \delta_0 + \delta_1(u_t - 1) + \frac{\delta_2}{2}(u_t - 1)^2 \tag{14}$$

Following Carlstrom et al. (2017) and Sims and Wu (2021), we impose that the representative wholesale firm borrows to fund investment. In other words, the firm uses a mixture $\mathcal{B}_t$ of loans and bonds to buy the fixed fraction $\psi \in [0,1]$ of new physical capital $\hat{I}$. This friction creates the "loan in advance constraint" that is always binding, shown in Equation 15. Innovating slightly from Sims and Wu (2021), we allow the marginal fraction of investment financed through borrowing to diverge from the total level of borrowing.

$$\psi_t = Q_t f_t^{NEW} + \ell_t^{NEW} \tag{15}$$

$$\psi_t \equiv \psi' p_t^k \hat{I}_t + \bar{\psi} + \epsilon_{\psi,t} \tag{16}$$

$$f_t^{NEW} = f_t - \kappa_f f_{t-1} \Pi_t^{-1} \tag{17}$$

$$\ell_t^{NEW} = \ell_t - \kappa_l \ell_{t-1} \Pi_t^{-1} \tag{18}$$

$$\mathcal{B}_t = \left[\zeta_{1,t}^{\frac{1}{\zeta_2}} \left(Q_t f_t^{NEW} \right)^{\frac{\zeta_2 - 1}{\zeta_2}} + (1 - \zeta_{1,t})^{\frac{1}{\zeta_2}} \left(\ell_t^{NEW} \right)^{\frac{\zeta_2 - 1}{\zeta_2}} \right]^{\frac{\zeta_2}{\zeta_2 - 1}} \tag{19}$$

$$\ell_t = \left[\int_0^1 \ell_{j,t}^{\frac{\xi_t^{\ell} - 1}{\xi_t^{\ell}}} dj \right]^{\frac{\xi_t^{\ell}}{\xi_t^{\ell} - 1}} \tag{20}$$

$\mathcal{B}_t$ is a CES aggregate of bond f_t^{NEW} and bank loan ℓ_t^{NEW}, which gives wholesale firms flexibility over whether they are financed by banks or NBFIs (Equation 19). This is intended to represent behaviour by the marginal wholesale firm, who is capable of borrowing either through bond markets

or the banking sector. Bonds are optimally a fraction ζ_1 of total borrowing; if $Q_t f_t^{NEW} < \zeta_{1,t}\mathcal{B}_t$ then firms are willing to pay a premium on bond debt (relative to bank loans) and vice-versa if $Q_t f_t^{NEW} > \zeta_{1,t}\mathcal{B}_t$. The extent of this premium depends on the elasticity of substitution ζ_2. If $\zeta_2 \to \infty$ then bank loans and bonds are perfect substitutes and there is never a spread between bank loans and bonds; if $\zeta_2 = 0$ then they are completely separate markets and wholesale firms will pay any spread to ensure $Q_t f_t^{NEW} = \zeta_{1,t}\mathcal{B}_t$.

Analogously to the household setup, the second layer of the CES in Equation 20 specifies that ℓ_t is itself a CES aggregate of individual bank loans $\ell_{j,t}$ from each bank $\ell_{j,t}$. This gives banks monopolistic market power over firms as in Gerali et al. (2010) and Ulate (2021) since bank loans are themselves not perfect substitutes. In equilibrium, this will ensure a spread between the policy rate of interest on reserves and bank loans.

Finally, Equation 18 states that bank loans are repaid at exactly the same rate as bonds. That is, a fraction κ_f of bonds mature and expire each period and similarly a fraction κ_l of bank loans are repaid. There is no reason this must be the case, and it is trivial to generalise the model such that they are repaid at different speeds. However, in the absence of a clear motivation for doing so we assume the same evolution process to simplify analysis. This can be interpreted as a long-term bank loan that pays a variable rate of interest.

Let NB_t denote net financing for convenience and R_t^ℓ be the average gross return paid on bank loan liabilities. The wholesale firm net dividend each period can be expressed as:

$$\begin{aligned}
\max_{\ell_t, f_t, L_{d,t}, \hat{I}_t} V_{F,t} &\equiv \sum_{j=0}^{\infty} \Lambda_{t,t+j} DIV_{m,t} \\
DIV_{m,t} &= p_{m,t} A_t \left(u_t K_t\right)^{\alpha} L_{d,t}^{1-\alpha} - w_t L_{d,t} - p_t^k \hat{I}_t + NB_t \\
NB_t &\equiv \mathcal{B}_t + (\ell_t - \ell_t^{NEW}) + Q_t(f_t - f_t^{NEW}) - \Pi_t^{-1}\left[(1+\kappa_f Q_t) f_{t-1} + R_{t-1}^{\ell}\ell_{t-1}\right] \\
R_t^{\ell} &\equiv \ell_t^{-1} \int_0^1 R_{j,t}^{\ell}\ell_{j,t} dj
\end{aligned}$$

The first order conditions with respect to labour $L_{d,t}$, capital K_{t+1}, bonds f_{t-1} and loans $\ell_{j,t}$ are:

$$w_t = (1-\alpha) p_{m,t} A_t (u_t K_t)^{\alpha} L_{d,t}^{-\alpha} \tag{21}$$

$$(1+\psi' M_{3,t})p_t^k = \mathbb{E}_t^F \Lambda_{t,t+1}\left[\alpha p_{m,t+1} A_{t+1} u_{t+1}^{\alpha} K_{t+1}^{\alpha-1} L_{d,t+1}^{1-\alpha} + (1-\delta(u_{t+1}))p_{t+1}^k(1+\psi' M_{3,t+1})\right] \quad (22)$$

$$Q_t M_{3,t} + \mathcal{B}_t^f = \mathbb{E}_t^F \Lambda_{t+1}\Pi_{t+1}^{-1}\left(1+\kappa_f Q_{t+1} + \kappa_f Q_{t+1} M_{3,t+1}\right) \quad (23)$$

$$M_{3,t} + \mathcal{B}_t^{\ell} = \mathbb{E}_t^F \Lambda_{t+1}\Pi_{t+1}^{-1}\left(R_{j,t}^{\ell} + \kappa_{\ell} M_{3,t+1}\right) \quad (24)$$

Where w_t is the real wage, $p_{m,t}$ is the price of wholesale output, p_t^k is the price of new capital, $M_{3,t}$ is the shadow value of the investment constraint, and $\mathcal{B}_t^X$ is the partial derivative of $\mathcal{B}_t$ with respect to X_t. All that remains is to resolve the partial derivatives and obtain loan demand as a function of each bank's interest rate. We obtain:

$$\mathcal{B}_t^f = Q_t\left[\frac{\zeta_{1,t}\mathcal{B}_t}{Q_t f_t}\right]^{\frac{1}{\zeta_2}} \quad (25)$$

$$\mathcal{B}_t^{\ell} = \left[\left(1-\zeta_{1,t}\right)\frac{\mathcal{B}_t}{\ell_t}\right]^{\frac{1}{\zeta_2}} \quad (26)$$

Finally, we resolve the optimal composition of bank loans as a cost-minimization exercise in Appendix A.6.

3.3 Financial Sector

3.3.1 NBFIs

There is a fixed number of NBFIs. They hold long-term corporate and sovereign bonds, as well as single-period wholesale deposits with banks. They fund themselves through shares issued to households and internal equity. The representative NBFI maximisation problem is the following:

$$\max_{\{f_t, b_t, h_t, d_t^s\}} V_t = \Lambda_{t,t+1}\left[\left(1-\sigma\right)n_{t+1}^s + \sigma V_{t+1}\right] \quad (27)$$

$$\text{s.t.} \quad Q_t f_t + Q_{B,t} b_t + h_t = d_t^s + n_t^s \quad (28)$$

$$n_t^s = \sigma\Pi_t^{-1}\left[R_t^F Q_{t-1} f_{t-1} + R_t^B Q_{B,t-1} b_{t-1} + R_{t-1}^H h_{t-1} - R_{t-1}^{d,s} d_{t-1}^s\right] - LSC_t - DSC_t \quad (29)$$

$$h_t = \left[\int_0^1 \left(h_t\left(j\right)\right)^{\frac{\xi_h - 1}{\xi_h}} dj\right]^{\frac{\xi_h}{\xi_h - 1}}, \quad (30)$$

Where f_t are corporate bonds issued by a representative wholesale firm, b_t are long-term bonds

issued by the fiscal authority, h_t are wholesale deposits with banks, n_t^s is net worth and d_t^s are shares issued to households. A fraction σ of NBFIs decay each period and return their net worth to households. This setup gives NBFIs a slightly higher discount rate than households, and creates inertia in their net worth. As with households and wholesale firms, NBFIs consider different each monopolistic bank to offer an imperfectly substitutable wholesale deposit product, creating a markdown on rates.

Importantly, the three assets owned by NBFIs are imperfect substitutes and provide to NBFIs *duration* through long term corporate and government bonds, as well as *liquidity benefits* through government bonds and wholesale deposits. We capture these properties with the following Liquidity Scarcity Cost, LSC_t, and Duration Scarcity Cost, DSC_t. We use two additional parameters $\overline{LSC}$ and $\overline{DSC}$, which are normalised to ensure costs are zero in steady state:

$$LSC_t = \frac{\nu_{1,t}}{1+\nu_2}\left(\frac{d_t^s}{\nu_{B,t}Q_{B,t}b_t + h_t}\right)^{1+\nu_2} - \overline{LSC} \tag{31}$$

$$DSC_t = \frac{\varphi_{1,t}}{1+\varphi_2}\left(\frac{d_t^s}{Q_{B,t}b_t + Q_t f_t}\right)^{1+\varphi_2} - \overline{DSC}. \tag{32}$$

Conceptually, these costs build on the "portfolio balance" channel widely employed in papers such as Harrison (2024) and Alpanda and Kabaca (2020), which are in turn motivated by the "preferred habitat" modelling developed by Ray (2019) and Vayanos and Vila (2021) amongst others. The specific functional form is adapted from Kumhof and Salgado-Moreno (2024), and is used for consistency with the banking sector setup (Section 3.3.2). This captures the fact that government bonds are substitutes for bank deposits (as they both provide liquidity) as well as for corporate bonds (as they have the same duration). Following central bank asset purchases, NBFIs therefore have a clear incentive to rebalance their portfolios into both corporate bonds and wholesale deposits to replace the lost liquidity and duration.

$\nu_{1,t}$, $\varphi_{1,t}$ and $\varphi_{B,t}$ are modelled as AR(1) shock processes with steady state values ν_1, ν_B and φ_1. These parameters will control the steady-state value of liquidity and duration to NBFIs, and hence determine steady-state spreads on the different assets. The parameters ν_2 and φ_2 will in turn determine how much this value changes along with portfolio composition; values $\nu_2 = \varphi_2 = -1$

would imply spreads do not react to portfolio composition while values $\nu_2 = \varphi_2 \to \infty$ would imply liquidity and duration costs are extremely strong and force the NBFI to keep its portfolio in a very strict ratio.

Let $\phi_t \equiv dV_t/dn_t$ denote the value of net worth (shadow value of budget constraint). Denote by LSC_t^X and DSC_t^X the partial derivatives of LSC and DSC with respect to X_t. First order conditions are therefore:

$$\phi_t \left(1 + LSC_t^B + DSC_t^B\right) = \mathbb{E}_t \Lambda_{t,t+1} \Omega_{t+1} \Pi_{t+1}^{-1} R_{t+1}^B \tag{33}$$

$$\phi_t \left(1 + DSC_t^F\right) = \mathbb{E}_t \Lambda_{t,t+1} \Omega_{t+1} \Pi_{t+1}^{-1} R_{t+1}^F \tag{34}$$

$$\phi_t \left(1 + LSC_t^H\right) = \mathbb{E}_t \Lambda_{t,t+1} \Omega_{t+1} \Pi_{t+1}^{-1} R_{t+1}^H \tag{35}$$

$$\phi_t \left(1 - LSC_t^D - DSC_t^D\right) = \mathbb{E}_t \Lambda_{t,t+1} \Omega_{t+1} \Pi_{t+1}^{-1} R_t^{d,s}. \tag{36}$$

Where $\Omega_t \equiv 1 - \sigma + \sigma\phi_t$. Partial derivatives of the liquidity and duration costs are straightforward, and defined in Appendix A.7.

3.3.2 Banks

Banks hold central bank reserves, m_t, loans to both households, ℓ_t^{hh}, and wholesale firms, ℓ_t^f and they fund themselves through retail deposits from households d_t^c and wholesale deposits from NBFIs h_t. Moreover, banks take the price of reserves and wholesale deposits as given, but impose markups over loans and markdowns over deposits as they are assumed to have market power as in Gerali et al. (2010). Banks are indifferent between extending new loans to household or wholesale firms, which are assumed to be adjustable-rate, long-term loans. This means that banks take into account the firms loan's law of motion given by Equation (18).

Leverage Friction. We introduce several frictions associated with the post-GFC banking environment in most advanced economies. That is, we introduce key frictions that capture both the macroprudential regulation and the abundant supply of central bank reserves. First, following Gerali et al. (2010) we assume banks face Ξ_t costs when deviating from their target leverage ratio, v^b. This frictions captures, in a reduced-form way, the supplemental leverage ratio introduced under Basel III.

Reserve Scarcity Cost. Second, we introduce bank's Reserve Scarcity Cost, RSC_t, following Kumhof and Salgado-Moreno (2024). Each bank faces a reserve scarcity cost that is increasing in the ratio of both household deposits d_t^c and wholesale deposits h_t, to reserves m_t. This specification captures the liquidity benefits of reserves for banks, such as reductions in transaction costs when faced with deposits outflows. Note that the functional form of our RSC_t is the inverse of the "reserves convenience yield function" in Vissing-Jørgensen (2023), and analagous to the NBFI liquidity and duration costs specified earlier.

Within the RSC, we capture one of the Basel Committee's key reform: the "Net Stable Funding Ratio" (BIS, 2014). For this, we innovate on Kumhof and Salgado-Moreno (2024) and introduce a distinction between household deposits and wholesale deposits with the parameter $\alpha^d \in (0,1)$. We restrict α_d to be less than one since household deposits are less volatile than wholesale deposits and consequently do not require the same degree of liquidity management; setting $\alpha^d = 0$ nests the setup in Kumhof and Salgado-Moreno (2024).

Operating Costs. Finally, we include bank operating costs ς as a share of bank's net worth, n_t^c, as in Ulate (2021). We also follow Ulate (2021) by imposing an exogenous dividend policy on the bank, which is a tractable method of capturing "dividend adjustment costs." Conceptually, the bank cannot immediately respond to sudden losses by raising new equity. Combined with the capital-to-assets target, this ensures that banks reduce lending after making a loss. We implement this (similar to Ulate) by defining profits (before operating costs ςn_{t-1}^c) $\mathcal{P}_{j,t}$. We then assume that dividends $DIV_{j,t} \equiv (1-\varrho)\,\mathcal{P}_{j,t}$ are a constant fraction of this net profit. In practice, ς and ϱ are not independent of each other; for any given cost fraction ς there is a defined value for dividends ϱ which ensures the existence of a stable steady state. We obtain two equations:

$$\begin{aligned}
\mathcal{P}_{j,t} &= \Pi_t^{-1}\Big[R_{j,t-1}^{\ell}\ell_{j,t-1}^{f} + R_{j,t-1}^{\ell,hh}\ell_{j,t-1}^{hh} + R_{t-1}^{m}m_{j,t-1} \\
&\qquad - R_{j,t-1}^{d,c}d_{j,t-1}^{d,c} - R_{j,t-1}^{h}h_{j,t-1}\Big] - \Xi_{j,t-1} - RSC_{j,t-1} \\
n_{j,t}^{c} &= \varrho\mathcal{P}_{j,t} + (1-\varsigma)\,n_{j,t-1}^{c}
\end{aligned}$$

The zero lower bound is also implemented as an occasionally binding constraint at this stage.

The optimization problem of bank j is therefore:

$$\max_{\left\{R^{\ell}_{j,t},R^{d,c}_{j,t},m_{j,t},h_{j,t}\right\}} V^{c}_{j,t} = (1-\varrho)\,\mathcal{P}_{j,t} + \mathbb{E}_t\left\{\Lambda_{t,t+1}V^{c}_{j,t+1}\right\} \tag{37}$$

$$\text{s.t.} \quad m_{j,t} + \ell_{j,t} + \ell^{hh}_{j,t} = d^{c}_{j,t} + h_{j,t} + n^{c}_{j,t} \tag{38}$$

$$n^{c}_{j,t} = \varrho\mathcal{P}_{j,t} + (1-\varsigma)\,n^{c}_{j,t-1} \tag{39}$$

$$\mathcal{P}_{j,t} = \Pi_t^{-1}\Big[R^{\ell}_{j,t-1}\ell^{f}_{j,t-1} + R^{\ell,hh}_{j,t-1}\ell^{hh}_{j,t-1} + R^{m}_{t-1}m_{j,t-1} - R^{d,c}_{j,t-1}d^{d,c}_{j,t-1} - R^{h}_{j,t-1}h_{j,t-1}\Big] - \Xi_{j,t-1} - RSC_{j,t-1} \tag{40}$$

$$R^{d,c}_{j,t} \geq 1 \tag{41}$$

with

$$\Xi_{j,t} \equiv \frac{\kappa^{c}_{t}}{2}\left(\frac{n^{c}_{j,t}}{\ell^{f}_{j,t}+\ell^{hh}_{j,t}} - v^{b}\right)^{2} \tag{42}$$

$$RSC_{j,t} \equiv \frac{\eth_{1,t}}{1+\eth_2}\left(\frac{\alpha^{d}d^{c}_{j,t}+h_{j,t}}{m_{j,t}}\right)^{1+\eth_2} \tag{43}$$

First order conditions are derived in full in Appendix A.9. We here simply present the solutions to the optimisation problem, with an auxiliary variable $\vartheta_{j,t}$ which is closely connected to the value of the balance sheet constraint/shadow value of net worth. In symmetric equilibrium we obtain:

$$R^{m}_{t} = \Pi_{t+1}\left(\Lambda^{-1}_{t,t+1}\vartheta_t + +RSC^{m}_{t}\right) \tag{44}$$

$$R^{h}_{t} = \Pi_{t+1}\left(\Lambda^{-1}_{t,t+1}\vartheta_t - RSC^{h}_{t}\right)\left(\frac{\xi^{h}_{t}}{\xi^{h}_{t}-1}\right) \tag{45}$$

$$R^{\ell}_{t} = \Pi_{t+1}\left(\Lambda^{-1}_{t,t+1}\vartheta_t + \Xi^{\ell}_{t}\right)\left(\frac{\xi^{\ell}_{t}}{\xi^{\ell}_{t}-1}\right) \tag{46}$$

$$R^{\ell,hh}_{t} = \Pi_{t+1}\left(\Lambda^{-1}_{t,t+1}\vartheta_t + \Xi^{\ell}_{t}\right)\left(\frac{\xi^{\ell,hh}_{t}}{\xi^{\ell,hh}_{t}-1}\right) \tag{47}$$

$$R^{d,c}_{t} = \max\left\{\Pi_{t+1}\left(\Lambda^{-1}_{t,t+1}\vartheta_t - RSC^{d}_{t}\right)\left(\frac{\xi^{d}_{t}}{\xi^{d}_{t}-1}\right), 1\right\} \tag{48}$$

3.4 Central Bank

3.4.1 Interest Rate Policy

The central bank sets the short-term (gross, nominal) policy rate R_t^m according to the following Taylor rule:

$$R_t^{tr} = (1-\rho_r)\bar{R}^m + \rho_r R_{t-1}^{tr} + (1-\rho_r)[\phi_\pi(\Pi_t^A)^{1/4} + \phi_y \ln(Y_t/\bar{Y})] + \epsilon_{r,t} \tag{49}$$

$$\Pi_t^A \equiv \sum_{j=-3}^{0} (\Pi_{t-j} - \bar{\Pi}) \tag{50}$$

$$R_t^m = \max\left\{R_t^{tr}, PELB\right\} \tag{51}$$

with $\bar{R}^m$, $\bar{Y}$ and $\bar{\Pi}$ being steady state values of the policy rate, output, and the inflation target. Π_t^A denotes year-on-year inflation. In standard times, i.e. away from the lower bound, the central bank sets the interest rate on reserves R_t^m equal to the Taylor rule R_t^{tr}. When the Taylor rate falls below the effective lower bound $PELB$, the central bank instead sets the rate on reserves equal to this lower bound.

