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Bank Regulation and Post-2008 US Monetary Policy*

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Abstract

Since U.S. bank capital holdings began rising almost concurrently with the monetary policy change after 2008, we examine the role of capital requirements for monetary policy regimes. While standard models predict that equilibrium determination and responses to aggregate shocks are fundamentally affected at the zero lower bound (ZLB), we show that these effects are absent when bank capital requirements are binding. Estimating a model version with occasionally binding capital requirements, we find that they have been almost permanently binding after 2008. We further show that capital requirements neither restore relevance of money supply nor amplify responses to macroeconomic shocks above the ZLB.

JEL classification: E52, G28, C11

Keywords: Capital Regulation, Monetary Policy, Local Equilibrium Determinacy, Regime-switching Estimation, Zero Lower Bound

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1. Introduction

In many industrialized countries, the implementation of monetary policy has undergone a structural change. Starting with the global financial crisis (GFC), central banks have reduced policy rates to the zero lower bound (ZLB) and raised money supply via large-scale asset purchase programs (LSAP). According to standard New Keynesian theory, the impact of monetary policy on macroeconomic dynamics is considerably altered when policy rates are at the ZLB, and responses to aggregate shocks are even found to be opposed compared to the off-ZLB case (see Eggertsson, 2011, 2012). The combination of ZLB and LSAP has further led to a change from a monetary policy regime of scarce bank reserves to a regime where reserves are abundant. The US Federal Reserve continued this regime under interest rates above the ZLB via interest payment on reserves (see Figure 1), ensuring that reserve holdings are not costly, such that banks have been willing to accommodate a large central bank balance sheet.

While this monetary policy regime change is well-documented and has been examined in a variety of studies (see e.g. Bianchi and Melosi, 2017; Arce et al., 2020; Sims and Wu, 2021), this paper focuses on a different policy change in the US that occurred almost simultaneously: The gradual implementation of regulatory standards according to Basel II and III after the GFC has led to an increase in total capital holdings of banks (see Walter, 2019). Figure 1 shows that the Tier 1 equity-to-asset ratio steadily increased since the onset of the GFC until the start of the COVID-19 pandemic, where capital requirements were temporarily relaxed. These observations show that US banks have experienced a transition from a regime with scarce reserves to a regime with satiated money demand and tighter capital requirements.

Motivated by these observations, we develop a model that accounts for monetary policy implementation before and after 2008 to examine the role of binding capital requirements under abundant/ample reserves. The paper provides three main novel contributions. *Firstly*, we show that the quantity restriction on financial intermediation induced by binding capital requirements has a fundamental impact on equilibrium determination. Specifically, we show that restrictions on the central bank's interest rate setting that is consistent with locally determined equilibria are much less severe than predicted by New Keynesian models that abstract from money or banking. *Secondly*, we estimate a model version with occasionally binding capital requirements and provide evidence that capital requirements have been almost permanently binding since the GFC. *Thirdly*, we show that responses to macroeconomic shocks are neither qualitatively affected by policy rates at the ZLB nor amplified above the ZLB when capital requirements bind. Unlike reserve requirements, binding capital requirements do not establish relevance of money supply, which is consistent with the lack of inflationary pressure following the post-2008 expansion in reserves.