3.4.2 Balance-sheet Policies

The central bank issues a single liability, reserves. They hold government bonds b_t^{CB} as their only asset, which we assume follows an autoregressive process. Balance sheet policy is implemented as in Sims and Wu (2021), with shock term ϵ_t^{QE} capturing QE/QT. The central bank has no net worth, returning any book value, T_t^{CB}, to the treasury and receiving treasury support to cover any book losses. We assume for simplicity that these transfers take place contemporaneously with the book profit or loss; in reality these payments may be delayed. Denoting by $\bar{X}$ the steady state level of X, we have central bank balance-sheet policies described by:

$$m_t = Q_{B,t} b_t^{CB} \tag{52}$$

$$\log b_t^{CB} = (1-\rho_b)\log \bar{b}^{CB} + \rho_b \log b_t^{CB} + \epsilon_t^{QE} \tag{53}$$

$$T_t^{CB} = \Pi^{-1}\left[(1+\kappa_b Q_{B,t}) b_{t-1}^{CB} - R_{t-1}^m m_{t-1}\right] \tag{54}$$

3.4.3 Discussion: Transmission of Monetary Policy

Interest Rate Policy How do changes in the policy interest rate transmit to the real economy? Taking a rate cut as an example, banks pass off the cut almost perfectly[6] to NBFIs through the wholesale deposits rate and to firms and households through loan rates. This first-stage transmission impact NBFIs *directly* as they receive a lower rate on their wholesale deposits and *indirectly* as they lower their rates on household savings and corporate bonds to compete with banks.[7] The pass-through to households is affected by their loan adjustment costs while the rate transmission to corporate bonds is impaired by frictions faced by firms (unable to arbitrage between bonds and loans) and NBFIs (Duration Scarcity Cost).

From here, the transmission is standard for a New Keynesian model. Households and firms respond to lower borrowing costs by borrowing more, consuming more, and investing more. Firms respond to this increase in demand by raising prices, fuelling inflation.

There is an additional layer to the monetary transmission, giving centre stage to NBFIs and wholesale deposits. In our model non-banks are critical for the transmission of monetary policy because they are the only holders of long-term assets.[8] This has important consequences: following the policy rate cut, the valuation of both corporate and government bonds rises, allowing NBFIs to record a windfall gain on their asset side and pay higher dividends, attracting more household savings. The higher household savings, however, trigger both the Liquidity and Duration Scarcity Costs. To avoid the former, NBFIs increase their wholesale deposits, that banks balance on the asset side with more loans to firms and households. To avoid the latter, NBFIs increase their holdings of long duration assets, pushing down yields of corporate and government bonds. Taken together, the larger loan supply from banks and the lower yields on bonds fuel investment and support aggregate demand.

[6] The transmission is not one-to-one, primarily due to the markups on loans and deposits. Deposit rates are also slightly affected by frictions on the banks side (Reserve Scarcity Cost).

[7] The extent of this pass-through will depend on the degree of competitive pressure between banks and NBFIs in each market, and the strength of the direct link between banks and non-banks through the wholesale deposit market.

[8] Banks issue loan-term loans to firms, but since these are variable-rate they are not subject to the same revaluation effects as fixed-rate products.

Quantitative Easing We model Quantitative Easing as central bank purchases of government bonds from NBFIs financed by the creation of reserves held by commercial banks. This mirrors asset purchases in practice, with major central banks buying assets from non-banks (Joyce et al., 2012). However, central banks are unable to credit NBFIs directly since NBFIs definitionally do not have access to the central bank balance sheet. Instead, the central bank creates reserves for the banking sector in exchange for non-banks being credited with wholesale deposits. Hence, deposits are a critical component of QE transmission (Acharya and Rajan, 2024). We replicate these dynamics and the key role of wholesale deposits.

In our model, following a QE shock, wholesale deposits increase. This is driven by two channels. First, on the NBFI side, the loss of liquid assets (government bonds) raises NBFI Liquidity Scarcity Costs, acting as a drag on NBFIs profits. To avoid this, NBFIs replace the lost government bonds with the alternative source of liquidity, wholesale deposits. Second, on the banks side, they have acquired reserves that must be balanced with increased funding, In addition, the larger reserves lower the banks Reserve Scarcity Costs, reducing the marginal cost to the bank of each wholesale deposit. Ultimately, banks are more willing to issue loans at lower rates.[9]

The QE shock also lowers the yields on corporate bonds. By selling government bonds to the central banks, NBFIs lose long duration assets, reducing their duration scarcity costs. As a results, NBFIs are willing to take on more of the alternative long duration asset, corporate bonds, lowering their yields. Taken together, the larger loan supply from banks and NBFIs portfolio rebalancing towards corporate bonds fuel investment and support aggregate demand.

We note that in our model QE transmits to the real economy also through consumption. This is because NBFIs, recording a lower average return on their assets, offer a lower return on their liabilities, attracting less households savings. Hence, households save less and increase consumption as per standard intertemporal consumption channel (Harrison, 2024).

[9]In the model the increase in wholesale deposits is less persistent than QE. This is because households ultimately arbitrage away the spread with loan rate by adjusting their allocation of NBFIs shares and bank loans (while in the short term this is restricted by the loan adjustment cost they face).

4 Model Calibration and Estimation

We use Bayesian methods to estimate 54 parameters, including key frictions in the financial sector. We employ the Dynare toolkit (Adjemian et al., 2024) to conduct a linear estimation with UK quarterly data between 1997Q2 and 2025Q3. Smets and Wouters (2007) is a classic example of a DSGE model estimated using this method, while Fernández-Villaverde and Guerrón-Quintana (2021) provide an excellent recent review of Bayesian estimation as applied to DSGE models and discuss the methods, strengths and limitations of this approach. In the rest of this Section, we set out our data and prior distributions for parameters.

4.1 Data

We use 19 time series of macroeconomic and financial variables, featuring data on banks and NBFIs balance sheets as well as on firms' funding sources. We use UK data from 1997Q2-2025Q3, choosing as our start date the first quarter after central bank independence. All data are shown in Table 1 below, along with their source. Some data have reduced availability, and these series are marked where appropriate.

Following Braun et al. (2025) and Albuquerque et al. (2025), we additionally treat all data in the period 2020-21 as 'missing'. This is a reasonable alternative to maximise available data without requiring the complex implementation of Covid-specific shocks, which are not well represented by traditional structural shocks (Albuquerque et al., 2025).

When applying a stationary DSGE to model to real-world data, it must be adjusted and de-trended where appropriate to account for trend growth. For most volume series such as GDP and consumption, we follow the common practice of taking logs, first differencing and de-meaning the resulting sequence. This strips out trend growth across our sample period and ensures variables are stationary. We prefer this procedure to the alternative method of de-trending the data using a filter method such as a one-sided HP (Wolf et al., 2020) or Hamilton (Hamilton, 2018) filters as these methods are more complex, entail more data loss from removing lagged values, and experience difficulties reconciling the different frequencies of financial and economic cycles.

For most rate measures, we instead take simple first-differences without logging or de-meaning.

Table 1: Data Series Used for Estimating the Model

Data	Source	Availability	Adjustment
GDP	ONS (ABMI)		Log-diff, de-meaned
Consumption	ONS (ABJR+HAYO)		Log-diff, de-meaned
Investment	ONS (NPQT)		Log-diff, de-meaned
Labour	ONS (YBUS)		Log-diff, de-meaned
Wages	ONS (KAB9)	2000Q1-	Log-diff, de-meaned
Bank Loans (firms)	Bank of England		Log-diff, de-meaned
Bank Loans (households)	Bank of England		Log-diff, de-meaned
NBFI Corp. Bonds	Bank of England		Log-diff, de-meaned
Bank Deposits	ONS UKEA		Log-diff, de-meaned
NBFI Shares	ONS UKEA		Log-diff, de-meaned
Wholesale Deposits	ONS UKEA		Log-diff, de-meaned
APF Bonds (QE)	Bank of England		Share of GDP
CPI	ONS (D7BT)		Log-Diff
Bank Rate	Bank of England		Differenced
Corp. Bond Yields	Bloomberg	2000Q1-	Differenced
Gov. Bond Yields	FRED		Differenced
Bank Deposit Rate	Bank of England	1998Q3-	Differenced
Loan Rate (firms)	Bank of England	2004Q1-	Differenced
Loan Rate (households)	Bank of England	2004Q1-	Differenced

Note: Data available 1997Q2 to 2025Q1 unless otherwise specified. Several items are aggregated from the ONS UK Economic Accounts (UKEA): bank deposits (sector S.14, item AF.22N1), NBFI shares (sector S.14, items AF.29 and AF.52N1) and wholesale deposits (sectors S.124-129, items AF.22N1 and AF.31N5). Corporate bond yields are the ICE BofA BBB Sterling Corporate Non-Financial Index (UC40). UK government bond yields from FRED (IRLTLT01GBQ156N). Bank deposits, firm and household loan rates and APF bonds from the Bank of England Database (CFMHSCV, CFMBI58, CFMBI64, LPMVYDG).

This amounts to asserting that interest rates and yields are trend-stationary and will eventually return to their steady-state level. This ensures we do not over-correct the data for the long period spent at the zero lower bound that dominates the later half of the sample, and impose an unrealistic downward trend.

The two exceptions to this process are inflation and the central bank balance sheet. Inflation is expressed in levels rather than first differences. This amounts to an assumption that long-term inflation is known to be exactly 2% both in the model and in the data. Similarly, the government bonds held by the central bank Asset Purchase Facility (APF) are expressed as a percentage of GDP and fixed at zero before 2009. The implicit assumption is that all assets during Quantitative Easing (QE) programs will eventually be unwound and either sold back to the market or simply

not replaced when they mature. In other words, we are asserting that the steady-state volume of QE is zero.

The choice of most data series is self-explanatory, but a few require some justification. For the loan rates offered to households and firms, we use the 'effective rate paid on secured-lending to households, variable rate only'. We focus on the secured lending rate as the most relevant rate since the overwhelming majority of bank lending to households is secured (against property), and use variable rate lending since loan rates in the model are variable rate. Similarly for firms, we use the 'effective rate paid on other loans to private non-financial corporations, variable rate only' as again all loans in our model are variable rate.

For corporate bonds, we use the spread between government bonds and UK investment-grade corporate bonds. We take the spread on investment grade bonds as representative, but results are broadly robust to using alternative measures.

A full visualisation of the transformed data can be seen in Figure A.3 in Appendix D.3.

4.2 Calibration

All model parameters not included in the estimation are listed below in Table 2. Many of our model parameters are standard, while otherwise are calibrated to specific targets.

A few parameters and calibration targets are worth discussing as they are more involved. We set the steady state debt/GDP ratio at 3.4 (85% of annual GDP), in line with the average since 2010. We use 2010 as our baseline given the significant structural shifts in fiscal policy and the introduction of the Office for Budget Responsibility; a full-sample average would produce an implausibly low value for public sector debt.

We assume for simplicity that firms repay bank debt at the same pace as corporate bond debt, i.e. at 10% per year. This avoids creating a needless asymmetry between the two types of corporate borrowing and simplifies analysis. Choosing a shorter duration for bank debt would increase steady-state *new* borrowing from banks without affecting the steady-state stock; this would not meaningfully shift model dynamics but would result in a smaller calibrated value for ζ_1.

Table 2: Standard and Calibrated Parameters

(A) Parameters

Parameter	Definition	Value	Source
α	Capital share	0.35	Standard
β	Discount factor	$0.97^{1/4}$	Standard
δ_0	Depreciation rate	0.0225	Standard
Π_s	Gross inflation (q)	1.005	Standard
ε_p	Inverse Markup (Goods)	11	Standard
ε_w	Inverse Markup (Wages)	11	Standard
g_y	Govt spending share	0.202	Mean 1997-2025
η	Inverse Frisch elasticity	0.5	Standard
σ	NBFI Survival	0.95	Sims and Wu (2021)
$\bar{\psi}$	Firm debt (fixed)	0.012	Calibrated
bg_y	Gov. Debt/GDP	0.85	Mean 2010-2025[a]
ϕ_π	Taylor rule inflation	1.5	Standard
ϕ_y	Taylor rule output	0.5	Standard
$frac_b$	SS CB reserves/GDP	0.52	Median 2006-2025
κ_b	Gov. Bond duration	$1-40^{-1}$	10-year
κ_f	Corp. Bond duration	$1-40^{-1}$	10-year
κ_e	Loan decay	κ_f	Assumed
ϱ	Bank Profit Retention	0.8889	Calibrated
δ_1	Capital Utilization	0.0299	$u=1$ in SS
χ	Labor disutility	0.9748	$L=1$ in SS
v_b	Gerali cost ratio	0.15	Zero Gerali costs in SS
ζ_1	Firm CES share	0.3999	Calibrated
ν_1	NBFI Liquidity	1.0534	Calibrated
φ_1	NBFI Duration	-0.0567	Calibrated
ξ_1	Inverse Markup (Wholesale)	-10 107	Calibrated
ξ_{2h}	Inverse Markup (household loans)	606.2	Calibrated
ξ_{2f}	Inverse Markup (firm loans)	199.3	Calibrated
ξ_3	Inverse Markup (Deposits)	-1468	Calibrated
$\eth_1$	Reserve convenience	0.0001	Calibrated
X	NBFI startup equity	0.0113	Calibrated
ν^d	Deposit velocity	0.2956	Calibrated

[a] ONS series HF6X.

4.3 Estimation Results

Table 3 shows the prior and posterior distributions of all structural parameters; shock variances and persistences are reported in Appendix D.4. Most values are standard and require little explanation. Where parameters are naturally bounded over $(0, \infty)$ we use gamma distributions, where they are

Table 2: Standard and Calibrated Parameters (continued)

(B) Calibration Targets

Calibration Target	Value	Source
Corp. bond spread ($R^F - R^B$)	1.34%	Mean 1997-2025[a]
Gov. bond spread ($R^B - R^m$)	0.69%	Mean 1997-2025, estimation data
Loan spread ($R^F - R^m$)	2.06%	Mean 2004-2025, estimation data
Loan spread ($R^H - R^m$)	1.87%	Mean 2004-2025, estimation data
Firm debt / GDP	1.751	Mean 1997-2025, estimation data
Bank deposit markdown	25 bps	UK effective lower bound 2016-20
NBFI market share	0.4	2008 market share, estimation data
FI leverage	4	Sims and Wu (2021)
Bank Leverage	6.5	Average 1997-2024, internal data
Bank loans households/firms	2.10	Mean 1997-2025, estimation data
Wholesale deposits/GDP	1.3	Mean 1997-2025, estimation data
Wholesale deposit spread	-2bps	SONIA median 2006-2025[b]
Wholesale deposit markdown	-4bps	SONIA median 2010-2019

[a] UK Investment grade corporate bond spread, Bank of America series URNF OAS.
[b] SONIA begins in 2006. See Appendix D.2.

bounded over $(0, 1)$ we instead use beta distributions. The elasticity parameters ν_2, φ_2 and ζ_2 are all strictly negative; we therefore assume that $-\nu_2$, $-\varphi_2$ and $-\zeta_2$ follow gamma distributions. Exceptionally, we apply a uniform distribution over $(0, 1)$ for the deposit reserve scarcity cost parameter α_D to facilitate the possibility of a very small value. The elasticity of reserve scarcity $\eth_2$ follows a gamma distribution downshifted by one, such that it is bounded on $(-1, \infty)$.

We discuss in depth only the financial parameters, since other results are broadly in line with those found by other papers such as Smets and Wouters (2007) and Albuquerque et al. (2025).

The most notable results are for the portfolio frictions. On the firm side, an elasticity parameter $\zeta_2 = 2.34$ suggests that firms are fairly inelastic over their funding mix, but not completely rigid either. They wish to keep their funding ratio close to their preferred mix $\zeta_{1,t}$, but are willing to deviate if they are offered a sufficiently attractive rate of return from either NBFIs or banks. On the NBFI side, an estimated value $\nu_2 = -0.83$ suggests that NBFIs have a close-to-constant marginal value from liquid assets, and the 'liquidity premium' does not respond much to changes in the NBFI portfolio structure. Conversely, a value $\varphi_2 = -37.42$ on the duration side suggests that the duration premium does react substantially to changes in the NBFI portfolio.

Table 3: Prior and Posterior Distributions

Par.	Description	Prior Mean	Post. Mean	90% HPD Interval	Prior	Pstdev
ζ_2	Firm CES	20.000	2.3382	[0.0046, 5.1226]	Γ	19.000
ν_2	NBFI Liquidity	0.000	-0.8273	[-0.9140, -0.7405]	$\mathcal{N}$	10.000
φ_2	NBFI Duration	0.000	-37.4244	[-42.9725, -31.5117]	$\mathcal{N}$	10.000
κ_h	Loan Adj. (HH)	0.002	0.0033	[0.0024, 0.0042]	Γ	0.0019
κ_{nbfi}	NBFI Share Adj.	0.002	0.00002	[0.00000, 0.00005]	Γ	0.0019
κ_c	Bank Leverage	10.000	0.1855	[0.0092, 0.3279]	Γ	10.000
α_d	Deposit RSC	1.000	0.4569	[0.0004, 0.9434]	Γ	0.9000
$\eth_2$	Reserve Scarcity	10.000	-0.0441	[-0.8662, 0.7782]	Γ	10.000
ψ'	Loan-In-Advance	0.500	0.1160	[0.0060, 0.2140]	β	0.2500
b_h	Habit Persistence	0.500	0.7398	[0.6959, 0.7870]	β	0.2000
κ_i	Investment Adj.	10.000	3.1939	[1.6725, 4.8343]	Γ	8.0000
γ_p	Price Indexation	0.200	0.0454	[0.0001, 0.0926]	β	0.1500
γ_w	Wage Indexation	0.200	0.3671	[0.2452, 0.4803]	β	0.1500
ϕ_p	Price Stickiness	0.850	0.8603	[0.8344, 0.8853]	β	0.0500
ϕ_w	Wage Stickiness	0.850	0.7766	[0.7446, 0.8104]	β	0.0500
δ_2	Capital Utilisation	0.010	0.0086	[0.0071, 0.0100]	Γ	0.0020
$\mathfrak{m}^H$	Myopia (HH)	0.100	0.0062	[0.0000, 0.0134]	Γ	0.0800
$\mathfrak{m}^F$	Myopia (Firm)	0.100	0.1447	[0.0936, 0.1947]	Γ	0.0800

On the banking side, the reserve scarcity parameter is estimated at $\eth_2 = -0.04$; this is similar to the NBFI liquidity parameter and consistent with banks having a close-to-constant marginal benefit from holding reserves. [10] This value implies that household deposits are a stable funding source for banks compared with flightier NBFI deposits, but still create some liquidity management concerns for commercial banks.

Overall, our results broadly support the idea that both financial and non financial corporates are far from perfectly flexible over their asset and financing options. Firms do not regard bank loans and corporate bonds as perfect substitutes, and nor do NBFIs consider bank deposits and corporate bonds to be equivalent assets. However, our results also reject the alternative simplification of perfectly segmented markets. As we shall see, both firms and NBFIs are able and willing to shift their portfolio structure in response to policy, but only for a sufficiently attractive spread.

It is also worth touching on the loan adjustment cost κ_{hh}, which we estimate to be fairly small. This suggests that households are relatively free to adjust their borrowing from banks. However,

[10] This is higher than the calibrated value of -0.96 in (Kumhof and Salgado-Moreno, 2024). This partly reflects a different institutional setting in the UK compared with their US data, and partly due to our estimated value $\alpha_D = 0.46$ for household deposits (whereas they assume it to be zero).

it is not zero and will play a role in our results below by smoothing the path of household credit after a shock. This is not the case for the NBFI saving friction κ_{nbfi}, which is essentially zero and suggests households can almost frictionlessly adjust their savings and investments in NBFIs. We also estimate the Gerali et al. (2010) leverage friction κ_t^c to be somewhat smaller than other papers such as Gebauer and Mazelis (2023). This likely reflects our inclusion of additional bank frictions such as the reserve scarcity costs, and consequently this leverage friction does not play a large role in our results.

The myopia parameters $\mathfrak{m}^H = 0.01$ and $\mathfrak{m}^F = 0.15$ are smaller than those in Gabaix (2020) (who calibrates values of 0.15 and 0.2 respectively), but are directionally the same in the sense that firms exhibit more myopia than households and are therefore less sensitive to long-horizon events. As Gabaix notes, it is in practice difficult to disentangle myopia from other intertemporal frictions such as investment adjustment costs and habit persistence; without myopia we would estimate larger values for the investment adjustment cost parameter in particular.

Finally, the novel borrowing constraint parameter ψ' is estimated at 0.12. This implies that each unit of marginal investment is financed 12% through new borrowing, and 88% through equity or retained profit. This is much smaller than in Carlstrom et al. (2017) where it is implicitly set to 1, and also smaller than Sims and Wu (2021) who calibrate it at 0.8 based on total US borrowing (including household borrowing). Since we model household debt separately to firm debt, it is natural that firm borrowing will be smaller in our setting. The estimated value of 0.12 makes it clear that this is true at the margin as well as in total.

5 Analysis: Monetary Policy Through the Shadows

In this section, we use our estimated model to analyse the transmission of monetary policy through the banking and non-banking sectors. Throughout this section, we simulate the response to monetary policy with both smaller and larger NBFI market shares. In the baseline (green solid line), NBFI corporate credit share is set at 40%, reflecting UK firms' funding mix in 2008. We run two alternative scenarios in which NBFI corporate credit share is increased to the current 60%.

In the first alternative scenario (orange dashed line), this is implemented by increasing the firm-side preference for corporate bonds $\zeta_{1,t}$, which ensures firms prefer more bonds in their optimal

funding mix. This 'firm-side' NBFI expansion could be interpreted as a reduced cost to firms of issuing bonds, or an increase in firm concentration with a lower share of SMEs and a greater share of large firms.

In the second alternative scenario (purple dashed line), NBFI corporate credit share is increased by changing the mark-up on bank's loan rate $-1/\xi_t^\ell$. This makes bond finance more attractive relative to bank loans, and hence firms substitute away from banks and towards relatively cheaper NBFIs. We model this as an increase in bank markups for simplicity, but this is intended to capture a broader array of 'bank-side' increases to loan rates (including macroprudential changes).

We begin by discussing traditional interest rate policy in Section 5.1, move on to central bank balance sheet expansion (QE) in Section 5.2, and then consider central bank balance sheet contraction (QT) in Section E.1. The alternative scenarios with larger reserves and a disrupted wholesale deposit market are simulated in Section 5.3. All simulations are conducted to a first-order approximation of the model, using Dynare 6.3 (Adjemian et al., 2024).

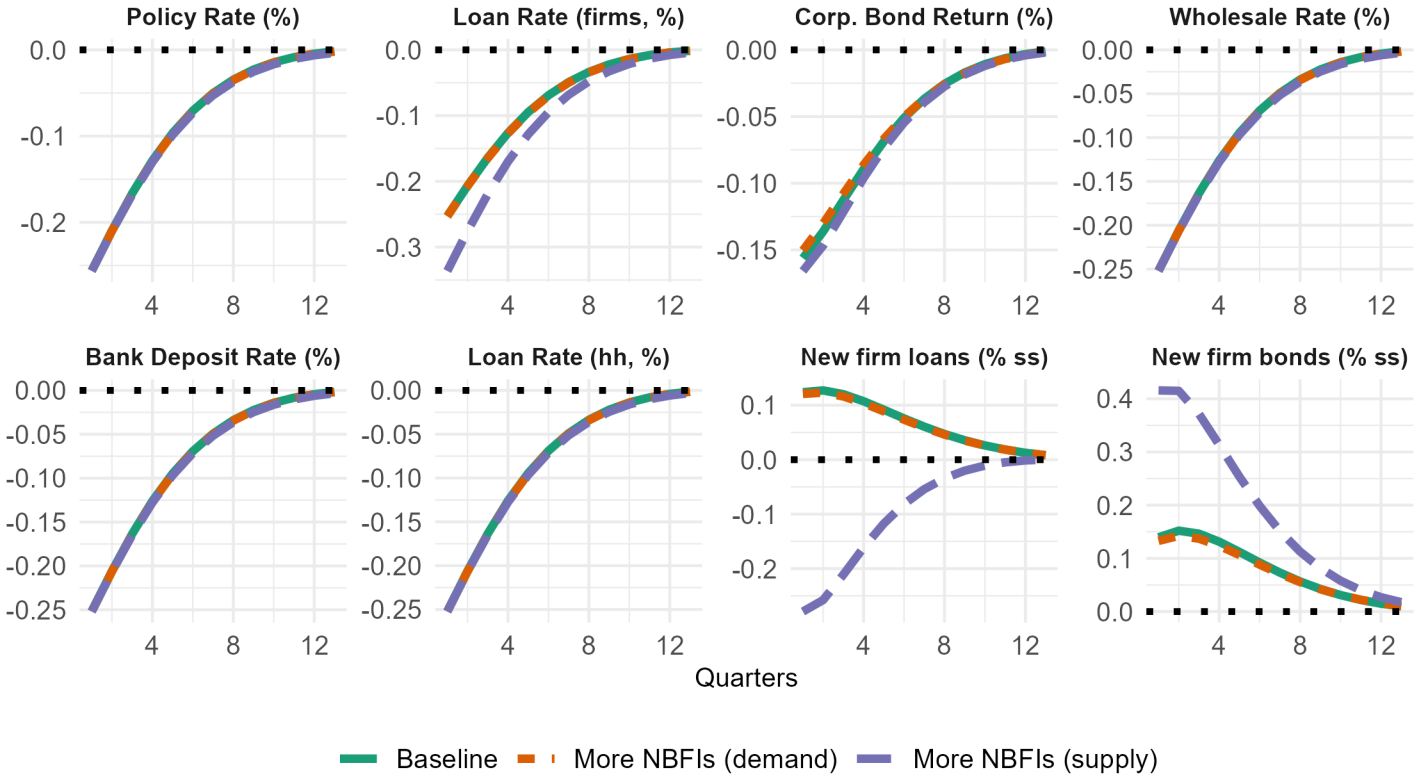
5.1 Traditional Interest Rate Policy

Figures 4 and 5 below show the response to a 25 bps Bank Rate cut, implemented using the interest rate shock ϵ^R. This is set slightly above 25 bps, as there is less than one-for-one pass-through from the shock to the policy rate given the normal operation of the Taylor rule. A full set of impulse responses can be seen Appendix E, Figure A.5.

Figure 4 shows the transmission of this rate shock through the financial sector. We observe that in the baseline scenario there is imperfect transmission through to loan and bond rates. The change in policy rate is not reflected one-for-one in other interest rates due to the varied financial frictions in the model, and corporate bonds in particular move by only 15bps given that NBFIs are only indirectly exposed to the change in policy rate. In the case with a bank-driven NBFI expansion (purple line), loan markups are extremely high. Loan rates move more than one-for-one with policy rate, and fall by about 32ps on impact. However, in this scenario firm loan markups are extremely high and hence loan rates are also extremely high. The fall in bond returns is therefore proportionally much bigger, and firms substitute from loan finance into bond finance.

The rate offered by banks to NBFIs on their wholesale deposits follows almost exactly the path

Figure 4: Lower Interest Rates: Transmission



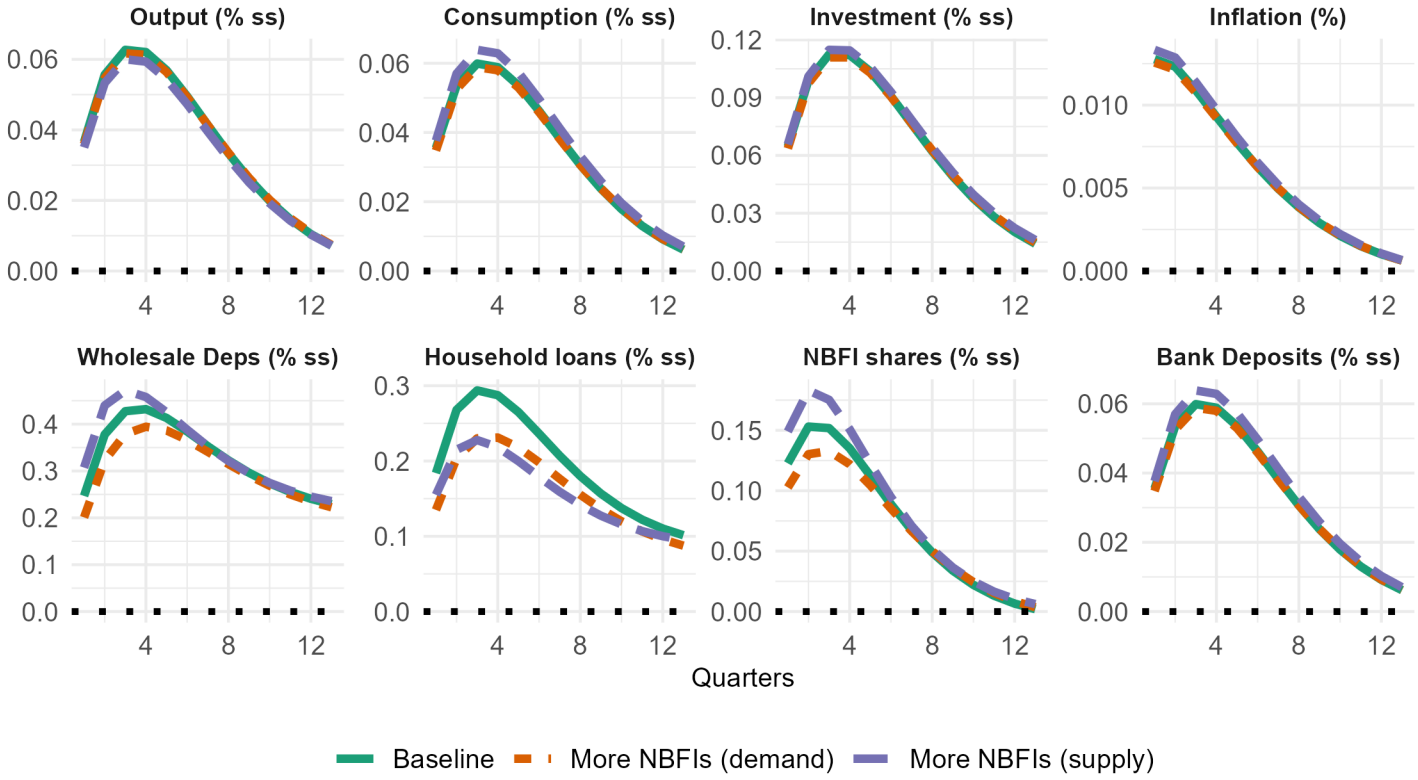
Response to an interest rate shock $\epsilon_1^R = -0.26$. *All rate variables are expressed in annualised percentage points, other variables are a percentage of steady-state.*

of the policy rate: banks pass off the cut in rates almost precisely to NBFIs. This is a crucial component of smooth transmission, as it helps ensure NBFIs pass the rate cut onwards to firm through the bond market.

Implication Our estimated setup is sufficiently low-friction that interest rates continue to pass through smoothly, even with a larger NBFI sector.

The resulting impact on macroeconomic aggregates is shown in the top row of Figure 5. In the baseline scenario, the policy rate cut increases output by about 0.06% (peak) and inflation by 0.012% (on impact). As in standard New Keynesian models, this is driven primarily by increased investment and secondarily by increased consumption. Households and firms respond to lower borrowing costs by borrowing more, consuming more, and investing more. Firms respond to this

Figure 5: Lower Interest Rate: Macroeconomy



Response to an interest rate shock $\epsilon_1^R = -0.26$. All rate variables are expressed in annualised percentage points, other variables are a percentage of steady-state.

increase in demand by raising prices, and inflation rises both on impact and persistently.

The crucial takeaway from Figure 5 is that the NBFI share has *no meaningful effect on output or inflation*, with almost exactly the same increase in each of our scenarios. For the firm-driven scenario, the larger NBFI share reduces the peak GDP (inflation) effect of a bank rate cut by 1.55% (1.65%); for the bank-driven scenario the peak GDP effect is reduced by 3.86% and the peak inflation effect *increased* by 3.58%. Ultimately, this arises because interest rates move in much the same direction and by much the same amount in each scenario, as shown in Figure 4. There is essentially no difference in the path for household loan rates, which is the primary consideration for household decision making, and the differences in firm lending rates are sufficiently small that the differences in investment behaviour are also small.

The second row of Figure 5 shows changes to deposit and lending volumes, both between households and the financial sector and within the financial sector. The crucial feature of the model that explains these results is the fact that NBFIs are the only actor in the model holding long-term assets.[11] Following the cut to the policy rate, the valuation of both corporate and government bonds rises sharply to reflect the lower discount rate. The repricing arrives as windfall gain to the asset side of the NBFI balance sheet, and NBFI shares increase.

More strikingly, Figure 5 shows a distinctive feature of our model: a substantial increase in both household and NBFI wholesale deposits at banks. The increase in bank lending mechanically increases deposits (Jakab and Kumhof, 2015; 2018; McLeay et al., 2014). The majority of this additional lending is to households, and therefore 'on impact' household deposits increase by the same amount as the increase in household loans. However, in equilibrium households are not obliged to hold on to these newly created deposits. In our estimated model, most of the additional deposits are therefore ultimately held by the NBFI sector, and in exchange household NBFI shares increase. This arises because the marginal value of liquidity to NBFIs exceeds the marginal value of liquidity to households. Households deposit demand is pinned by Equation 4, and any deposits beyond this minimum provide zero marginal liquidity.

Implication This exercise demonstrates that monetary policymakers retain strong rate control regardless of the share of credit supplied by NBFIs.

5.2 Quantitative Easing

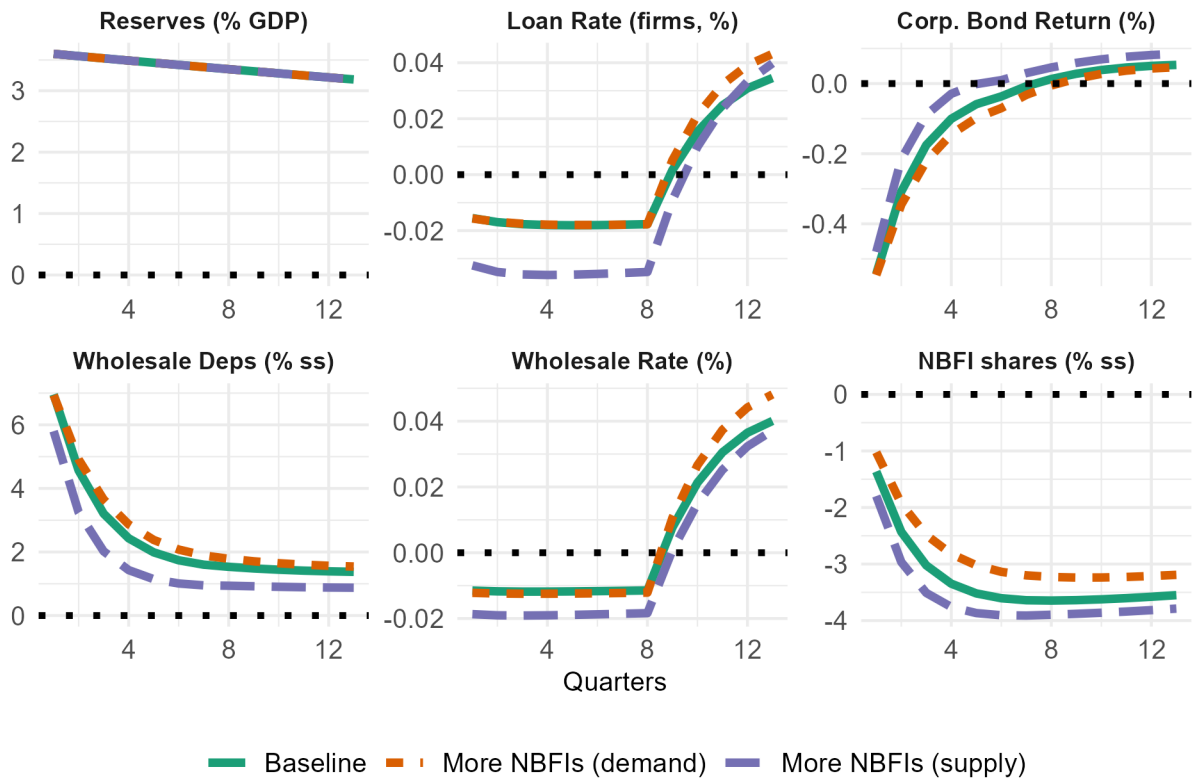
Figures 6 and 7 below shows the IRFs to a QE shock worth £100 billion (3.6% of GDP). Since typically central banks deploy Quantitative Easing only when there is no scope to lower interest rates, we simulate the effect of QE at the Effective Lower Bound (ELB) on interest rates. We assume that the ELB binds for eight quarters and is subsequently slack.[12] A full set of impulse responses are plotted in Appendix E, Figure A.6.

Figure 6 shows that QE transmits to the economy in three ways: a portfolio balance *liquidity*

[11] Banks issue loan-term loans to firms, but since these are variable-rate they are not subject to the same revaluation effects as fixed-rate products.

[12] For the purposes of implementation, we use a sequence of anticipated interest rate shocks to keep the policy rate fixed for the duration of the lower bound.

Figure 6: QE at the Lower Bound: Transmission



Response to a QE shock $\epsilon_1^b = 1$. The effective lower bound binds for eight quarters. All rate variables are expressed in annualised percentage points, other variables are a percentage of steady-state.

channel, a portfolio balance *duration* channel, and a *reserve creation* channel. The two portfolio balance channels are in the spirit of Alpanda and Kabaca (2020) and Harrison (2024), but in our model this takes place distinctively through separate 'liquidity' and 'duration' components.

Considering *liquidity* first, with fewer liquid government bonds in their portfolio, NBFIs experience an increase in (marginal) liquidity costs. It is therefore willing to hold additional wholesale deposits at commercial banks, since this is the only other liquid asset available. However, in our estimated model $\eth_2 \approx 0$ and hence the marginal value of liquidity does not change very much. This can be seen in Figure 6, with the wholesale rate falling (increased marginal of liquidity) but only by 1-2bps. Within a few quarters, wholesale deposits settle at a higher level than before QE, but only slightly.

The *duration* channel is the most important component of QE transmission. With fewer long-duration government bonds in their portfolio, NBFIs experience a reduction in their (marginal) duration costs. They are therefore more willing to hold long-duration corporate bonds; corporate bond returns fall (Figure 6) and volumes increase (Figure 7).