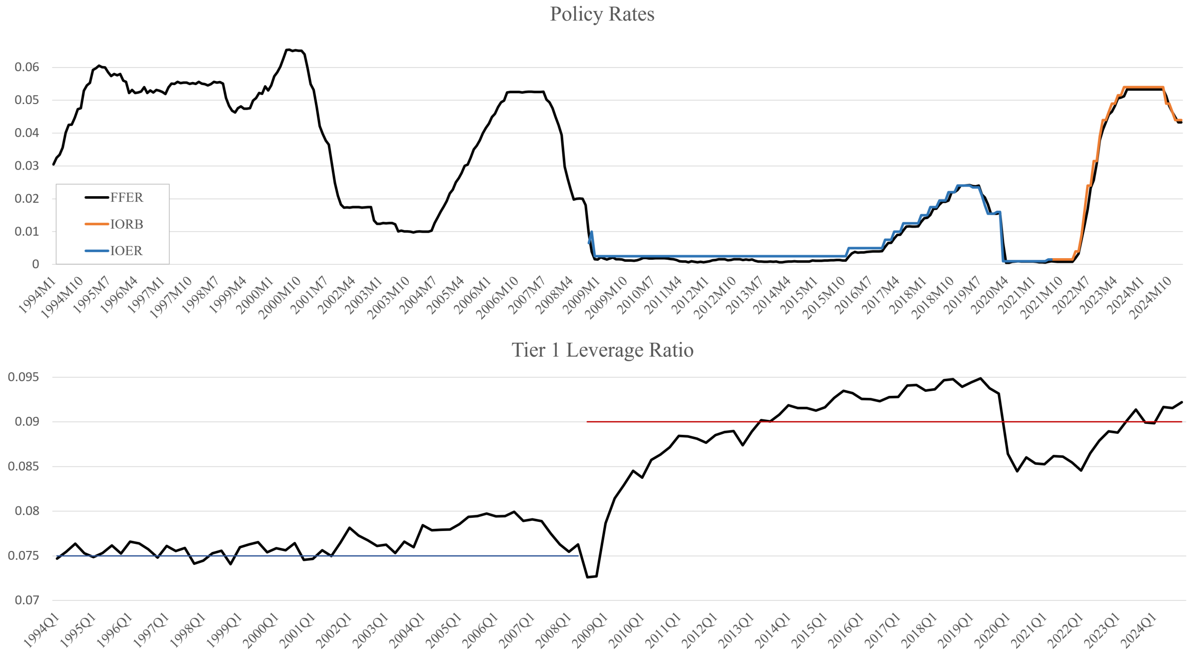

Figure 1: The upper panel depicts the Federal Funds Effective Rate (FFER) (black line) alongside the Interest on Reserve Balances (IORB) (orange line) and the Interest on Excess Reserves (IOER) (blue line). The IOER was discontinued in 2021M7 and replaced by the IORB. The lower panel represents the Tier 1 leverage ratio, defined as Tier 1 capital over total assets. (*Source*: The FRED database.)

Regarding the first main contribution of this paper, we show that a binding capital requirement can fundamentally affect equilibrium determination, in particular when the monetary policy rate is at the ZLB. The reason is that a binding capital requirement imposes a limit on the creation of deposits, similar to a reserve requirement, and relates them to bank assets. This restriction acts as an equilibrium selection device, which links nominal public sector liabilities to bank deposits and loans. This property supports local equilibrium determination regardless of whether the monetary policy rates, i.e., the Federal funds rate and IOR, are pegged (e.g., at the ZLB) or follow a state-contingent feedback rule (e.g., a Taylor rule), which we prove analytically for a simplified model version. This outcome relates to Diba and Loisel (2021), where the central bank controls money supply under an interest rate peg and a non-satiated money demand. In contrast, we consider the case where money supply is satiated due to IOR set equal to the Federal Funds rate, which is consistent with an abundant/ample reserves regime.[1] Notably, a binding capital requirement does not restore relevance of money supply, unlike in Ennis (2018) price level determination analysis.[2] The reason for this is that we account for the fact that money supply operations are conducted as asset swaps, such that changes in bank reserves holding are accompanied by an equally sized inverse change in other bank assets (i.e.

[1] A regime of abundant and, subsequently, ample reserves has been implemented by the US Federal Reserve since 2008. In contrast to a scarce reserve regime, reserve supply is sufficiently plentiful so that market rates can solely be controlled via administered rates (see Ihrig et al., 2020) and reserves do not carry any significant convenience yield (see Ennis and McMillan, 2023).

[2] In Ennis (2018), scarce bank capital and abundant reserves are inconsistent if the central bank pays interest on reserves equal to the market rate, while prices are linked to money when the capital requirement binds.

treasury bills). As a consequence, the model does not predict inflation to rise in response to a surge in reserve supply, like after the GFC.

As the second main contribution, we provide evidence from macroeconomic data that capital requirements have been almost permanently binding since the GFC. For this, we allow for the possibility that capital requirements bind occasionally which we account for by regime-switches, a strategy that relates to Bianchi and Melosi (2017) or Benigno et al. (2025). For the regime switches, we apply endogenous transition probabilities between states where capital requirements are either slack or binding. We introduce an additional Markov chain that accounts for a switch in macroeconomic volatility, particularly during the GFC and the COVID-19 pandemic, following Sims and Zha (2006) and Bianchi and Ilut (2017). To facilitate identification of these two Markov chains, we abstain from further modelling endogenous policy changes and apply data-driven specifications for monetary and fiscal policy, both being exogenous to the model similar to Sims and Wu (2021). A Bayesian estimation of the model reveals that capital requirements have been binding since 2008, with the exception of the onset of the COVID-19 pandemic, when capital requirements were temporarily relaxed. We further estimate two alternative versions of the model with a permanently binding and a permanently slack capital requirement. A formal comparison of all three versions indicates that the model fits the data best when the capital requirement binds occasionally. Our analysis suggests that the prevalence of binding capital requirements is rather driven by relatively low real interest rates – which increase the cost of equity and thereby the multiplier on the capital requirement – than by the implementation of more stringent regulatory standards.