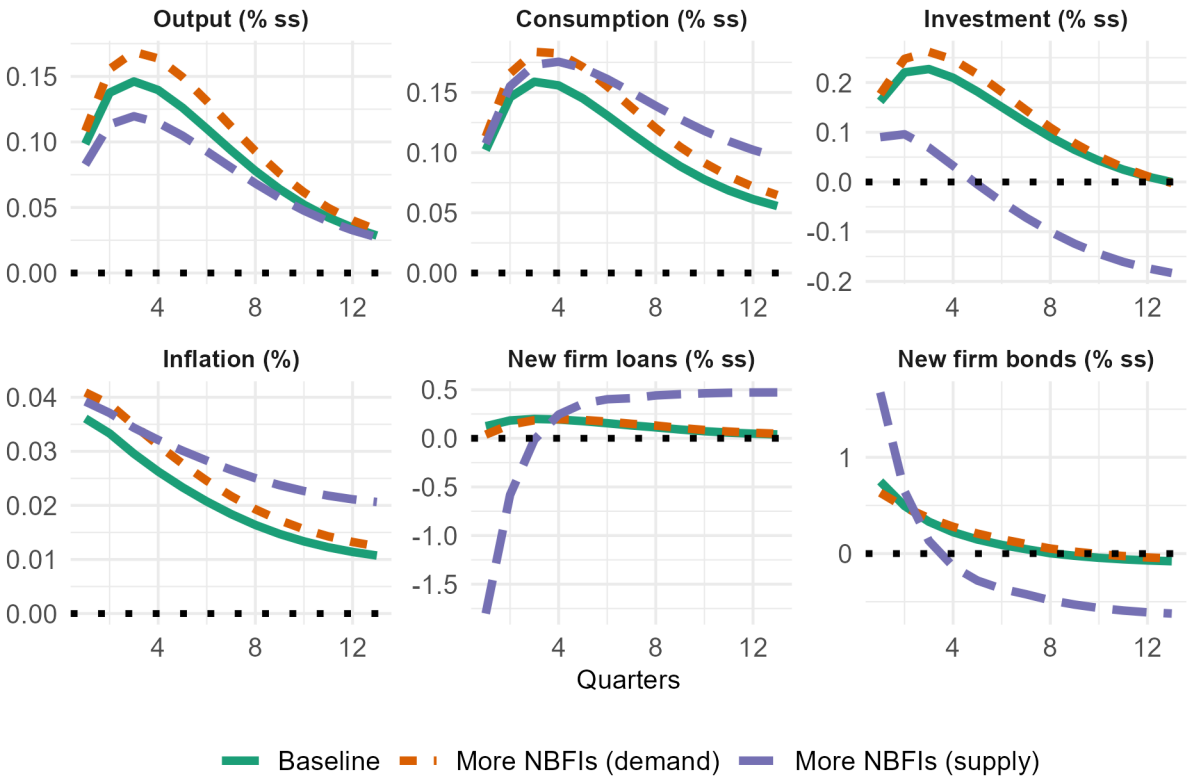
Thirdly, by creating reserves the central bank generates a *reserve creation* channel in the banking system, similar to Kumhof and Salgado-Moreno (2024). Banks have more liquid reserves, in principle are willing to increase the rates they offer to households and NBFIs on their deposits. This is initially dominated by the sharp increase in wholesale deposits. This large increase in unstable short-term liabilities increases the banking sector's demand for reserves. This is the complement to NBFIs increased demand for liquid wholesale deposits, and jointly determines that the wholesale rate falls rather than rises following QE. This is consistent with the reserve creation channel being relatively weak in our model

Figure 7 shows the consequences. In the baseline scenario (green line) QE increases peak output by 0.146% (peak) and peak inflation by 0.036%, with transmission through both household consumption and firm investment. On the household side, with reduced returns on both government and corporate bonds, the return on NBFI shares falls. Households respond to this as they would to an interest rate cut, reducing their net saving and increasing their consumption. Similarly, on the firm side, the reduced yield on corporate bonds lowers the cost of corporate borrowing; firms respond by increasing investment.

Unlike for bank rate, *the size of the NBFI sector and the source of its expansion matter for QE transmission* . We find that in our scenario with a larger, firm-driven (bank-driven) NBFI sector the effect of QE on output is 15% larger (16% smaller) than in the baseline. In other words, a bank-driven expansion of the NBFI sector *weakens* the transmission of QE, while a firm-driven expansion *strengthens* it. This difference is modest, but large enough to be economically relevant when designing asset purchase programs.

What drives these opposing results? In principle, a larger NBFI sector should amplify QE as we see in the firm-driven scenario. A larger NBFI sector by definition holds more corporate bonds, and therefore more long-duration assets. The marginal cost of duration is therefore higher, and

Figure 7: QE at the Lower Bound: Macroeconomy



Response to a QE shock $\epsilon_1^b = 1$. The effective lower bound binds for eight quarters. All rate variables are expressed in annualised percentage points, other variables are a percentage of steady-state.

NBFIs are more sensitive to further changes to their long-term bond holdings. We see this in Figure 6, with corporate bond returns falling by more in the firm-driven scenario than in baseline. Since corporate bond yields fall by more, both investment and consumption respond more.

In the bank-driven scenario, this is confounded by the huge rise in bank lending costs. This sharply increases the marginal cost of investment, because each additional unit of investment requires borrowing from commercial banks at a punitively high rate. This is therefore why in figure 7 we observe much less of an investment response to QE even as the consumption response is similar to the firm-driven scenario. This occurs despite firms taking advantage of the lower corporate bond yields to substitute strongly away from bank loans and towards corporate bonds.

In Appendix E, we repeat this exercise for Quantitative Tightening (QT) away from the lower

bound. NBFIs have much the same influence on QT transmission as for QE, and for much the same reasons: a larger NBFI sector increases the effect of QT if this is a firm-driven expansion, and reduces it if it is a bank-driven expansion. However the magnitude of these effects is asymmetric and smaller for QT, because the policy rate adjusts rapidly to cushion the effects.

Implication This exercise demonstrates that the transmission of QE is substantially affected by NBFIs, and the source of their credit expansion.

5.3 Reserves and Wholesale Deposits

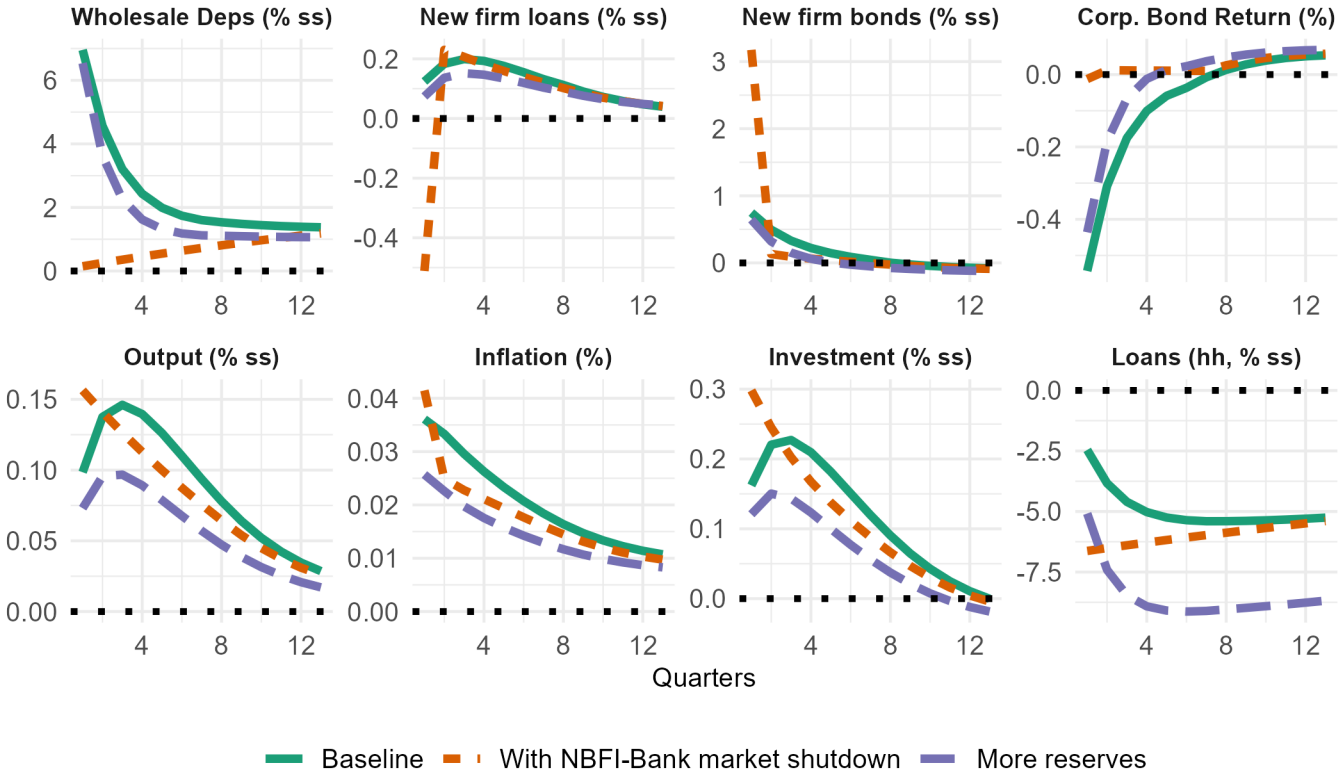
We now consider how two alternative structural changes - a wholesale deposits market shutdown and a higher level of steady-state reserves - impact the transmission of QE.[13] The results of both exercises are displayed in Figure 8, which shows the IRFs to a QE shock worth £100 billion exactly as in Figure 6.

Firstly, we explore the effect of the wholesale deposits market in our model by preventing non-banks from holding additional wholesale deposits. The specifics of implementation are discussed in Appendix C, but in essence an arbitrarily large adjustment cost is applied to wholesale deposits such that the NBFI always chooses to hold the steady-state level. Conceptually, wholesale deposits must always increase in the immediate aftermath of QE - this is mechanically how the central bank pays NBFIs for the acquired asset. This scenario is therefore modelling a situation similar to Cui and Sterk (2021) in which NBFIs are completely unwilling to hold (additional) wholesale deposits, and immediately spend them to either acquire new assets or to return funds to households. This might be the case if, for example, NBFIs perceive a high risk of banking sector defaults, or if liquidity demand by NBFIs is satiated.

This significantly changes the effects of QE, as shown by the orange dashed line in Figure 8. In the baseline wholesale deposits increase sharply (green line); conversely, when the wholesale deposits market is shut down, NBFIs reallocate these deposits towards corporate bonds and firms substitute strongly from bank loans into corporate bonds. With higher liquidity management costs, the effective return on NBFI shares is lower. Households reduce their NBFI shares, using this to

[13]For a policy rate shock, GDP and inflation results are similar to Section 5.1. The response of household loans and wholesale deposits is much weaker in both cases.

Figure 8: Alternative Configurations



Response to an QE shock $\epsilon_1^b = -1$. All rate variables are expressed in annualised percentage points, other variables are a percentage of steady-state.

repay bank loans and to increase consumption. Overall, the peak effect on output is similar to baseline, but occurs on impact rather than with a delay.

Secondly, we explore the effect of conducting QE with a higher level of steady-state reserves, increasing the steady-state level of reserves from 12% of annual GDP to 25%. [14] We find that this does weaken QE, but it clearly remains effective. This softening of impact runs through both the banking and NBFI sectors. On the banking side, with a larger steady state level of reserves, the 'reserve creation' channel is weaker as the marginal reserve is less valuable to commercial banks. On the NBFI side, with a lower steady state level of government bonds the marginal duration channel is weaker; term premia respond less to a further change in government bond holdings and hence corporate bond yields fall by less.

[14] This is close to the peak reached by the Bank of England Asset Purchase Facility in 2021-22.

Implication This demonstrates that the wholesale deposit market matters for QE, and transmission is significantly faster if NBFIs are forced to spend these deposits on impact. There are diminishing marginal returns to central bank asset purchases.

6 Robustness Checks

To check that our results are robust to a range of parameter values, Table 4 shows our headline results for bank rate and QE repeated across a range of values for our key parameters. This show the effect of increasing NBFI market share via firm preference (firm-side, ζ_1) on the transmission of bank rate and QE, for both output and inflation. We omit the QT results since these very closely track the QE results in percentage terms.

Table 4: Robustness Analysis: Change in Peak Policy Transmission with Higher NBFI Share

	Bank Rate		QE at ELB	
Scenario	ΔY^{peak} (%)	$\Delta\Pi^{\text{peak}}$ (%)	ΔY^{peak} (%)	$\Delta\Pi^{\text{peak}}$ (%)
Baseline	-1.55	-1.62	15.47	13.35
$\zeta_2 = 0.05$	-1.56	-1.62	15.47	13.36
$\zeta_2 = 20$	-1.54	-1.62	15.41	13.26
$\rho_r = 0.7$	-2.94	-2.65	15.40	13.23
$\nu_2 = -0.95$	-1.56	-1.62	15.61	13.35
$\nu_2 = 10$	-1.43	-1.55	13.15	11.60
$\varphi_2 = -1$	0.08	-0.03	-0.57	4.78
$\varphi_2 = -60$	-1.43	-1.60	17.89	14.52
$\mathfrak{m}^F = 0.05$	-1.87	-5.86	26.82	33.34
$\mathfrak{m}^H = 0.1$	-2.55	-2.56	5.44	3.64
$\kappa_I = 6$	-1.27	-1.54	15.35	13.04
$\kappa_h = 0.006$	-2.09	-1.99	11.59	10.64
$\kappa_h = 0.02$	-2.33	-2.12	5.48	5.70
$\kappa_h = 0.05$	-1.83	-1.67	-0.52	-0.55
$\kappa_{\text{nbfi}} = 0.002$	-1.17	-1.23	12.13	8.19
$\alpha_d = 0$	-1.55	-1.62	16.21	14.00
$\kappa_f = \kappa_e = 0.99$	-3.52	-3.58	41.49	35.36
$\rho_r = 0.7$, $\kappa_h = 2$	-3.75	-3.27	4.78	4.22
$\kappa_f = \kappa_e = 0.99$, $\rho_r = 0.7$, $\kappa_h = 2$	-6.97	-7.59	17.47	17.93

Notes: Each cell reports the percentage change in peak response when NBFI share increases via $\zeta_1 \times 1.5$. ΔY^{peak} and $\Delta\Pi^{\text{peak}}$ denote the percentage change in peak output and inflation responses, respectively. Bank Rate refers to a conventional monetary policy shock; QE at ELB refers to quantitative easing implemented at the effective lower bound.

Our qualitative finding that an increase in NBFI share has very little effect on bank rate

transmission, and a small but substantial effect on QE transmission, holds up across a range of parameters. The firm elasticity ζ_2, NBFI liquidity preference parameter ν_2 and deposit parameter α_d have a negligible effect on our headline results. The myopia parameters $\mathfrak{m}^H$ and $\mathfrak{m}^F$ also matter to results. Smaller values for myopia increase the importance of NBFI share, larger values reduce it.

The Taylor rule persistence parameter ρ_r is important for the bank rate result. If monetary policy is less persistent then the NBFI share has a greater impact on bank rate transmission, though the effect remains small for reasonable values of ρ_r. The reason for this is that when monetary policy is less persistent, it has less effect on long-term bond yields. It follows naturally that when monetary policy has less impact on long-term bond yields, and long-term bonds are a larger share of financial markets, monetary policy is less effective. A similar story applies to the bond duration parameter κ_f.[15] When bonds are more persistent, monetary policy has less effect on bond yields, and is therefore more sensitive to the share of long-term bonds.

Unsurprisingly, the NBFI duration parameter φ_2 does matter for results. If this is sufficiently small in magnitude, then the NBFI share has even less impact on both bank rate and QE transmission. Conceptually what is happening here is that when this is close to -1, the duration premium on bonds is essentially constant and does not respond to QE; the 'preferred habitat' channel of QE therefore vanishes and QE has almost no effect on the economy at all via NBFIs[16]. The effect therefore converges on zero. Conversely when φ_2 is more strongly negative, NBFIs are even more important to QE transmission and this result is strengthened.

The household adjustment cost parameters also matter, and in particular the loan adjustment cost κ_h. When this is set to be much larger than the estimated value of 0.003, the effect of QE is less sensitive to the NBFI share and the effect of bank rate is slightly stronger. As shown above in Section 5.2, a reduction in bank lending is an important part of the financial system adjusting to QE. With a larger adjustment cost, this reduction in bank lending creates a marginal adjustment cost to lending and a marginal return to saving, raising the 'effective rate' received by households

[15] We increase loan duration κ_ℓ as well for symmetry, but since these are variable-rate loans the duration is much less important.

[16] There remains a small effect via reserve creation and the banking side.

on saving. When this is very strong therefore, there is a higher marginal return to saving for households and consequently a weaker inter-temporal response of consumption.

Finally, we demonstrate that a combination of changes (bond duration, monetary policy persistence and loan adjustment cost) deliver an outcome where monetary policy is meaningfully impaired by the NBFI share; transmission of bank rate is 7-7.6% less effective with an NBFI share of 60%. The purpose of this exercise is to demonstrate that our model is *capable* of finding that NBFI's weaken bank rate transmission; it simply finds that this is not supported in UK data. Were the model to be applied in a different jurisdiction, such as one where NBFIs supply even longer-duration fixed rate products, it might well support the hypothesis that NBFIs weaken the transmission of conventional monetary policy.

7 Conclusions

How does a larger NBFI sector affect the transmission of conventional interest rate policy and Quantitative Easing and Tightening? To answer this question the paper develops a novel DSGE model and employs Bayesian methods to estimate it on UK data.

We find that the transmission of conventional interest-rate policy to output and inflation is essentially unaffected by the size of the NBFI sector. Conversely, the transmission of QE/QT is strongly altered by the size of the NBFI sector and the source of its expansion: a larger, firm-driven (bank-driven) NBFI sector amplifies (weakens) QE/QT. Quantitative simulations reveal that the transmission of QE hinges critically on the wholesale deposits market. If this channel is impaired, QE is highly more effective on impact but less so after only two quarters. We also find that there are diminishing marginal returns to QE, but it remains an effective policy tool even with a significantly larger balance sheet.

While our model abstracts from certain frictions and crisis dynamics, it provides a tractable framework for evaluating policy effectiveness in an evolving financial landscape. Our results focus on the specific context of the UK where NBFIs experienced a striking growth over the past two decades. However, these findings are also relevant to all advanced economies with increased NBFIs' lending, including the United States and the Euro area. To apply our model specifically to these jurisdictions, two key changes must be applied: for the Euro Area, commercial banks must be

allowed to hold government bonds, as unlike in the UK, Eurozone banks provide significant finance to fiscal authorities. For the US, NBFIs must be modelled as net borrowers from banks (currently they are net lenders to banks). We leave these extensions for future research.

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APPENDIX

A Extended Equations

In this section we set out the rest of the background macroeconomic model.

A.1 Myopia

Following Gabaix (2020); Gust et al. (2022); Woodford (2019), we assume that households, firms and trade unions are not perfectly rational and have imperfect expectations of the future ('myopia'). We assume that banks and non-bank financial intermediaries are professional forecasters and have perfectly rational expectations. We assume that households have a different degree of myopia to firms and trade unions; it is reasonable that an individual or a household will have a less accurate forecast of the future than a professional organisation. This is supported by our estimated results for myopia (Section 4).

We introduce myopia as it is a realistic feature strongly supported by the data (Gust et al., 2022) which therefore helps to improve the quantitative accuracy of our results. This is particularly true for examining the dynamic response to extremely persistent shocks, such as QE and QT, since it ensures that households and firms do not pay outsized attention to these shocks relative to more short-lived ones. This is something which afflicts many papers that consider QE and QT; for example Sims and Wu (2021) assume that QE is unwound within just 5 quarters to prevent these policies having implausibly large effects.

We adopt the behavioural formulation of Gabaix (2020), in which future expectations are a blend of their true expectation and their steady-state value. This contrasts with the finite horizon planning model of Woodford (2019), in which agents have perfectly rational expectations but only for a limited timespan. Gust et al. (2022) finds that the two versions have similar properties, with the finite planning version performing somewhat better empirically but at the expense of tractability.