As the third main contribution, we show that a binding capital requirement can substantially affect the transmission of macroeconomic shocks at the ZLB. We show analytically that negative productivity and positive cost push shocks at the ZLB, which are known to lead to a real expansion in a standard New Keynesian model (see Eggertsson, 2012), induce (conventional) adverse effects on real activity when the capital requirement binds. The reason is that the growth rate of agents' shadow value of wealth is not exclusively related to the real policy rate but also to the multiplier on the capital requirement. As a consequence, a sign reversal of real policy rate responses at the ZLB does not necessarily lead to a change in consumption/saving responses under binding capital requirements, which relates to the model of Michaillat and Saez (2021) featuring wealth in the utility function. A quantitative analysis confirms that productivity and cost push shocks lead to output and inflation effects at and above the ZLB that differ quantitatively, but not qualitatively, when capital requirements bind. Relatedly, we find that the fiscal multiplier, which takes extreme values at the ZLB in standard New Keynesian model (see Christiano et al., 2011), is only slightly altered at the ZLB under binding capital requirements. For monetary policy rates above the ZLB, we further find that capital requirements rather dampen effects of macroeconomic shocks, which relates to the finding of Piazzesi et al. (2022) for a New Keynesian model with leverage constrained banks, than lead to an amplification of macroeconomic shocks.

The remainder is structured as follows. Section 2 develops a monetary model with banking. Section 3 provides analytical results on equilibrium determinacy and responses to macroeconomic shocks for a simplified model version. Section 4 presents the results of the model estimation, providing evidence for binding capital requirements since the GFC, and presents impulse responses to macroeconomic shocks for the estimated model. Section 5 concludes.

Related Literature The analysis of equilibrium determinacy properties under post-2008 monetary policy regimes in our paper relates to Ennis (2018), Piazzesi et al. (2022), Michaillat and Saez (2021), and Diba and Loisel (2021). Ennis (2018) constructs a flexible price model where banks are constrained by reserve and capital requirements, and the central bank controls IOR and money supply. Like in our paper, the reserve requirement is slack under sufficiently high IOR, implying that the price level is decoupled from the money supply. He shows that a link between money supply and the price level can be restored when money supply is sufficiently large, such that a bank capital requirement binds. Piazzesi et al. (2022) develop a New Keynesian model where banks face a leverage constraint and administered interest rates are disconnected from the relevant return on agents' saving decision. When the central bank controls money supply and interest on reserves, the endogenous spread induces a relaxation of the Taylor principle, which closely relates to the result of our determinacy analysis. In contrast to these studies, money is irrelevant under a binding capital requirement in our paper, where the supply of reserves (via open market operations) is specified as an asset swap, such that the impact of a change in money supply on bank assets is off-set by an equally sized inverse change in other bank assets (typically, t-bills). Michaillat and Saez (2021) augment a basic New Keynesian by introducing wealth in the utility function, which causes consumption growth to be related to a marginal utility term in addition to a real interest rate. They show that this property alters equilibrium determinacy properties and can resolve anomalies of the New Keynesian model at the ZLB. Diba and Loisel (2021) apply a New Keynesian model with a standard money demand, which is not fully satiated, and the central bank exogenously sets IOR and money supply, like in Ennis (2018). They show that pegging IOR at the ZLB does not lead to indeterminacy and that responses to macroeconomic shocks do not lead to "limit puzzles", which arise in a standard New Keynesian model.