In brief, we simply define two expectations operators $\mathbb{E}_t^H$ ($\mathbb{E}_t^F$) for households (firms and trade unions) respectively:

$$\mathbb{E}_t^H [X_{t+1}] = (1 - \mathfrak{m}^H)\mathbb{E}_t [X_{t+1}] + \mathfrak{m}^H \bar{X} \tag{A.1}$$

$$\mathbb{E}_t^F [X_{t+1}] = (1 - \mathfrak{m}^F)\mathbb{E}_t [X_{t+1}] + \mathfrak{m}^F \bar{X} \tag{A.2}$$

where $\bar{X}$ is the steady-state value, and $\mathfrak{m}^H, \mathfrak{m}^F \in [0, 1)$ are parameters capturing the degree of myopia of households and firms. The special case $\mathfrak{m}^X = 0$ nests the perfectly rational expectations case.

A.2 Labour Market

The labour market has two tiers: a labour packer and labour unions.

A.2.1 Labour packer

The labour packer buys union labour $L_{d,t}(h)$ at $W_t(h)$ and converts it into the labour ready for production, $L_{d,t}$, using a CES technology with elasticity of substitution $\epsilon_t^w > 1$:

$$L_{d,t} = \left(\int_0^1 L_{d,t}(h)^{\frac{\epsilon_t^w - 1}{\epsilon_t^w}} dh \right)^{\frac{\epsilon_t^w}{\epsilon_t^w - 1}} \tag{A.3}$$

The labour packer sells $L_{d,t}$ to production firms at W_t, the aggregate wage. The maximisation problem of the labour packer is the following:

$$\max_{L_{d,t}(h)} W_t = \left(\int_0^1 L_{d,t}(h)^{\frac{\epsilon_t^w - 1}{\epsilon_t^w}} dh \right)^{\frac{\epsilon_t^w}{\epsilon_t^w - 1}} - W_t(h) L_{d,t}(h) \tag{A.4}$$

The FOC with respect to $L_{d,t}(h)$ is the standard labour demand function:

$$L_{d,t}(h) = \left(\frac{W_t(h)}{W_t} \right)^{-\epsilon_t^w} L_{d,t} \tag{A.5}$$

The labour packer sells $L_{d,t}$ to production firms at W_t, the aggregate wage, according to:

$$W_t^{1-\epsilon_t^w} = \int_0^1 W_t(h)^{1-\epsilon_t^w} dh \tag{A.6}$$

A.2.2 Labour Union

Labour unions — indexed by h and subject to Calvo wage rigidity — buy labour from households at w_t^h and sell it to the labour packer. The nominal profit of a labour union is:

$$DIV_{L,t}(h) = W_t(h)L_{d,t}(h) - w_t^h L_t(h) \tag{A.7}$$

Assuming $L_t(h) = L_{d,t}(h)$ and plugging in the demand function:

$$DIV_{L,t}(h) = W_t(h)^{1-\epsilon_t^w} W_t^{\epsilon_t^w} L_{d,t} - w_t^h W_t(h)^{-\epsilon_t^w} W_t^{\epsilon_t^w} L_{d,t} \tag{A.8}$$

Labour unions are subject to Calvo wage rigidity: Each period there is a $1-\phi_w$ probability (with $\phi_w \in [0,1]$) that a union can update its nominal wage. At time $t+j$, there is a ϕ_w^j probability that the wage chosen at time t is still valid. Wages that are not changed can be be indexed to lagged inflation at $\gamma_w \in [0,1]$. Hence, nominal wage at $t+j$ for a non-updating union since t is: $W_t(h)\left(\frac{P_{t+j-1}}{P_{t-1}}\right)^{\gamma_w}$. The maximisation problem of a union that updates its wage at time t choosing a new $W_t(h)$ is:

$$\begin{aligned}\max_{W_t(h)} \mathbb{E}_t^F \sum_{j=0}^{\infty} \phi_w^j \Lambda_{t,t+j} \Bigg[\left(\frac{P_{t+j-1}}{P_{t-1}}\right)^{(1-\epsilon_t^w)\gamma_w} W_t(h)^{1-\epsilon_t^w} P_{t+j}^{\epsilon_t^w - 1} w_{t+j}^{\epsilon_t^w} L_{d,t+j} \\ - w_{t+j}^h \left(\frac{P_{t+j-1}}{P_{t-1}}\right)^{-\epsilon_t^w \gamma_w} W_t(h)^{-\epsilon_t^w} P_{t+j}^{\epsilon_t^w} w_{t+j}^{\epsilon_t^w} L_{d,t+j} \Bigg]\end{aligned} \tag{A.9}$$

The FOC with respect to $W_t(h)$ is:

$$\begin{aligned}(\epsilon_t^w - 1) W_t(h)^{-\epsilon_t^w} \mathbb{E}_t^F \sum_{j=0}^{\infty} \phi_w^j \Lambda_{t,t+j} \left(\frac{P_{t+j-1}}{P_{t-1}}\right)^{(1-\epsilon_t^w)\gamma_w} P_{t+j}^{\epsilon_t^w - 1} w_{t+j}^{\epsilon_t^w} L_{d,t+j} = \\ \epsilon_t^w W_t(h)^{-\epsilon_t^w - 1} \mathbb{E}_t^F \sum_{j=0}^{\infty} \phi_w^j \Lambda_{t,t+j} w_{t+j}^h \left(\frac{P_{t+j-1}}{P_{t-1}}\right)^{-\epsilon_t^w \gamma_w} P_{t+j}^{\epsilon_t^w} w_{t+j}^{\epsilon_t^w} L_{d,t+j}\end{aligned} \tag{A.10}$$

Since all the unions that can update will set the same wage W_t^*:

$$W_t^* = \frac{\epsilon_t^w}{\epsilon_t^w - 1} \frac{F_{1,t}}{F_{2,t}} \tag{A.11}$$

Where $F_{1,t}$ and $F_{2,t}$ are:

$$F_{1,t} = w_t^h P_t^{\epsilon_t^w} w_t^{\epsilon_t^w} L_{d,t} + \phi_w \Lambda_{t,t+1} \Pi_t^{-\epsilon_t^w \gamma_w} F_{1,t+1} \tag{A.12}$$

$$F_{2,t} = P_t^{\epsilon_t^w - 1} w_t^{\epsilon_t^w} L_{d,t} + \phi_w \Lambda_{t,t+1} \Pi_t^{(1-\epsilon_t^w)\gamma_w} F_{2,t+1} \tag{A.13}$$

Knowing that $f_{1,t} = F_{1,t}/P_t^{\epsilon_t^w}$, $f_{2,t} = F_{2,t}/P_t^{\epsilon_t^w - 1}$ and dividing by the aggregate price level P_t, we obtain real $w_t^* = W_t^*/P_t$ equal to:

$$w_t^* = \frac{\epsilon_t^w}{\epsilon_t^w - 1} \frac{f_{1,t}}{f_{2,t}} \tag{A.14}$$

With:

$$f_{1,t} = w_t^h w_t^{\epsilon_t^w} L_{d,t} + \phi_w \mathbb{E}_t^F \Lambda_{t,t+1} \left(\frac{\Pi_{t+1}}{\Pi_t^{\gamma_w}} \right)^{\epsilon_t^w} f_{1,t+1} \tag{A.15}$$

$$f_{2,t} = w_t^{\epsilon_t^w} L_{d,t} + \phi_w \mathbb{E}_t^F \Lambda_{t,t+1} \left(\frac{\Pi_{t+1}}{\Pi_t^{\gamma_w}} \right)^{\epsilon_t^w - 1} f_{2,t+1} \tag{A.16}$$

A.3 Capital producer

Unconsumed final output I_t is used by a capital producer to create new physical capital $\hat{I}_t$:

$$\hat{I}_t = I_t \, \mu_t^I \left[1 - \frac{\kappa^I}{2} \left(\frac{I_t}{I_{t-1}} - 1 \right)^2 \right] \tag{A.17}$$

Where $S()$ is an adjustment cost as in Christiano et al. (2005). The new capital is sold to firm at P_t^k. The capital producer's nominal profit is:

$$DIV_{k,t} = P_t^k \left[1 - \frac{\kappa^I}{2} \left(\frac{I_t}{I_{t-1}} - 1 \right)^2 \right] I_t \, \mu_t^I \; - P_t I_t \tag{A.18}$$

In real terms ($p_t^k = P_t^k/P_t$), profit becomes:

$$div_{k,t} = p_t^k \left[1 - \frac{\kappa^I}{2} \left(\frac{I_t}{I_{t-1}} - 1 \right)^2 \right] I_t \, \mu_t^I \; - I_t \tag{A.19}$$

The maximisation problem then is:

$$\max_{I_t} \mathbb{E}_t^F \sum_{j=0}^{\infty} \Lambda_{t,t+j} \left\{ p_{t+j}^k \left[1 - \frac{\kappa^I}{2} \left(\frac{I_{t+j}}{I_{t+j-1}} - 1 \right)^2 \right] I_{t+j} \, \mu_{t+j}^I \; - I_{t+j} \right\} \tag{A.20}$$

And the FOC with respect to I_t is the following:

$$\begin{aligned} 1 = p_t^k \, \mu_t^I \left(1 - \frac{\kappa^I}{2} \left(\frac{I_t}{I_{t-1}} - 1 \right)^2 - \frac{I_t}{I_{t-1}} \, \kappa^I \left(\frac{I_t}{I_{t-1}} - 1 \right) \right) + \dots \\ \dots + \mathbb{E}_t^F \left\{ \kappa^I \, p_{t+1}^k \, \beta_E \, \Lambda_{t+1} \, \mu_{t+1}^I \left(\frac{I_{t+1}}{I_t} - 1 \right) \left(\frac{I_{t+1}}{I_t} \right)^2 \right\} \end{aligned} \tag{A.21}$$

A.4 Final Goods Firm

A final goods firm buys and combines retail outputs from retail firms — indexed by f — at $P_t(f)$ and sells it at P_t. For the production of Y_t, the final goods firm uses a CES technology with elasticity of substitution $\epsilon_t^p > 1$, creating:

$$Y_t = \left(\int_0^1 Y_t(f)^{\frac{\epsilon_t^p - 1}{\epsilon_t^p}} df \right)^{\frac{\epsilon_t^p}{\epsilon_t^p - 1}} \tag{A.22}$$

The maximisation problem of the final goods firm is the following:

$$\max P_t \left(\int_0^1 Y_t(f)^{\frac{\epsilon_t^p - 1}{\epsilon_t^p}} dh \right)^{\frac{\epsilon_t^p}{\epsilon_t^p - 1}} - P_t(f) Y_t(f) \tag{A.23}$$

The FOC with respect to $Y_t(f)$ is the below standard retail output demand function:

$$Y_t(f) = \left(\frac{P_t(f)}{P_t} \right)^{-\epsilon_t^p} Y_t \tag{A.24}$$

While the aggregate price (price of the final output good) P_t is:

$$P_t^{1-\epsilon_t^p} = \int_0^1 P_t(f)^{1-\epsilon_t^p} df \tag{A.25}$$

A.5 Retail firms

Retail firms buy at $P_{m,t}$ and repackage wholesale output $Y_{m,t}$ and sell it to a final goods firm ($Y_{m,t}(f) = Y_t(f)$) at $P_t(f)$.

The profit of a retail firm is:

$$DIV_{R,t}(f) = P_t(f)Y_t(f) - P_{m,t}Y_{m,t}(f) \tag{A.26}$$

that becomes:

$$DIV_{R,t}(f) = P_t(f)^{1-\epsilon_t^p} P_t^{\epsilon_t^p} Y_t - P_{m,t}P_t(f)^{-\epsilon_t^p} P_t^{\epsilon_t^p} Y_t \tag{A.27}$$

Retail firms are subject to Calvo price rigidity: Each period there is a $1-\phi_p$ probability (with $\phi_p \in [0,1]$) that a retail firm can update its price. At time $t+j$, there is a ϕ_p^j probability that the price chosen at time t is still valid. Prices that are not changed can be indexed to lagged inflation at $\gamma_p \in [0,1]$. Hence, a price at $t+j$ for a non-updating retail firm since t is: $P_t(f)\left(\frac{P_{t+j-1}}{P_{t-1}}\right)^{\gamma_p}$. The maximisation problem of a retail firm that updates its price at time t choosing a new $P_t(f)$ is the following:

$$\max_{P_t(f)} \mathbb{E}_t^F \sum_{j=0}^{\infty} \phi_p^j \Lambda_{t,t+j} \left[P_t(f)^{1-\epsilon_t^p} \left(\frac{P_{t+j-1}}{P_{t-1}}\right)^{(1-\epsilon_t^p)\gamma_p} P_{t+j}^{\epsilon_t^p - 1} Y_{t+j} - P_{m,t+j} P_t(f)^{-\epsilon_t^p} \left(\frac{P_{t+j-1}}{P_{t-1}}\right)^{-\epsilon_t^p \gamma_p} P_{t+j}^{\epsilon_t^p - 1} Y_{t+j} \right] \tag{A.28}$$

The FOC with respect to $P_t(f)$ is:

$$\begin{aligned} (\epsilon_t^p - 1) P_t(f)^{-\epsilon_t^p} \mathbb{E}_t^F \sum_{j=0}^{\infty} \phi_p^j \Lambda_{t,t+j} \left(\frac{P_{t+j-1}}{P_{t-1}}\right)^{(1-\epsilon_t^p)\gamma_p} P_{t+j}^{\epsilon_t^p - 1} Y_{t+j} = \\ \epsilon_t^p P_t(f)^{-\epsilon_t^p - 1} \mathbb{E}_t^F \sum_{j=0}^{\infty} \phi_p^j \Lambda_{t,t+j} P_{m,t+j} \left(\frac{P_{t+j-1}}{P_{t-1}}\right)^{-\epsilon_t^p \gamma_p} P_{t+j}^{\epsilon_t^p} Y_{t+j} \end{aligned} \tag{A.29}$$

We denote two variables:

$$X_{1,t} = \sum_{j=0}^{\infty} (\phi_p \beta)^j \frac{\mu_{t+j}}{\mu_t} P_{m,t+j} \left(\frac{P_{t+j-1}}{P_{t-1}}\right)^{-\epsilon_t^p \gamma_p} P_{t+j}^{\epsilon_t^p} Y_{t+j} \tag{A.30}$$

$$X_{2,t} = \sum_{j=0}^{\infty} (\phi_p \beta)^j \frac{\mu_{t+j}}{\mu_t} \left(\frac{P_{t+j-1}}{P_{t-1}}\right)^{(1-\epsilon_t^p)\gamma_p} P_{t+j}^{\epsilon_t^p - 1} Y_{t+j} \tag{A.31}$$

That written recursively are:

$$X_{1,t} = p_{m,t} P_t^{\epsilon_t^p} Y_t + \phi_p \Lambda_{t,t+1} \Pi_t^{-\epsilon_t^p \gamma_p} X_{1,t+1} \tag{A.32}$$

$$X_{2,t} = P_t^{\epsilon_t^p - 1} Y_t + \phi_p \Lambda_{t,t+1} \Pi_t^{1-\epsilon_t^p \gamma_p} X_{2,t+1} \tag{A.33}$$

All the retailers that can update their price, they will set the same, P_t^*. Hence, the first order condition can be re-written as:

$$P_t^* = \frac{\epsilon_t^p}{\epsilon_t^p - 1} \frac{X_{1,t}}{X_{2,t}} \tag{A.34}$$

Knowing that $x_{1,t} = X_{1,t}/P_t^{\epsilon_t^p}$, $x_{2,t} = X_{2,t}/P_t^{\epsilon_t^p - 1}$, $p_{m,t} = \frac{P_{m,t}}{P_t}$ and $p_t^* = P_t^*/P_t$, we obtain:

$$p_t^* = \frac{\epsilon_t^p}{\epsilon_t^p - 1} \frac{x_{1,t}}{x_{2,t}} \tag{A.35}$$

$$x_{1,t} = p_{m,t} Y_t + \phi_p \mathbb{E}_t^F \Lambda_{t,t+j} \left(\frac{\Pi_{t+1}}{\Pi_t^{\gamma_p}} \right)^{\epsilon_t^p} x_{1,t+1} \tag{A.36}$$

$$x_{2,t} = Y_t + \phi_p \mathbb{E}_t^F \Lambda_{t,t+j} \left(\frac{\Pi_{t+1}}{\Pi_t^{\gamma_p}} \right)^{\epsilon_t^p - 1} x_{2,t+1} \tag{A.37}$$

A.6 Markups and Adjustment Costs

A.6.1 Loan Markups and Deposit Markdowns

We resolve the optimal composition of bank loans and deposits as a cost-minimization exercise. Markups and markdowns are determined by elasticity parameters ξ_t^X which vary across all different products offered by the banking sector and follow time-varying shock processes.

For the wholesale firm, the problem is:

$$\min_{\ell_{j,t}} \quad C = \int_0^1 \left(1 + R_{j,t}^{\ell}\right) \ell_{j,t}$$

$$\text{s.t. } \ell_t = \left[\int_0^1 \ell_{j,t}^{\frac{\xi_t^{\ell} - 1}{\xi_t^{\ell}}} dj \right]^{\frac{\xi_t^{\ell}}{\xi_t^{\ell} - 1}}$$

Demand schedule for bank loans is therefore:

$$\ell_{j,t} = \left(\frac{1 + R_{j,t}^{\ell}}{1 + R_t^{\ell}} \right)^{-\xi_t^{\ell}} \ell_t \tag{A.38}$$

Similarly for households, we have:

$$d_{j,t}^{c} = \left(\frac{R_{j,t}^{d,c}}{R_{t}^{d,c}} \right)^{-\xi_{t}^{d}} d_{t}^{c} \tag{A.39}$$

$$\ell_{j,t}^{hh} = \left(\frac{R_{j,t}^{\ell,hh}}{R_{t}^{\ell,hh}} \right)^{-\xi_{t}^{\ell,hh}} \ell_{t}^{hh}. \tag{A.40}$$

And for NBFIs:

$$h_{j,t} = \left(\frac{R_{j,t}^{h}}{R_{t}^{h}} \right)^{-\xi_{t}^{h}} h_{t} \tag{A.41}$$

A.6.2 Household Adjustment Costs

We resolve the partial derivatives of the household adjustment cost term $\mathcal{A}_{\sqcup}$ as:

$$\mathcal{A}_{t} \equiv \mathcal{A}_{\sqcup}^{\infty} + \mathcal{A}_{\sqcup}^{\in}, \tag{A.42}$$

$$\mathcal{A}_{t}^{1} \equiv 0.5\kappa_{hh}\ell_{t}^{hh}\left(\ell_{t}^{hh} - \ell_{t-1}^{hh}\right)^{2}, \tag{A.43}$$

$$\mathcal{A}_{t}^{2} \equiv 0.5\kappa_{nbfi}d_{t}^{s}\left(d_{t}^{s} - d_{t-1}^{s}\right)^{2}, \tag{A.44}$$

$$\mathcal{A}_{t}^{\ell} \equiv \mathcal{A}_{t}^{1}/\ell_{t}^{hh} + \kappa_{hh}\ell_{t}^{hh}\left[\ell_{t}^{hh} - \ell_{t-1}^{hh} - \Lambda_{t,t+1}\left(\ell_{t+1}^{hh} - \ell_{t}^{hh}\right)\right] \tag{A.45}$$

$$\mathcal{A}_{t}^{s} \equiv \mathcal{A}_{t}^{2}/d_{t}^{s} + \kappa_{nbfi}d_{t}^{s}\left[d_{t}^{s} - d_{t-1}^{s} - \Lambda_{t,t+1}\left(d_{t+1}^{s} - d_{t}^{s}\right)\right] \tag{A.46}$$

A.7 NBFI Partial Derivatives

The partial derivatives of the loan and durations scarcity costs are:

$$LSC_{t}^{D} = (1+\nu_{2})\frac{LSC_{t}}{\nu_{1,t}} \cdot \frac{1}{d_{t}} \tag{A.47}$$

$$LSC_{t}^{H} = -(1+\nu_{2})\frac{LSC_{t}}{\nu_{1,t}} \cdot \frac{1}{\nu_{B,t}Q_{B,t}b_{t} + h_{t}} \tag{A.48}$$

$$LSC_{t}^{B} = \nu_{B,t}LSC_{t}^{H} \tag{A.49}$$

$$DSC_{t}^{D} = (1+\varphi_{2})\frac{DSC_{t}}{\varphi_{1,t}} \cdot \frac{1}{d_{t}} \tag{A.50}$$

$$DSC_{t}^{B} = -(1+\varphi_{2})\frac{DSC_{t}}{\varphi_{1,t}} \cdot \frac{1}{Q_{B,t}b_{t} + Q_{t}f_{t}} \tag{A.51}$$

$$DSC_{t}^{F} = DSC_{t}^{B} \tag{A.52}$$

A.8 Fiscal Authority

The government spends G_t and it raises revenues by collecting taxes from households τ_t, issuing debt b_t^G and receiving transfers from the central bank T_t^{CB}:

$$G_t + \Pi_t^{-1} b_{t-1}^G = \tau_t + T_t^{CB} + Q_{B,t}(b_t^G - \kappa_b \Pi_t^{-1} b_{t-1}^G) \tag{A.53}$$

Where $\kappa_b \in [0,1]$ is the decay parameter for coupon payments. As in Sims and Wu (2021), we assume there is a fixed quantity of outstanding real government bonds, e.g. $b_t^G = \bar{b^G}$, and nominal government bonds grow with the price level, e.g $B_{G,t} = P_t \bar{b}_G$. Real government bonds b_t^G and government spending G_t follow an exogenous AR(1) process. Lump sum taxes τ_t adjust to always keep the government budget constraint satisfied each period.

A.9 Banks

To restate the conditions in Section 3.3.2, the optimization problem of bank j is:

$$\max_{\left\{R_{j,t}^{\ell}, R_{j,t}^{d,c}, m_{j,t}, h_{j,t}\right\}} V_{j,t}^c = (1-\varrho)\,\mathcal{P}_{j,t} + \mathbb{E}_t\left\{\Lambda_{t,t+1} V_{j,t+1}^c\right\} \tag{A.54}$$

$$\text{s.t.} \quad m_{j,t} + \ell_{j,t} + \ell_{j,t}^{hh} = d_{j,t}^c + h_{j,t} + n_{j,t}^c \tag{A.55}$$

$$n_{j,t}^c = \varrho \mathcal{P}_{j,t} + (1-\varsigma)\, n_{j,t-1}^c \tag{A.56}$$

$$\mathcal{P}_{j,t} = \Pi_t^{-1}\Big[R_{j,t-1}^{\ell} \ell_{j,t-1}^f + R_{j,t-1}^{\ell,hh} \ell_{j,t-1}^{hh} + R_{t-1}^m m_{j,t-1} \tag{A.57}$$

$$- R_{j,t-1}^{d,c} d_{j,t-1}^{d,c} - R_{j,t-1}^h h_{j,t-1}\Big] - \Xi_{j,t-1} - RSC_{j,t-1} \tag{A.58}$$

$$R_{j,t}^{d,c} \geq 1 \tag{A.59}$$

with

$$\Xi_{j,t} \equiv \frac{\kappa_t^c}{2}\left(\frac{n_{j,t}^c}{\ell_{j,t}^f + \ell_{j,t}^{hh}} - v^b\right)^2 \tag{A.60}$$

$$RSC_{j,t} \equiv \frac{\eth_{1,t}}{1+\eth_2}\left(\frac{\alpha^d d_{j,t}^c + h_{j,t}}{m_{j,t}}\right)^{1+\eth_2} \tag{A.61}$$

Note that as in Ulate (2021) there are three separate cases with respect to the zero lower bound. In case (a) it does not bind. In case (b) it binds but the bank remains profitable and accepts nonzero deposits. In case (c) it binds and is sufficiently severe that the bank makes negative profits, closing down completely. This situation occurs when the interest rate on reserves is strongly negative. In practice, it is this condition that defines a reversal rate for negative interest rate policy, bank value $V_{j,t}^t \geq 0$ implicitly sets an "actual lower bound" (reversal rate) on bank rate. As in Ulate (2021) we discount case (c) by assuming that the policy rate of interest never goes low enough to trigger bank closures, and focus on cases (a) and (b).

Before resolving, it is helpful to obtain the derivative of loan/deposit demand with respect to their real interest rate, and similarly for the derivatives of capital costs. We have:

$$\frac{\partial d_{j,t}^c}{\partial R_{j,t}^{d,c}} = \frac{-\xi_d}{R_t^{d,c}} \left(\frac{R_{j,t}^{d,c}}{R_t^{d,c}} \right)^{-\xi_d - 1} d_t^c \tag{A.62}$$

$$\frac{\partial \ell_{j,t}^{hh}}{\partial R_{j,t}^{\ell,hh}} = \frac{-\xi_t^{\ell,hh}}{R_t^{\ell,hh}} \left(\frac{R_{j,t}^{\ell,hh}}{R_t^{\ell,hh}} \right)^{-\xi_t^{\ell,hh} - 1} \ell_t^{hh} \tag{A.63}$$

$$\frac{\partial \ell_{j,t}}{\partial R_{j,t}^{\ell}} = \frac{-\xi_t^{\ell}}{R_t^{\ell}} \left(\frac{R_{j,t}^{\ell}}{R_t^{\ell}} \right)^{-\xi_t^{\ell} - 1} \ell_t \tag{A.64}$$

$$\frac{\partial h_{j,t}}{\partial R_{j,t}^{h}} = \frac{-\xi_h}{R_t^{h}} \left(\frac{R_{j,t}^{h}}{R_t^{h}} \right)^{-\xi_h - 1} h_t \tag{A.65}$$

$$\Xi_{j,t}^{\ell} \equiv \frac{\partial \Xi_{j,t}}{\partial \ell_{j,t}} = -\frac{\kappa_t^c n_{j,t}}{\left(\ell_{j,t} + \ell_{j,t}^{hh} \right)^2} \left(\frac{n_{j,t}^c}{\ell_{j,t} + \ell_{j,t}^{hh}} - v^b \right) \tag{A.66}$$

$$\Xi_{j,t}^{m} \equiv \frac{\partial \Xi_{j,t}}{\partial m_{j,t}} = -\frac{\kappa_t^c n_{j,t}}{\left(\ell_{j,t} + \ell_{j,t}^{hh} \right)^2} \left(\frac{n_{j,t}^c}{\ell_{j,t} + \ell_{j,t}^{hh} t} - v^b \right) \tag{A.67}$$

$$RSC_{j,t}^{d} \equiv \frac{\partial RSC_{j,t}}{\partial d_{j,t}^c} = \alpha^d \left(\frac{\eth_{1,t}}{m_{j,t}} \right) \left(\frac{\alpha^d d_t^c + h_t}{m_{j,t}} \right)^{\eth_2} \tag{A.68}$$

$$RSC_{j,t}^{h} \equiv \frac{\partial RSC_{j,t}}{\partial h_{j,t}} = \left(\frac{\eth_{1,t}}{m_{j,t}} \right) \left(\frac{\alpha^d d_t^c + h_t^c}{m_{j,t}} \right)^{\eth_2} \tag{A.69}$$

$$RSC_{j,t}^{m} \equiv \frac{\partial RSC_{j,t}}{\partial m_{j,t}} = -\left(\frac{\eth_{1,t}}{m_{j,t}} \right) \left(\frac{\alpha^d d_t^c + h_t^c}{m_{j,t}} \right)^{1+\eth_2} \tag{A.70}$$

First order conditions are (with $\varpi_{j,t}$ the value of the balance sheet constraint/shadow value of

net worth, and defining an auxiliary variable $\vartheta_{j,t} \equiv \varpi_{j,t}/(1-\varrho+\varrho\varpi_{j,t+1})$ for ease of notation):

$$R_t^m = \mathbb{E}_t\left\{\Pi_{t+1}\left(\Lambda_{t,t+1}^{-1}\vartheta_t + RSC_t^m\right)\right\} \tag{A.71}$$

$$R_t^h = \mathbb{E}_t\left\{\Pi_{t+1}\left(\Lambda_{t,t+1}^{-1}\vartheta_t - RSC_t^h\right)\left(\frac{\xi_t^h}{\xi_t^h-1}\right)\right\} \tag{A.72}$$

$$R_t^{\ell,hh} = \mathbb{E}_t\left\{\Pi_{t+1}\left(\Lambda_{t,t+1}^{-1}\vartheta_t + \Xi_t^\ell\right)\left(\frac{\xi_t^{\ell,hh}}{\xi_t^{\ell,hh}-1}\right)\right\} \tag{A.73}$$

$$R_t^{\ell} = \mathbb{E}_t\left\{\Pi_{t+1}\left(\Lambda_{t,t+1}^{-1}\vartheta_t + \Xi_t^\ell\right)\left(\frac{\xi_t^{\ell}}{\xi_t^{\ell}-1}\right)\right\} \tag{A.74}$$

where we have simplified the conditions by applying symmetric equilibrium and dropping index j.

Deposits are slightly different due to the zero lower bound. We obtain the two cases as:

$$R_t^{d,c} = \mathbb{E}_t\left\{\Pi_{t+1}\left(\Lambda_{t,t+1}^{-1}\vartheta_t - RSC_t^d\right)\left(\frac{\xi_t^d}{\xi_t^d-1}\right)\right\} \qquad \text{if } R_t^{d,c} > 1$$

$$R_t^{d,c} = 1 \qquad \text{else}$$

It is worth pausing briefly to discuss the implications of this in steady state. Assume that v^b is calibrated such that in steady state $\Xi = \Xi^m = \Xi^\ell = 0$ and that the ZLB does not bind, and set $\eth_1 = 0$, i.e., assuming reserves earn no convenience yield and hence $RSC = RSC^m = RSC^d = RSC^h = 0$. It follows that:

$$R^{d,c} = \mathbb{E}_t\left\{\left(\frac{\xi_t^d}{\xi_t^d-1}\right)R^m\right\}$$

$$R^{\ell} = \mathbb{E}_t\left\{\left(\frac{\xi_t^\ell}{\xi_t^\ell-1}\right)R^m\right\}$$

$$R^{\ell,hh} = \mathbb{E}_t\left\{\left(\frac{\xi_t^{\ell,hh}}{\xi_t^{\ell,hh}-1}\right)R^m\right\}$$

$$R^{h} = \mathbb{E}_t\left\{\left(\frac{\xi_t^h}{\xi_t^h-1}\right)R^m\right\}$$

This makes it clear that when $\xi_t^d, \xi_t^h < (-1)$ and $\xi_t^\ell, \xi_t^{\ell,hh} > 1$, the deposit rate and wholesale deposit rate are a markdown on the reserve rate of interest and loan rates are marked up. Away

from steady state, markups/markdowns follow broadly the same pattern but may deviate somewhat due to both the capital/asset target and the Zero Lower Bound (ZLB).

The "deposit ZLB" binds when the (net) deposit rate equals zero. However, the "Policy Effective Lower Bound" (PELB) on the reserve rate is somewhat different than this, because the reserve rate will not in general equal the deposit rate. Taking the deposit equation at the point where it just binds and applying to the reserve equation, we find the PELB to bind when:

$$R_t^m = \left(\frac{\xi_t^d - 1}{\xi_t^d} \right) + \mathbb{E}_t \left\{ \Pi_{t+1} \left(RSC_t^d + RSC_t^m \right) \right\} \tag{A.75}$$

Note that since $\xi_d < (-1)$, $RSC_t^m < 0$, and $RSC_t^d > 0$, the location of the PELB with respect to the ZLB is ambiguous. If $|\xi_t^d|$ is small, then the monopolistic markdown will dominate and $R_t^m > R_t^{d,c}$ at the ZLB. Similarly, deposits create a large marginal reserve scarcity cost (RSC_t^d) is large, that ensures deposits are priced well below reserves and $R_t^m > R_t^{d,c}$ at the ZLB.

Conversely if the marginal value of an additional reserve RSC_t^m is large, the reserve scarcity effect will dominate and $R_t^m < R_t^{d,c}$. Confusingly, the policy rate can continue to be reduced past the PELB but will be less impactful as it does not transmit to deposit rates. This process continues until we reach the "true lower bound" where bank profits become negative, beyond which a lower policy rate is actively harmful to the economy.

B Equilibrium Equations

Household's equations:

$$\Lambda_t = \beta \psi_{c,t} \frac{\mu_t}{\mu_{t-1}} \tag{A.1}$$

$$\mu_t = \frac{1}{(C_t - bC_{t-1})} - \beta b \mathbb{E}_t^H \left\{ \frac{1}{(C_{t+1} - bC_t)} \right\} \tag{A.2}$$

$$\psi_{l,t} \chi L_t^{\eta} = \mu_t w_t^h \tag{A.3}$$

$$1 = \mathbb{E}_t^H \left\{ \Lambda_{t,t+1} \Pi_{t+1}^{-1} R_t^{d,c} \right\} + \mu_t^d \nu_t^d \tag{A.4}$$

$$1 = \mathbb{E}_t^H \left\{ \Lambda_{t,t+1} \Pi_{t+1}^{-1} R_t^{d,s} + \mathcal{A}_t^s \right\} \tag{A.5}$$

$$1 = \mathbb{E}_t^H \left\{ \Lambda_{t,t+1} \Pi_{t+1}^{-1} R_t^{\ell,hh} + \mathcal{A}_t^{\ell} \right\} \tag{A.6}$$

$$C_t \leq \nu_t^d d_t^c \tag{A.7}$$

Labour union's equations:

$$w_t^* = \frac{\epsilon_t^w}{\epsilon_t^w - 1} \frac{f_{1,t}}{f_{2,t}} \tag{A.8}$$

$$f_{1,t} = w_t^h w_t^{\epsilon_t^w} L_{d,t} + \phi_w \mathbb{E}_t^F \Lambda_{t,t+1} \left(\frac{\Pi_{t+1}}{\Pi_t^{\gamma_w}} \right)^{\epsilon_t^w} f_{1,t+1} \tag{A.9}$$

$$f_{2,t} = w_t^{\epsilon_t^w} L_{d,t} + \phi_w \mathbb{E}_t^F \Lambda_{t,t+1} \left(\frac{\Pi_{t+1}}{\Pi_t^{\gamma_w}} \right)^{\epsilon_t^w - 1} f_{2,t+1} \tag{A.10}$$

Retail firm's equations:

$$p_t^* = \frac{\epsilon_t^p}{\epsilon_t^p - 1} \frac{x_{1,t}}{x_{2,t}} \tag{A.11}$$

$$x_{1,t} = p_{m,t} Y_t + \phi_p \mathbb{E}_t^F \Lambda_{t,t+1} \left(\frac{\Pi_{t+1}}{\Pi_t^{\gamma_p}} \right)^{\epsilon_t^p} x_{1,t+1} \tag{A.12}$$

$$x_{2,t} = Y_t + \phi_p \mathbb{E}_t^F \Lambda_{t,t+1} \left(\frac{\Pi_{t+1}}{\Pi_t^{\gamma_p}} \right)^{\epsilon_t^p - 1} x_{2,t+1} \tag{A.13}$$

Wholesale firm's equations:

$$Y_{m,t} = A_t(u_t K_t)^{\alpha} L_{d,t}^{1-\alpha} \tag{A.14}$$

$$w_t = (1-\alpha) p_{m,t} A_t (u_t K_t)^{\alpha} L_{d,t}^{-\alpha} \tag{A.15}$$

$$(1+\psi_t M_{3,t}) p_t^k (\delta_1 + \delta_2(u_t - 1)) = \alpha p_m A_t (u_t K_t)^{\alpha-1} L_d^{1-\alpha} \tag{A.16}$$

$$(1+\psi_t M_{3,t}) p_t^k = \mathbb{E}_t^F \Lambda_{t,t+1} [\alpha p_{m,t+1} A_{t+1} (u_{t+1} K_{t+1})^{\alpha-1} u_{t+1} L_{d,t+1}^{1-\alpha} \dots$$

$$\dots + (1 - \delta(u_{t+1})) p_{t+1}^k (1 + \psi_{t+1} M_{3,t+1})] \tag{A.17}$$

$$f_t^{NEW} = f_t - \kappa_f f_{t-1} \Pi_t^{-1} \tag{A.18}$$

$$\ell_t^{NEW} = \ell_t - \kappa_l \ell_{t-1} \Pi_t^{-1} \tag{A.19}$$

$$\mathcal{B}_t^f = Q_t \left[\frac{\zeta_{1,t} \mathcal{B}_t}{Q_t f_t} \right]^{\frac{1}{\zeta_2}} \tag{A.20}$$

$$\mathcal{B}_t^{\ell} = \left[(1 - \zeta_{1,t}) \frac{\mathcal{B}_t}{\ell_t} \right]^{\frac{1}{\zeta_2}} \tag{A.21}$$

$$Q_t M_{3,t} + \mathcal{B}_t^f = \mathbb{E}_t^F \Lambda_{t+1} \Pi_{t+1}^{-1} (1 + \kappa_f Q_{t+1} + \kappa_f Q_{t+1} M_{3,t+1}) \tag{A.22}$$

$$M_{3,t} + \mathcal{B}_t^{\ell} = \mathbb{E}_t^F \Lambda_{t+1} \Pi_{t+1}^{-1} \left(R_t^{\ell} + \kappa_f M_{3,t+1} \right) \tag{A.23}$$

$$K_{t+1} = \hat{I}_t + (1 - \delta_0 - \delta_1(u_t - 1) - \frac{\delta_2}{2}(u_t - 1)^2) K_t \tag{A.24}$$

$$\psi_t p_t^k \hat{I}_t + \bar{\psi} + (Q_t f_t + \ell_t) \epsilon_{\psi,t} = Q_t f_t^{NEW} + \ell_t^{NEW} \tag{A.25}$$

Capital producer's equations:

$$\hat{I}_t = I_t \, \mu_t^I \left(1 - \frac{\kappa^I}{2} \left(\frac{I_t}{I_{t-1}} - 1 \right)^2 \right) \tag{A.26}$$

$$1 = p_t^k \, \mu_t^I \left(1 - \frac{\kappa^I}{2} \left(\frac{I_t}{I_{t-1}} - 1 \right)^2 - \frac{I_t}{I_{t-1}} \, \kappa^I \left(\frac{I_t}{I_{t-1}} - 1 \right) \right) + \dots$$

$$\dots + \mathbb{E}_{t\ t}^F \left\{ \kappa^I \, p_{t+1}^k \, \beta_E \, \Lambda_{t+1} \, \mu_{t+1}^I \left(\frac{I_{t+1}}{I_t} - 1 \right) \left(\frac{I_{t+1}}{I_t} \right)^2 \right\} \tag{A.27}$$