Our paper further relates to studies developing macroeconomic models where banks face balance sheet constraints: Arce et al. (2020) compare the conduct of monetary policy under a corridor and a floor system using a macroeconomic model with banking and a non-Walrasian interbank market. Lenel et al. (2019) consider collateral services of bonds to study the disconnect between the interest rate administered by the central bank and other interest rates, which leads to short-term relations between spreads and leverage consistent with the data. Benigno and Benigno (2021) develop a model with banking where government bonds enter agents' utility function, giving rise to stimulating effects of publicly provided liquidity. They examine a variety of impulse responses above the ZLB and argue that the model is consistent with a reduced power of forward guidance. Bianchi and Bigio (2022) develop a model with liquidity management of heterogeneous banks, which they apply to describe the pass-through of the monetary policy rate to lending rates and the collapse of bank lending during the GFC. Piazzesi and Schneider (2022) develop a model where central bank digital currency (CBDC) competes with bank deposits and credit lines, and examine welfare effects of CBDC introduction. In a real business cycle model, Malherbe (2020) shows that the optimal capital requirement is countercyclical, being tighter during economic booms than in recessions. Mendicino et al. (2020) and Begenau (2020) show that tighter capital requirements can enhance financial stability and welfare, though at the cost of potential credit reallocation.

None of the above mentioned studies provides direct evidence for binding capital requirements. Our empirical assessment of the relevance of capital requirements relates to studies that apply regime-switching methods for occasionally binding constraints: Guerrieri and Iacoviello (2017) estimate a model with an occasionally binding collateral constraint, solved using a piecewise linear solution method, for the U.S. economy. Benigno et al. (2025) estimate a regime-switching model for Mexico over the period since 1981 and find that it successfully replicates key business cycle dynamics and sudden stop episodes. Bianchi (2013) estimates a New Keynesian model with post-war US data, providing evidence for regime switches between hawkish and dovish monetary policy stances as well as for the central role of belief formation on future policy regimes. Bianchi and Melosi (2017) provide evidence on a US monetary and fiscal policy regime-switch at the ZLB using a New Keynesian model, which accounts for the lack of deflation in the US. Bjørnland et al. (2018) show that structural macroeconomic shocks and a hawkish monetary policy regime played an important role in mitigating macroeconomic fluctuations during the Great Moderation. Chang et al. (2021) show how underlying structural shocks influence the degree of monetary policy hawkishness, allowing transition probabilities to depend on macroeconomic conditions, like in our paper.

2. The Model

In this Section, we develop a medium-scale macroeconomic model with sticky prices, a banking sector as well as a specification of central bank operations and instruments that allows accounting for different monetary policy regimes. Banks intermediate funds between households and firms while being constrained by reserve and capital requirements. The non-financial sectors consist of intermediate goods firms, capital producers, and retailers. The central bank can control the main policy rate (Federal Funds rate), IOR, and the supply of reserves. The government receives central bank transfers, issues bonds, and has access to lump-sum taxes. For the model estimation (see Section 4), we introduce several aggregate shocks and allow for an occasionally binding capital requirement.

2.1. Households

There is a continuum of infinitely lived households of mass one. The representative household chooses working hours n_t and real consumption c_t. Let $\mathcal{C}_t = c_t - hc_{t-1}$ be consumption adjusted by a degree of internal habits h. Household instantaneous utility increases with $\mathcal{C}_t$ and decreases n_t. Their lifetime preferences are specified as follows,

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left[\psi_t^P \ln \mathcal{C}_t - \chi \psi_t^N \frac{n_t^{1+\sigma_n}}{1+\sigma_n} \right], \tag{1}$$

where $\chi > 0$, $\sigma_n \geq 0$, ψ_t^P denotes a preference shock, and ψ_t^N a labor supply shock. Households have access to bank deposits, which serve as a means of payment. We account for the fact that households typically hold more deposits than necessary for realized consumption expenditures, which can be motivated by uncertainty with regard to liquidity needs. Specifically, we assume that households are restricted by the following liquidity constraint,

$$P_t c_t \leq \mu D_t, \tag{2}$$

where $\mu \in [0, 1]$ denotes an exogenously determined fraction of deposits used for transaction purposes. Let $w_t = W_t/P_t$ denote the real wage rate, τ_t lump-sum taxes, and div_t dividend payments, which is the sum of dividends from bankers div_t^B, intermediate goods firms div_t^F, capital producers div_t^{CP}, and retailers div_t^R. The household budget constraint is given by

$$P_t c_t + D_t + P_t \tau_t = W_t n_t + R_{t-1}^D D_{t-1} + P_t div_t. \tag{3}$$