NBFI's equations:

$$R_t^F = \frac{1 + k_f Q_t}{Q_{t-1}} \tag{A.28}$$

$$R_t^B = \frac{1 + k_b Q_{B,t}}{Q_{B,t-1}} \tag{A.29}$$

$$n_t^s = \sigma \Pi_t^{-1} \left[R_t^F Q_{t-1} f_{t-1} + R_t^B Q_{B,t-1} b_{t-1} + R_{t-1}^H h_{t-1} - R_{t-1}^{d,s} d_{t-1}^s \right] \tag{A.30}$$

$$\Omega_t = 1 - \sigma + \sigma \phi_t \tag{A.31}$$

$$\phi_t \left(1 + LSC_t^B + DSC_t^B \right) = \mathbb{E}_t \Lambda_{t,t+1} \Omega_{t+1} \Pi_{t+1}^{-1} R_{t+1}^B \tag{A.32}$$

$$\phi_t \left(1 + DSC_t^F \right) = \mathbb{E}_t \Lambda_{t,t+1} \Omega_{t+1} \Pi_{t+1}^{-1} R_{t+1}^F \tag{A.33}$$

$$\phi_t \left(1 + LSC_t^H \right) = \mathbb{E}_t \Lambda_{t,t+1} \Omega_{t+1} \Pi_{t+1}^{-1} R_{t+1}^H \tag{A.34}$$

$$\phi_t \left(1 - LSC_t^D - DSC_t^D \right) = \mathbb{E}_t \Lambda_{t,t+1} \Omega_{t+1} \Pi_{t+1}^{-1} R_t^{d,s} \tag{A.35}$$

$$Q_t f_t + Q_{B,t} b_t + h_t = d_t^s + n_t^s \tag{A.36}$$

$$V_t = \mathbb{E}_t \Lambda_{t,t+1} \left[(1 - \sigma) n_{t+1}^s + \sigma V_{t+1} \right] \tag{A.37}$$

$$\tag{A.38}$$

Commercial bank's equations:

$$m_{j,t} + \ell^f_{j,t} + \ell^{hh}_{j,t} = d^c_{j,t} + h_{j,t} + n^c_{j,t} \tag{A.39}$$

$$\mathcal{P}_t = \Pi_t^{-1}\left[R^{\ell}_{t-1}\left(\ell^f_{t-1} + \ell^{hh}_{t-1}\right) + R^m_{t-1}m_{t-1} - R^{d,c}_{t-1}d^{d,c}_{t-1} - R^h_{t-1}h_{t-1}\right] - \Xi_{t-1} - RSC_{t-1} \tag{A.40}$$

$$\Xi_{j,t} \equiv \frac{\kappa^c_t}{2}\left(\frac{n^c_{j,t}}{\ell^f_{j,t} + \ell^{hh}_{j,t}} - v^b\right)^2 \tag{A.41}$$

$$RSC_{j,t} \equiv \frac{\eth_{1,t}}{1+\eth_2}\left(\frac{\alpha^d d^c_{j,t} + h_{j,t}}{m_{j,t}}\right)^{1+\eth_2} \tag{A.42}$$

$$n^c_t = \varrho\mathcal{P}_t + (1-\varsigma)\, n^c_{t-1} \tag{A.43}$$

$$\Xi^{\ell}_{j,t} \equiv \frac{\partial \Xi_{j,t}}{\partial \ell_{j,t}} = -\frac{\kappa^c_t n_{j,t}}{\left(\ell_{j,t} + \ell^{hh}_{j,t}\right)^2}\left(\frac{n^c_{j,t}}{\ell_{j,t} + \ell^{hh}_{j,t}} - v^b\right) \tag{A.44}$$

$$R^m_t = \Pi_{t+1}\left(\Lambda^{-1}_{t,t+1}\vartheta_t + RSC^m_t\right) \tag{A.45}$$

$$R^h_t = \Pi_{t+1}\left(\Lambda^{-1}_{t,t+1}\vartheta_t - RSC^h_t\right)\left(\frac{\xi_h}{\xi_h - 1}\right) \tag{A.46}$$

$$R^{\ell}_t = \Pi_{t+1}\left(\Lambda^{-1}_{t,t+1}\vartheta_t + \Xi^{\ell}_t\right)\left(\frac{\xi^{\ell}_t}{\xi^{\ell}_t - 1}\right) \tag{A.47}$$

$$R^{\ell,hh}_t = \Pi_{t+1}\left(\Lambda^{-1}_{t,t+1}\vartheta_t + \Xi^{\ell}_t\right)\left(\frac{\xi^{\ell,hh}_t}{\xi^{\ell,hh}_t - 1}\right) \tag{A.48}$$

$$R^{d,c}_t = \max\left\{\Pi_{t+1}\left(\Lambda^{-1}_{t,t+1}\vartheta_t - RSC^d_t\right)\left(\frac{\xi^d_t}{\xi^d_t - 1}\right), 1\right\} \tag{A.49}$$

Fiscal authority's equations:

$$G_t + \Pi_t^{-1}\bar{b}_{G,t} = T_t + T_{cb,t} + Q_{B,t}(b_{G,t} - \kappa_b\Pi_t^{-1}b_{G,t-1}) \tag{A.50}$$

Central Bank's equations:

$$m_t = Q_{B,t}b^{CB}_t \tag{A.51}$$

$$T^{CB}_t = \Pi^{-1}\left[(1+\kappa_b Q_{B,t})b^{CB}_{t-1} - R^m_{t-1}m_{t-1}\right] \tag{A.52}$$

$$R^{tr}_t = (1-\rho_r)\bar{R}^m + \rho_r R^{tr}_{t-1} + (1-\rho_r)[\phi_\pi(\Pi^A_t)^{1/4} + \phi_y \ln(Y_t/\bar{Y})] + \epsilon_{r,t} \tag{A.53}$$

$$R^m_t = \max\left\{R^{tr}_t, PELB\right\} \tag{A.54}$$

Aggregate condition's equations:

$$Y_t v_t^p = Y_{m,t} \tag{A.55}$$

$$v_t^p = (1-\phi_p)(p_t^*)^{-\epsilon_t^p} + \phi_p \left(\frac{\Pi_t}{\Pi_{t-1}^{\gamma_p}}\right)^{\epsilon_t^p} v_{t-1}^p \tag{A.56}$$

$$1 = (1-\phi_p)(p_t^*)^{1-\epsilon_t^p} + \phi_p \Pi_{t-1}^{\gamma_p(1-\epsilon_t^p)} \Pi_t^{\epsilon_t^p - 1} \tag{A.57}$$

$$L_t = L_{d,t} v_t^w \tag{A.58}$$

$$v_t^w = (1-\phi_w)\left(\frac{w_t^*}{w_t}\right)^{-\epsilon_t^w} + \phi_w \left(\frac{\Pi_t}{\Pi_{t-1}^{\gamma_w}}\right)^{\epsilon_t^w} \left(\frac{w_t}{w_{t-1}}\right)^{\epsilon_t^w} v_{t-1}^w \tag{A.59}$$

$$w_t^{1-\epsilon_t^w} = (1-\phi_w)(w_t^*)^{1-\epsilon_t^w} + \phi_w \Pi_{t-1}^{\gamma_w(1-\epsilon_t^w)} \Pi_{t-1}^{\epsilon_t^w - 1} w_{t-1}^{1-\epsilon_t^w} \tag{A.60}$$

$$f_{m,t} = f_t \tag{A.61}$$

$$b_{G,t} = b_t + b_{cb,t} \tag{A.62}$$

$$Y_t = C_t + G_t + I_t \tag{A.63}$$

Exogenous processes' equations:

$$\ln \xi_t^{\ell} = (1-\rho_{\xi^{\ell}}) \ln \xi^{\ell} + \rho_{\xi^{\ell}} \ln \xi_{t-1}^{\ell} + \epsilon_{\ell,t} \tag{A.64}$$

$$\ln \xi_t^{\ell,hh} = (1-\rho_{\xi^{\ell,hh}}) \ln \xi^{\ell} + \rho_{\xi^{\ell,hh}} \ln \xi_{t-1}^{\ell,hh} + \epsilon_{\ell,hh,t} \tag{A.65}$$

$$\ln \xi_t^{h} = (1-\rho_{\xi^{h}}) \ln \xi^{h} + \rho_{\epsilon^{h}} \ln \xi_{t-1}^{h} + \epsilon_{h,t} \tag{A.66}$$

$$\ln \xi_t^{d} = (1-\rho_{\xi^{d}}) \ln \xi^{d} + \rho_{\epsilon^{d}} \ln \xi_{t-1}^{d} + \epsilon_{d,t} \tag{A.67}$$

$$\ln \zeta_{1,t} = (1-\rho_{\zeta_1}) \ln \zeta_1 + \rho_{\zeta_1} \ln \zeta_{1,t-1} + \epsilon_{\zeta,t} \tag{A.68}$$

$$\ln \nu_{1,t} = (1-\rho_{\nu_1}) \ln \nu_1 + \rho_{\nu_1} \ln \nu_{1,t-1} + \epsilon_{\nu_1,t} \tag{A.69}$$

$$\ln \nu_{B,t} = (1-\rho_{\nu_B}) \ln \nu_B + \rho_{\nu_B} \ln \nu_{B,t-1} + \epsilon_{\nu_B,t} \tag{A.70}$$

$$\ln \varphi_{1,t} = (1-\rho_{\varphi_1}) \ln \varphi_1 + \rho_{\varphi_1} \ln \varphi_{1,t-1} + \epsilon_{\varphi,t} \tag{A.71}$$

$$\ln \eth_{1,t} = (1-\rho_{\eth_1}) \ln \eth_1 + \rho_{\eth_1} \ln \eth_{1,t-1} + \epsilon_{\eth,t} \tag{A.72}$$

$$\epsilon_t^{w} = (1-\rho_{\epsilon^{w}})\epsilon^{w} + \rho_{\epsilon^{w}} \epsilon_{t-1}^{w} + \epsilon_{w,t} \tag{A.73}$$

$$\epsilon_t^{p} = (1-\rho_{\epsilon^{p}})\epsilon^{p} + \rho_{\epsilon^{p}} \epsilon_{t-1}^{p} + \epsilon_{p,t} \tag{A.74}$$

$$\ln A_t = \rho_A \ln A_{t-1} + \epsilon_{A,t} \tag{A.75}$$

$$\ln \mu_t^{I} = \rho_{\mu^{I}} \ln \mu_{t-1}^{I} + \epsilon_{\mu,t} \tag{A.76}$$

$$\ln \psi_{c,t} = \rho_{\psi_c} \ln \psi_{c,t-1} + \epsilon_{\psi_c,t} \tag{A.77}$$

$$\ln \psi_{l,t} = \rho_{\psi_l} \ln \psi_{l,t-1} + \epsilon_{\psi_l,t} \tag{A.78}$$

$$\ln \nu_t^{d} = (1-\rho_{\nu^{d}}) \ln \nu^{d} + \rho_{\nu^{d}} \ln \nu_{t-1}^{d} + \epsilon_{\nu,t} \tag{A.79}$$

$$\ln G_t = (1-\rho_G) \ln G + \rho_G \ln G_{t-1} + \epsilon_{G,t} \tag{A.80}$$

$$\ln b_t^{G} = (1-\rho_{b^{G}}) \ln b^{G} + \rho_{b^{G}} \ln b_{t-1}^{G} + \epsilon_{B,t} \tag{A.81}$$

$$b_{cb,t} Q_t^{B} = (1-\rho_b) b_{cb} Q^{B} + \rho_b b_{cb,t-1} Q_{t-1}^{B} + \epsilon_{QE} \tag{A.82}$$

C NBFI's wholesale deposits adjustment cost

To simulate wholesale market disruption, we introduce the below wholesale deposits adjustment costs $\mathbb{H}_t$ in the NBFIs problem. The intuition is that by facing a large adjustment cost, NBFIs are prevented from holding additional wholesale deposits and always choose to hold the steady-state level.

$$\mathbb{H}_t \equiv 0.5\kappa_h h_t \left(h_t - h_{t-1}\right)^2 \tag{A.83}$$

The first order condition with respect to the wholesale deposits market is the following:

$$\phi_t \left(1 + LSC_t^H\right) = \mathbb{E}_t \Lambda_{t,t+1} \Omega_{t+1} \Pi_{t+1}^{-1} R_{t+1}^H - \mathbb{H}_t^h \tag{A.84}$$

Where $\mathbb{H}_t^h$ is the partial derivative of the wholesale deposits adjustment costs with respect to h_t:

$$\mathbb{H}_t^h \equiv \mathbb{H}_t / h_t + \kappa_h h_t \left[h_t - h_{t-1} - \Lambda_{t,t+1} \left(h_{t+1} - h_t\right)\right] \tag{A.85}$$

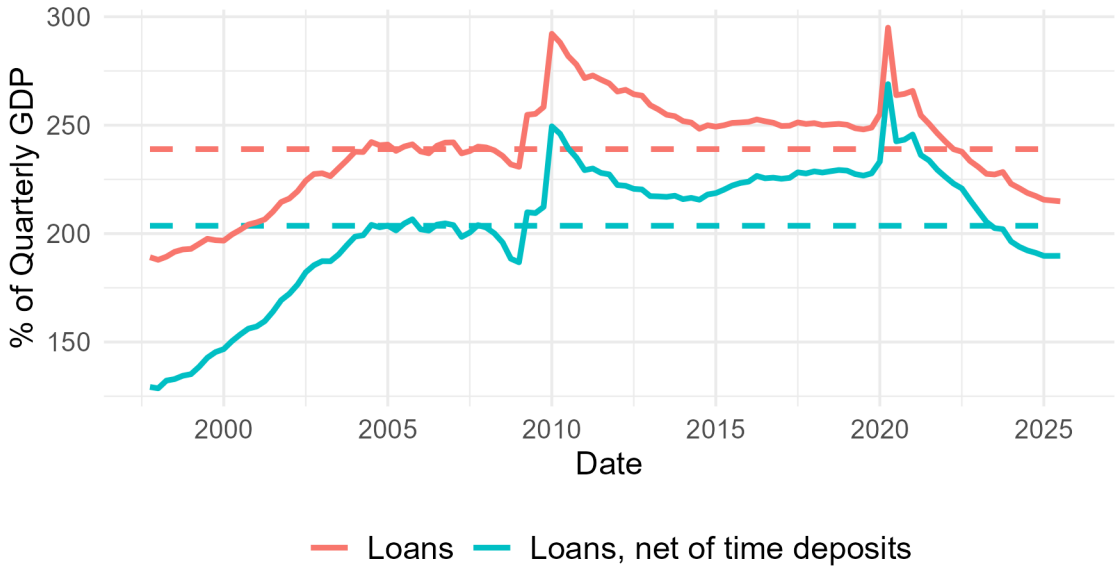
D Data, Calibration and Estimation

D.1 Household Loans from Banks

We calculate the ratio of household loans to GDP as the mean value 1997-2025. For all our results, we use bank loans to households *net of time deposits*. This is because the value we are interested in is bank net financing of households, with respect to illiquid assets and liabilities (since we model liquid deposits separately). However as shown in Figure A.1, this adjustment makes a comparatively small difference. Bank loans to households are 232% of quarterly GDP, this falls to 204% once we account for illiquid time deposits. The two series have much the same dynamics over time, and results are robust to using the alternative measure. The main difference is that the net series has grown slightly more across the time horizon, which is mostly stripped out of the estimation once the series have been differenced and demeaned.

Note that the time deposit series was disaggregated into separate series for banks and building societies before 2008.

Figure A.1: Household Loans to GDP

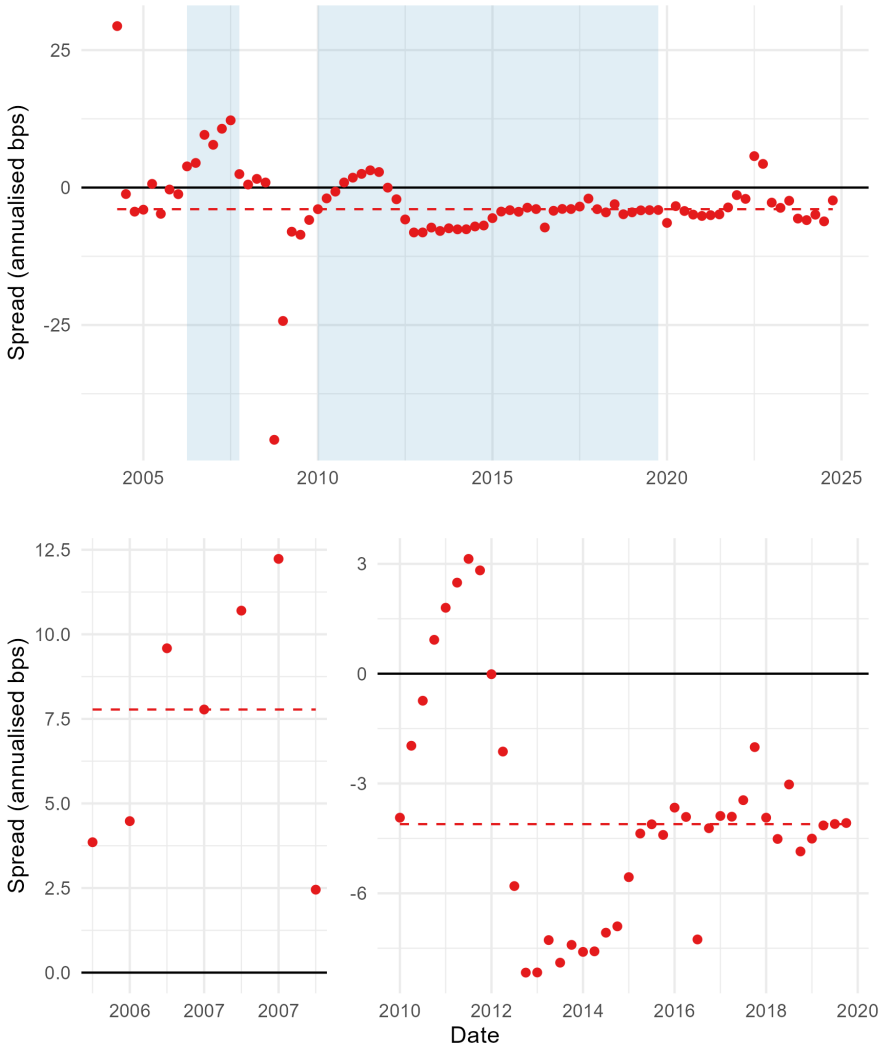


Loan and time deposit data from the Bank of England Database. Monetary Financial Institutions (MFI) loans to households excluding overdrafts (LPMB3TB), and MFI loans to households net of household time deposits held at MFIs (sum of series LWMB2F8 and LWMB2F7 before 2008, series LPMZ3TZ from 2008). GDP data from the ONS, series ABMI.

D.2 SONIA Spreads

Figure A.2 shows the Sterling Overnight Index Average (SONIA) spread to policy rate across different time horizons. This shows the cost to commercial banks of obtaining short term funding, and is thus a reasonable proxy of the interest paid to NBFIs on their bank deposits. It can be seen readily that this drops sharply after the introduction of QE, and thereafter remains low and broadly flat.

Figure A.2: SONIA Spreads



Spread between the Sterling Overnight Index Average (SONIA) and Bank of England policy rate, for full sample (top) and selected subsamples (bottom). Dashed lines indicate median value for each sample.