Households maximize (1) subject to the liquidity constraint (2) and the budget constraint (3), leading to the first-order conditions for consumption, deposit, and working hours

$$\psi_t^P (\mathcal{C}_t)^{-1} - \beta h \mathbb{E}_t \psi_{t+1}^P (\mathcal{C}_{t+1})^{-1} = \lambda_t + \vartheta_t^H, \tag{4}$$

$$\mu \frac{\vartheta_t^H}{\lambda_t} + \mathbb{E}_t \Lambda_{t,t+1} \pi_{t+1}^{-1} R_t^D = 1, \tag{5}$$

$$\lambda_t w_t = \chi \psi_t^N n_t^{\sigma_n}, \tag{6}$$

where π_t denotes inflation, λ_t the multiplier on (3), $\vartheta_t^H \geq 0$ the multiplier on (2), and $\Lambda_{t,t+1} = \beta\lambda_{t+1}/\lambda_t$. Further, the complementary slackness condition holds $\vartheta_t^B [\mu D_t - P_t c_t] \geq 0$. It should be noted that the model properties would be unchanged if we assume that households were able to trade IOUs among each other at an interest rate that is – in contrast to a textbook New Keynesian model – not administered by the central bank. Piazzesi et al. (2022) refer to this interest rate as the "shadow rate".

2.2. Banks

There is a unit-mass continuum of competitive banks indexed by i. They receive deposits $D_{i,t}$ from households, hold risky assets $L_{i,t}$, and short-term government bonds $B_{i,t}$. They further hold central bank money in the form of reserves $M_{i,t}$ because of their unique ability to settle deposit transactions. Banks are assumed to maximize the present value of dividends $div_{i,t}^B$,

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \Lambda_{0,t} div_t^B, \tag{7}$$

where $\Lambda_{0,t} = \beta^t \lambda_t/\lambda_0$. The bond market opens at the early stage of the period, where new bonds $\tilde{B}_{i,t}$ are purchased. Then, banks receive/pay returns on maturing assets/liabilities, i.e. they pay $R_{t-1}^D D_{i,t-1}$ for deposits and earn $R_t^L L_{i,t-1}$ from risky assets. Reserves can be acquired either from the central bank via open market operations or from borrowing $F_{i,t}$ intratemporally in an interbank market. For simplicity, we specify the latter as a frictionless Walrasian market. The central bank supplies money through outright purchases of eligible assets. Since we abstract from the analysis of money supply facilities that are specific to the GFC or the COVID-19 pandemic, we restrict our analysis to treasury securities as eligible assets. The relative price of money $I_{i,t}^B$ supplied in open market operations is the rate $R_t^M \geq 1$, which is administered by the central bank

$$I_{i,t}^B = \Delta B_{i,t}^C / R_t^M, \tag{8}$$

where $\Delta B_{i,t}^C$ denotes securities transferred to the central bank. The asset exchange specification (8), which corresponds to the Standing Repo Facility of the US Federal Reserve Bank, applies not only to regular open market operations, but can also be interpreted as money supply via an asset purchase programme in terms of treasuries at the purchase price $1/R_t^M$. Banks' demand for reserves arises from the need to settle deposit transactions, which are not explicitly modelled. For this, banks hold reserves as a minimum fraction $\varrho > 0$ of deposits, leading to the following liquidity constraint

$$M_{i,t-1} + I_{i,t}^B + F_{i,t} \geq \varrho D_{i,t}. \tag{9}$$

Before the end of the period, banks receive IOR, i.e., interest payments R_t^R on their reserves holdings $M_{i,t-1} + I_{i,t}^B + F_{i,t}$. Then, bank i repays $R_t^F F_{i,t}$ to its interbank counterparties, where

R_t^F denotes the Federal Funds rate, pays dividends to the household, and adjusts end-of-period treasury balances $B_{i,t}$ and reserve balances $M_{i,t}$.[3] Bank operations are constrained by the following balance sheet identity in terms of the market value of the end-of-period stock of assets/liabilities:

$$L_{i,t} + B_{i,t} + M_{i,t} = D_{i,t} + E_{i,t}, \tag{10}$$

where $E_{i,t}$ denotes bank capital. We assume that banks face a regulatory capital requirement. This type of regulation can in principle be justified by the possibility of bank runs in the form of roll-over crises triggered by risky assets ($L_{i,t}$), as in Gertler and Kiyotaki (2015). The capital requirement is specified as a leverage restriction, which mandates minimum capital holdings proportional to the end-of-period asset balance, $E_{i,t} \geq \bar{\kappa}_t(L_{i,t} + B_{i,t} + M_{i,t})$, where $\bar{\kappa}_t > 0$ denotes the policy-imposed minimum capital requirement. With the balance sheet (10), the capital requirement can be expressed in terms of a leverage requirement, which relates equity to deposit $E_{i,t} \geq \phi_t D_{i,t}$ or deposits to total assets (like in Piazzesi et al., 2022, or Bianchi and Bigio, 2022)

$$(1 + \phi_t)D_{i,t} \leq L_{i,t} + B_{i,t} + M_{i,t}, \text{ where } \phi_t = \frac{\bar{\kappa}_t}{1 - \bar{\kappa}_t}. \tag{11}$$