D.3 Observables

Figure A.3: Estimation Observables



D.4 Parameters

Table A.1: Shock Persistence Parameters

Par.	Description	Prior Mean	Post. Mean	90% HPD Interval	Prior	Pstdev
ρ_A	Productivity	0.500	0.7728	[0.6920, 0.8535]	β	0.2000
ρ_r	Monetary Policy	0.800	0.8774	[0.8622, 0.8925]	β	0.0500
ρ_m	Investment	0.500	0.3463	[0.2178, 0.4777]	β	0.2000
ρ_l	Labour Preference	0.500	0.9284	[0.8221, 0.9988]	β	0.2000
ρ_c	Consumption Preference	0.500	0.6113	[0.5369, 0.6823]	β	0.2000
ρ_G	Government Spending	0.500	0.9021	[0.8472, 0.9558]	β	0.2000
ρ_{ε_w}	Wage Markup	0.500	0.1304	[0.0123, 0.2529]	β	0.2000
ρ_{ε_p}	Price Markup	0.500	0.5395	[0.4431, 0.6426]	β	0.2000
ρ_{ζ_1}	Firm Bond Pref.	0.500	0.3049	[0.1857, 0.4300]	β	0.2000
ρ_{ξ_1}	MM Deposit Markup	0.500	0.5831	[0.3891, 0.7947]	β	0.2000
ρ_{ξ_2}	Loan Markup	0.500	0.9504	[0.9132, 0.9904]	β	0.2000
ρ_{ξ_3}	Deposit Markdown	0.500	0.9683	[0.9439, 0.9932]	β	0.2000
ρ_b	QE	0.980	0.9898	[0.9835, 0.9961]	β	0.0100
ρ_{ν_1}	NBFI Liquidity	0.500	0.9918	[0.9868, 0.9971]	β	0.2000
ρ_{ν_B}	NBFI Gov. Bond Liq.	0.500	0.9982	[0.9964, 0.9999]	β	0.2000
ρ_{φ_1}	NBFI Duration	0.500	0.3775	[0.1550, 0.5879]	β	0.2000
$\rho_{\nu_{velo}}$	Velocity	0.500	0.9514	[0.9202, 0.9858]	β	0.2000
$\rho_{\eth_1}$	Reserve Scarcity	0.500	0.9826	[0.9670, 0.9986]	β	0.2000
ρ_B	Government Debt	0.500	0.9596	[0.9323, 0.9891]	β	0.2000

Table A.2: Shock Standard Deviations

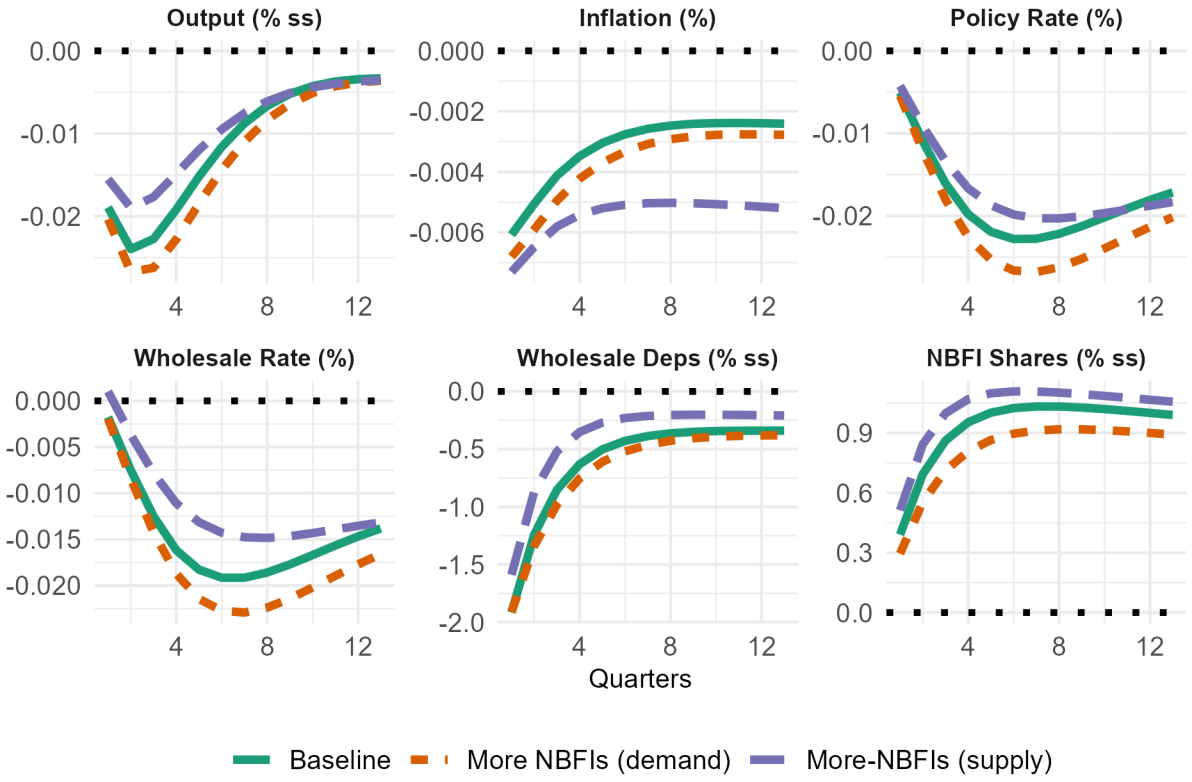
Par.	Description	Prior Mean	Post. Mean	90% HPD Interval	Prior	Pstdev
σ_A	Productivity	0.050	0.0066	[0.0057, 0.0073]	Γ	0.0450
σ_l	Labour Preference	0.050	0.0171	[0.0048, 0.0325]	Γ	0.0450
σ_c	Consumption Preference	0.050	0.0499	[0.0243, 0.0712]	Γ	0.0450
σ_m	Investment	0.050	0.0980	[0.0497, 0.1487]	Γ	0.0450
σ_G	Government Spending	0.050	0.0341	[0.0302, 0.0379]	Γ	0.0450
σ_{ζ_1}	Firm Bond Pref.	0.050	0.6770	[0.6042, 0.7599]	Γ	0.0450
σ_{ξ_1}	MM Deposit Markup	0.050	0.1027	[0.0178, 0.1777]	Γ	0.0450
$\sigma_{\xi_{2h}}$	HH Loan Markup	0.050	0.0880	[0.0524, 0.1229]	Γ	0.0450
$\sigma_{\xi_{2f}}$	Firm Loan Markup	0.050	0.0353	[0.0244, 0.0462]	Γ	0.0450
σ_{ξ_3}	Deposit Markdown	0.050	0.6094	[0.5545, 0.6628]	Γ	0.0450
σ_{ν_1}	NBFI Liquidity	0.050	0.4781	[0.4367, 0.5208]	Γ	0.0450
σ_{ν_B}	NBFI Gov. Bond Liq.	0.050	0.9314	[0.8875, 0.9669]	Γ	0.0450
σ_{φ_1}	NBFI Duration	0.050	0.0224	[0.0001, 0.0475]	Γ	0.0450
$\sigma_{\nu_{velo}}$	Velocity	0.050	0.0085	[0.0075, 0.0094]	Γ	0.0450
σ_B	Government Debt	0.050	0.0524	[0.0458, 0.0585]	Γ	0.0450
σ_r	Monetary Policy	0.020	0.0075	[0.0067, 0.0084]	Γ	0.0150
σ_ψ	Loan-In-Advance	0.050	0.0235	[0.0208, 0.0261]	Γ	0.0450
σ_{nbfi}	NBFI Equity	1.000	7.7395	[6.9658, 8.5606]	Γ	0.9000
σ_{bank}	Bank Equity	1.000	0.1495	[0.1332, 0.1662]	Γ	0.9000
σ_{ε_w}	Wage Markup	1.000	4.8882	[4.0542, 5.6695]	Γ	0.9000
σ_{ε_p}	Price Markup	1.000	4.1017	[2.9618, 5.1021]	Γ	0.9000
$\sigma_{\eth_1}$	Reserve Scarcity	1.000	5.1542	[4.2125, 6.1063]	Γ	0.9000
σ_b	QE	1.000	1.2083	[1.0703, 1.3418]	Γ	0.9000

E Extended Results

E.1 Quantitative Tightening

Figure A.4 below shows the IRFs to a QT shock worth £100 billion, equal in size to the QE shock of Section 5.2. Differently from the QE shock, however, QT is simulated above the Effective Lower Bound, reflecting policy choices of major central banks. A full set of impulse responses are plotted below, Figure A.7.

Figure A.4: QT in normal times



Response to a QT shock $\epsilon_1^b = -1$. All rate variables are expressed in annualised percentage points, other variables are a percentage of steady-state.

Mirroring QE, QT transmits to the economy through two channels: the central bank sale of government bonds causes a *portfolio rebalancing channel* through the NBFIs' balance sheet while the destruction of reserves prompts a *liquidity channel* through the banking sector. Both these channels drive a reduction in wholesale deposits: having satisfied their liquidity preferences through

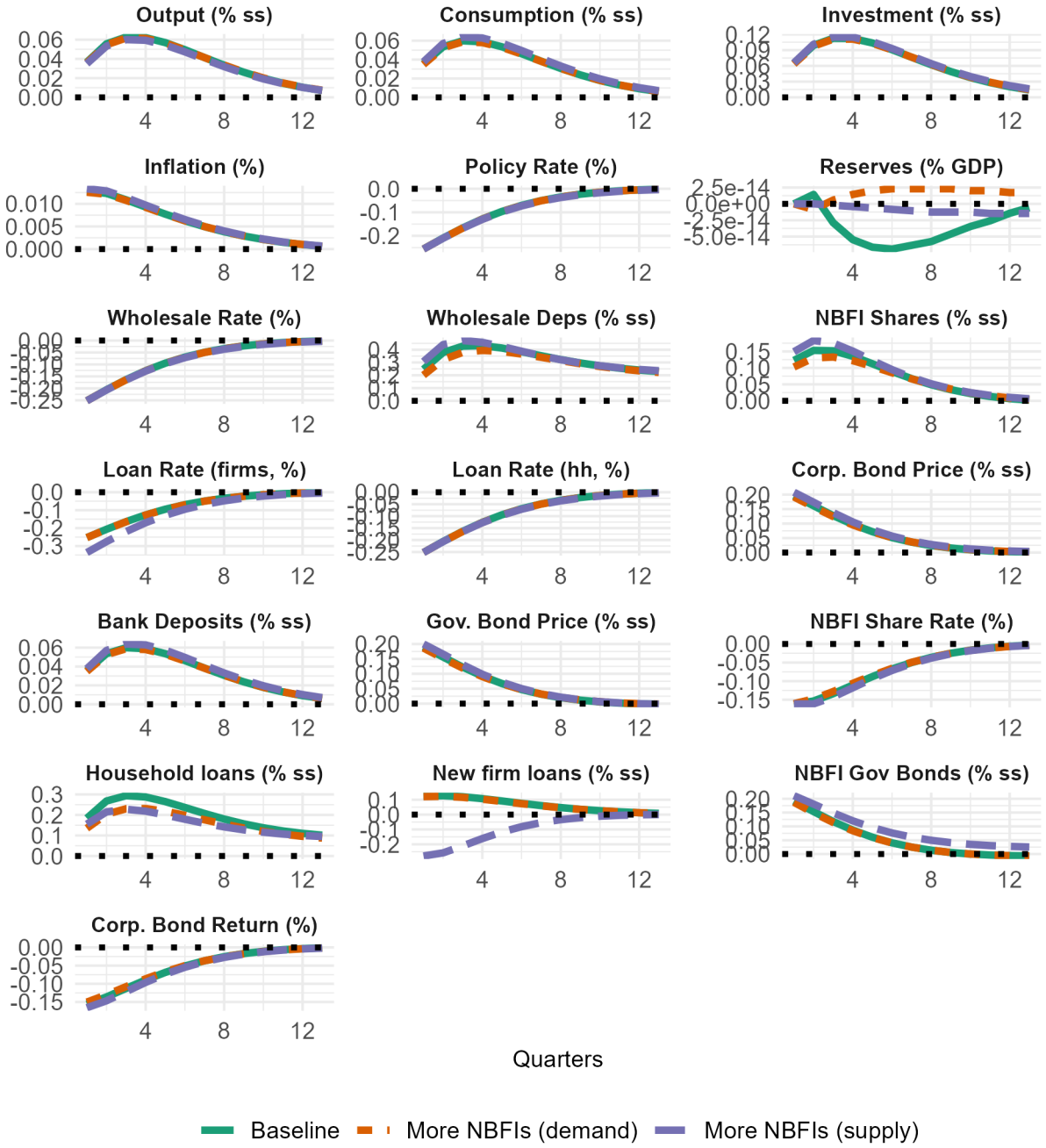
the purchases of government bonds, NBFIs can lower wholesale deposits. Banks record a fall in reserves, and in general equilibrium this is balanced with a decrease in funding.

This transmission process for QT through financial markets is much the same for QT as for QE. However, the macroeconomic effects are asymmetric and much smaller for QT, because the policy rate adjusts and cushions the contraction in aggregate demand following QT. With QT output falls by about -0.024% (at peak, Figure A.4) while with QE it increases by 0.146% (Figure 7). Similarly, inflation under QT falls by -0.006% while with QE it increases by 0.036%. The source of this asymmetry is the policy rate: under QE, the policy rate is stuck at the ELB for eight quarters while under QT the policy rate falls on impact and in the subsequent quarters.

Implication QT follows the same pattern as for QE: a larger firm-driven (bank-driven) NBFI sector amplifies (weakens) the effect of the central bank balance sheet operations. Magnitudes are smaller because of the interest rates respond and cushion the effect.

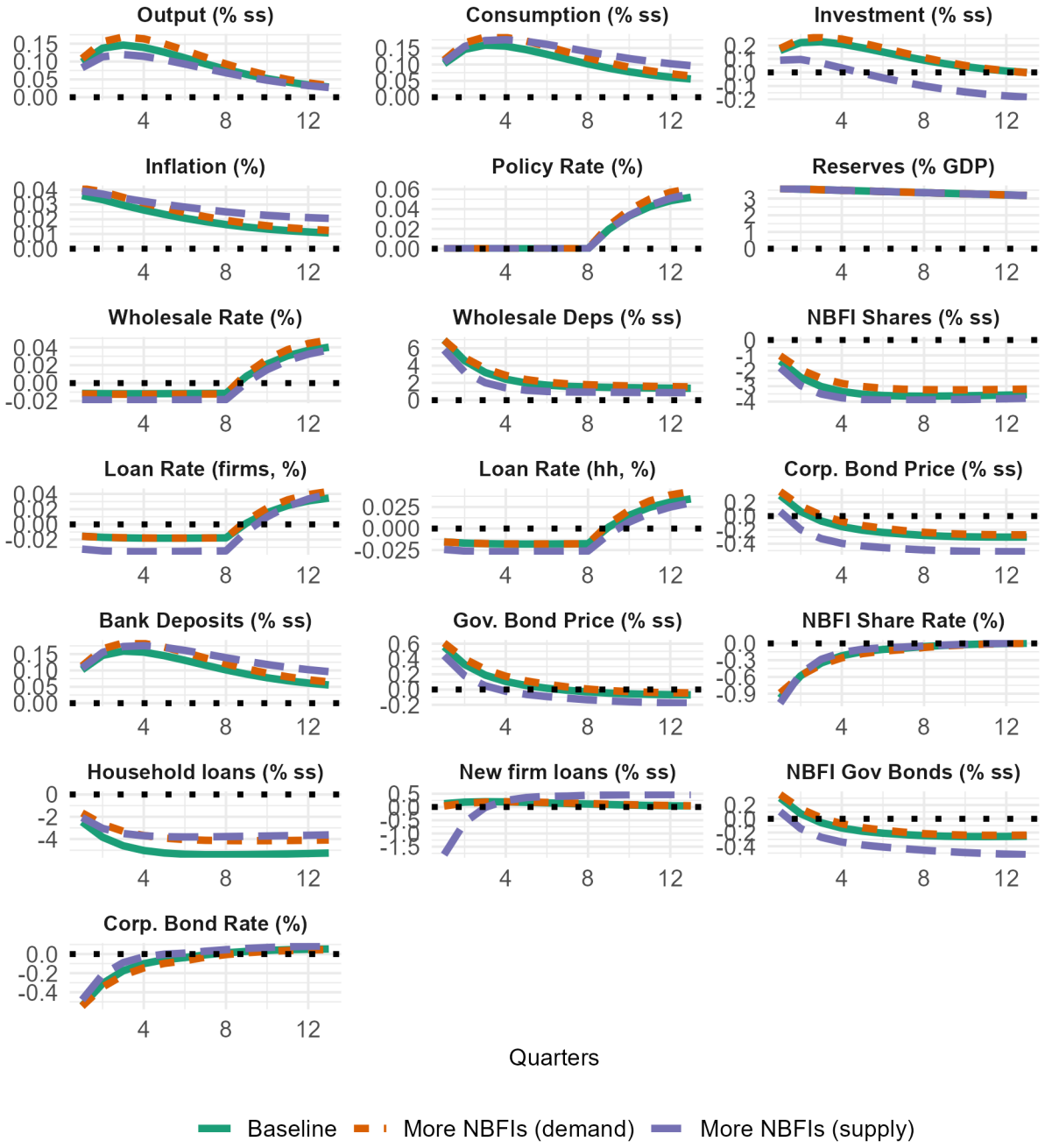
E.2 Extended IRFs

Figure A.5: Lower Interest Rates in normal times



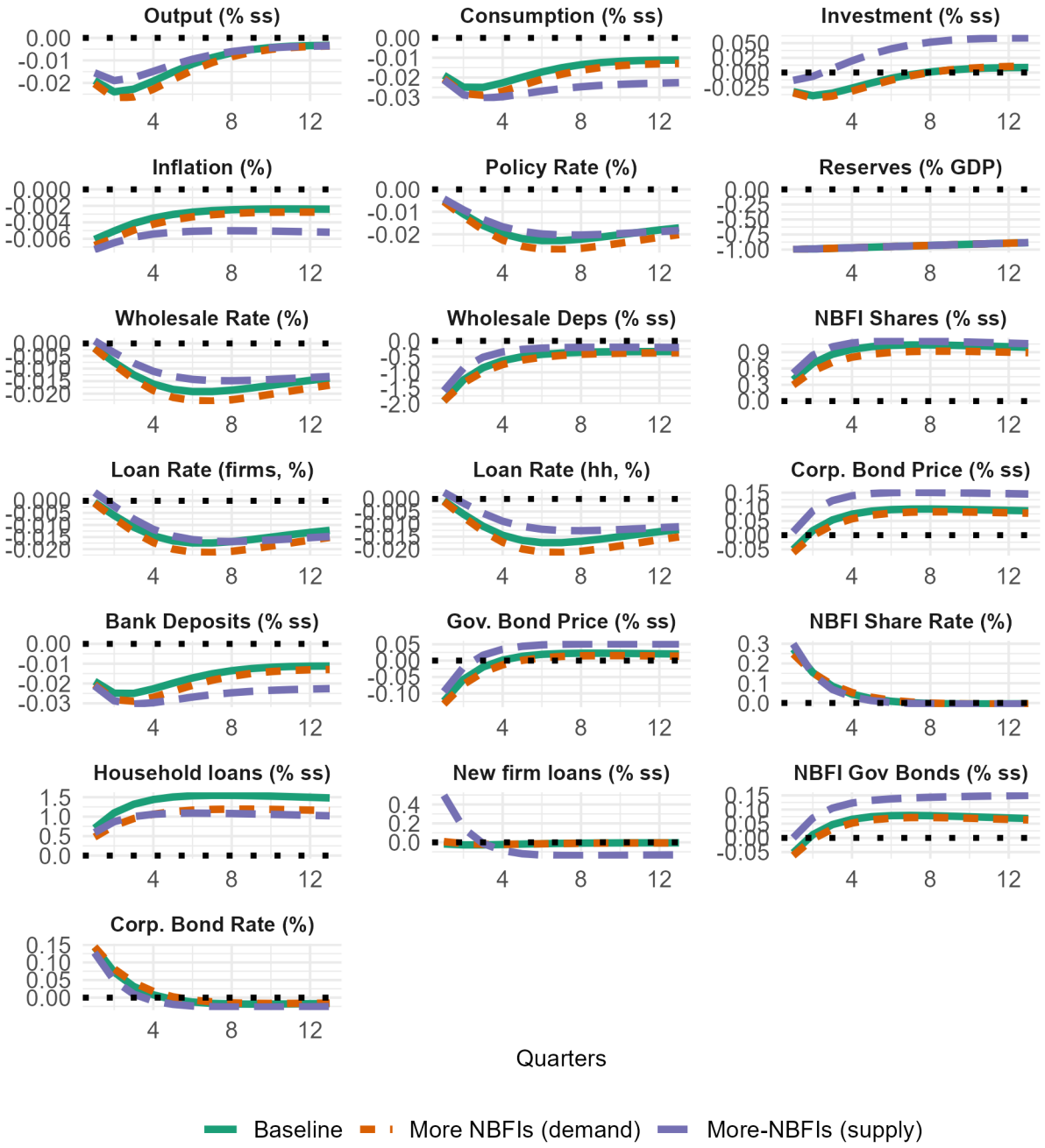
Response to an interest rate shock $\epsilon_1^R = 0.32$. All rate variables are expressed in annualised percentage points, other variables are a percentage of steady-state.

Figure A.6: QE at the lower bound



Response to a QE shock $\epsilon_1^b = 1$. The effective lower bound binds for eight quarters. All rate variables are expressed in annualised percentage points, other variables are a percentage of steady-state.

Figure A.7: QT in normal times



Response to a QT shock $\epsilon_1^b = -1$. All rate variables are expressed in annualised percentage points, other variables are a percentage of steady-state.