The reserve requirement (9) and the capital requirement (11) impose two distinct limits on holdings of deposits. Notably, an alternative specification where capital requirements are conditioned on risk-weighted assets, for example, on risky assets $L_{i,t}$ with a weight of 100%, $E_{i,t} \geq \widetilde{\kappa}_t L_{i,t}$ with $\widetilde{\kappa}_t > 0$, would imply a similar relation between deposits and bank assets, $D_{i,t} \leq (1 - \widetilde{\kappa}_t)L_{i,t} + B_{i,t} + M_{i,t}$. Hence, bank holdings of public sector liabilities $B_{i,t} + M_{i,t}$, which will be crucial for the impact of the capital requirement (see below), enter both versions for the capital requirement in the same way. The bank i's flow budget constraint is given by

$$\begin{aligned} P_t div_{i,t}^B = (1 - \kappa_D)D_{i,t} - R_{t-1}^D D_{i,t-1} - M_{i,t} + R_t^R M_{i,t-1} - (R_t^F - R_t^R)F_{i,t} \\ -B_{i,t} + R_{t-1}B_{i,t-1} - \left(R_t^M - R_t^R\right) I_{i,t}^B - L_{i,t} + (R_t^L - \kappa_L)L_{i,t-1}, \end{aligned} \tag{12}$$

where $\kappa_L > 0$ and $\kappa_D > 0$ denote constant marginal costs of managing loans and deposits. The term $(R_t^M - R_t^R)I_{i,t}^B$ measures the costs of reserves acquired in open market operations and $(R_t^F - R_t^R)F_{i,t}$ the costs of interbank borrowing. Maximizing (7) subject to (9), (11), and (12), as well as $M_{i,t} \geq 0$ and $B_{i,t} \geq 0$, leads to the following first-order conditions for money injections, interbank borrowing/lending, bonds, reserves, lending, and deposits

$$\vartheta_t^B = R_t^M - R_t^R, \tag{13}$$

$$\vartheta_t^B = R_t^F - R_t^R, \tag{14}$$

$$\varkappa_t = 1 - \mathbb{E}_t \Lambda_{t,t+1}\pi_{t+1}^{-1} R_t, \tag{15}$$

[3] Hence, reserves can be used for trades in treasury such that end-of-period reserves holdings can be adjusted even after open market operations and interbank transactions are settled.

$$1 = \varkappa_t + \mathbb{E}_t \Lambda_{t,t+1} \pi_{t+1}^{-1} \left(R_{t+1}^R + \vartheta_{t+1}^B \right), \tag{16}$$

$$1 = \varkappa_t + \mathbb{E}_t \Lambda_{t,t+1} \pi_{t+1}^{-1} \left(R_t^L - \kappa_L \right), \tag{17}$$

$$1 = (1+\phi)\varkappa_t + \kappa_D + \varrho \vartheta_t^B + \mathbb{E}_t \Lambda_{t,t+1} \pi_{t+1}^{-1} R_t^D, \tag{18}$$

where $\vartheta_t^B \geq 0$ denotes the multiplier on the reserve requirement (9) and $\varkappa_t \geq 0$ the multiplier on the capital requirement (11). Further, the complementary slackness conditions $\vartheta_t^B(M_{i,t-1} + I_{i,t}^B + F_{i,t} - \varrho D_{i,t}) = 0$ and $\varkappa_t \left[L_{i,t} + B_{i,t} + M_{i,t} - (1+\phi_t) D_{i,t} \right] = 0$ hold.

Since reserves acquired through open market operations and interbank loans equally serve liquidity purposes (see 9), the Federal Funds rate is identical to the policy rate $R_t^F = R_t^M$ (see 13 and 14). The multiplier ϑ_t^B on the reserve requirement (9) measures banks' costs of reserves. When these costs of acquiring additional reserves are positive, $R_t^M - R_t^R > 0$, banks will not hold reserves in excess of what is required, i.e., the reserve requirement (9) binds. When IOR fully compensates for the costs of reserve acquisition in open market operations and in the interbank market, $R_t^R = R_t^M = R_t^F$, acquiring central bank money incurs no costs. Then, the multiplier ϑ_t^B equals zero, implying that the reserve requirement (9) is slack and that banks are willing to hold excess reserves. Combining (13) with (16), further yields

$$\varkappa_t = 1 - \mathbb{E}_t \Lambda_{t,t+1} \pi_{t+1}^{-1} R_{t+1}^M. \tag{19}$$

As indicated by condition (19), the multiplier on the capital requirement $\varkappa_t$ is positive if the expected policy rate R_{t+1}^M is lower than the inverse of agents' nominal stochastic discount factor $\Lambda_{t,t+1}\pi_{t+1}^{-1}$. Then, bank owners prefer the payout of profits relative to investments in bank assets at relative low real rates. In this case, the build-up of equity gets costly, and banks hold equity at the minimum level imposed by the capital requirement (11). Comparing (15) with (19) further implies that the bond rate equals the expected policy rate up to first order $R_t \approx \mathbb{E}_t R_{t+1}^M$. Note that we deliberately abstained from accounting for additional equity costs due to taxation or equity issuances, which would tend to bias our analysis in favor of our finding that capital requirements have been binding since 2008. Instead, we focus on the role of real interest rates for the capital requirement multiplier, which will be relevant for equilibrium determination and the transmission of policy rate changes.

2.3. Intermediate goods firms, capital producers, and retailers

Homogeneous *intermediate goods firms* operate in a competitive market to produce intermediate goods and engage in capital goods transactions with capital producers. Intermediate goods y_t are produced using capital k_{t-1} and labor n_t with a constant-return-to-scale technology,

$$y_t = a_t k_{t-1}^{\alpha} n_t^{1-\alpha}, \tag{20}$$

where a_t denotes stochastic total factor productivity. At the end of period $t-1$, an intermediate goods firm purchases capital k_{t-1} at the prevailing market price q_{t-1}. After goods are produced in period t, it sells the effective depreciated capital $(1-\delta)k_{t-1}$ to the capital-producing sector. Acquisition of new capital can be financed through retained earnings and bank funds. For simplicity, we abstract from an endogenous funding decision and assume that a constant fraction ξ of capital purchases is financed with bank funds

$$L_t = \xi q_t k_t, \tag{21}$$

where $\xi \in (0,1)$ is consistent with empirical evidence (see Section 4.). Let mc_t denote the price of each goods unit sold to the retail sector. Then, profit maximization of an intermediate goods firm satisfies, $(1-\alpha)\, mc_t \frac{y_t}{n_t} = w_t$, while the return on capital, which equals the return on bank lending, is given by

$$R_t^L \pi_t^{-1} = \frac{\alpha mc_t \frac{y_t}{k_{t-1}} + q_t(1-\delta)}{q_{t-1}}.$$

At the end of period t, *capital producers* purchase the depreciated capital from intermediate good firms. New capital is produced following a standard capital accumulation technology with investment x_t, i.e, $k_t = (1-\delta)k_{t-1} + x_t$, and with adjustment costs $\Psi_t(x_t/x_{t-1})$. Profits of capital producers are $div_t^{CP} = q_t k_t - q_t(1-\delta)k_{t-1} - [\Psi(x_t/x_{t-1}) + 1]\, x_t/\psi_t^X$, where $\Psi(x_t/x_{t-1}) = 0.5\kappa_I (x_t/x_{t-1} - 1)^2$, $\kappa_I > 0$ and ψ_t^X denotes an investment technology shock. The capital producer maximizes the present value of dividends, i.e., $\mathbb{E}_0 \sum_{t=0}^{\infty} \Lambda_{0,t} div_t^{CP}$, such that the optimal choice for investment x_t satisfies

$$q_t \psi_t^X = 1 + \frac{\kappa_I}{2}\left(\frac{x_t}{x_{t-1}} - 1\right)^2 + \kappa_I \left(\frac{x_t}{x_{t-1}} - 1\right)\frac{x_t}{x_{t-1}} - \kappa_I \mathbb{E}_t \Lambda_{t,t+1}\left(\frac{x_{t+1}}{x_t} - 1\right)\left(\frac{x_{t+1}}{x_t}\right)^2 \frac{\psi_t^X}{\psi_{t-1}^X}.$$

Each *retailer*, indexed by $j \in [0,1]$, purchases intermediate goods from the intermediate goods firm at the price mc_t. They re-package and resell them monopolistically in the final goods market. Final output y_t is a CES composite of retailers' output $y_{j,t}$, $y_t = [\int_0^1 y_{j,t}^{\frac{\eta_t - 1}{\eta_t}} dj]^{\frac{\eta_t}{\eta_t - 1}}$, where η_t is a stochastic elasticity. Demand for $y_{j,t}$ is given by $y_{j,t} = (P_{j,t}/P_t)^{-\eta_t} y_t$ and the aggregate price satisfies $P_t = [\int_0^1 P_{j,t}^{1-\eta_t} dj]^{\frac{1}{1-\eta_t}}$, where $P_{j,t}$ denotes the price of retail goods $y_{j,t}$. We consider adjustment costs of price setting following Rotemberg (1982) with price indexation at the target/long-run inflation π. Specifically, each period a retailer j maximizes the present value of profits $\mathbb{E}_t \sum_{i=1}^{\infty} \Lambda_{t,t+i}\left[(P_{j,t}/P_t - mc_{t+i})\, y_{j,t+i} - 0.5\kappa_p \left(\pi^{-1} P_{j,t}/P_{j,t-1} - 1\right)^2 y_{t+i}\right]$, where κ_p measures the degree of the nominal price rigidity.[4] For $P_{j,t} = P_t$, optimal price setting leads to a New Keynesian Phillips curve

$$\eta_t - 1 = \eta_t mc_t - \kappa_p \left(\frac{\pi_t}{\pi} - 1\right)\left(\frac{\pi_t}{\pi}\right) + \kappa_p \mathbb{E}_t \Lambda_{t,t+1} \frac{y_{t+1}}{y_t}\left(\frac{\pi_{t+1}}{\pi} - 1\right)\left(\frac{\pi_{t+1}}{\pi}\right). \tag{22}$$

[4] A positive cost-push term ψ_t^η is related to the elasticity η_t by $\eta_t = \eta(\psi_t^\eta)^{-\kappa_p}$.

2.4. Public Sector

The central bank supplies reserves to banks in exchange for bank assets, where the asset swap specification given in (8) can be applied to regular open market operations as well as to larger scale asset purchase programmes in terms of treasuries. At the beginning of each period, central bank holdings of treasuries and the stock of outstanding money are B^C_{t-1} and $M_{t-1} = \int_0^1 M_{i,t-1}di$. The central bank then receives returns on maturing assets and can over-roll bond holdings in the bond market. In open market operations, it receives an amount $\Delta B^C_t = \int_0^1 \Delta B^C_{i,t}di$ of treasuries in exchange for money at the amount $\Delta B^C_t/R^M_t$. It then pays interest on banks' reserve holdings $R^R_t(M_{t-1} + I^B_t)$. At the end of the period, reserves held by banks satisfy $\int_0^1 M_{i,t}di = \int_0^1 (M_{i,t-1}+I^B_{i,t}+F_{i,t})di$, and aggregate reserves satisfy $M_t = M_{t-1}+I^B_t$. Hence, the central bank budget constraint can be written as

$$P_t div^C_t = R_{t-1}B^C_{t-1} - B^C_t + M_t - R^R_t M_{t-1} + \left(R^M_t - R^R_t\right) I^B_t. \tag{23}$$

Related to central bank practice, we assume that remittances $P_t div^C_t$ to the treasury consist of interest earnings from reserve supply as well as from asset holdings net of IOR payments $P_t div^C_t = \left(R^M_t - 1\right) I^B_t + \left(R_{t-1} - 1\right) B^C_{t-1} - \left(R^R_t - 1\right)\left(M_{t-1} + I^B_t\right)$. Substituting out remittances in the central bank budget constraint (23) shows that central bank asset holdings evolve according to $B^C_t - B^C_{t-1} = M_t - M_{t-1}$. Further assuming that initial values satisfy $B^C_{-1} = M_{-1}$, implies for the central bank balance sheet

$$B^C_t = M_t. \tag{24}$$

The central bank has three main instruments at its disposal: the main policy rate R^M_t $(= R^F_t)$, interest on reserves (IOR) R^R_t, and the supply of reserves M_t; the latter being potentially relevant under a slack reserve requirement.

Fiscal policy has access to lump-sum taxes $P_t\tau_t$, which ensure public sector solvency. The government's budget constraint is given by $B^T_t + P_t\tau_t + P_t div^{CB}_t = R_{t-1}B^T_{t-1}$, where B^T_t denotes the total supply of treasuries, which are held by banks and the central bank.

2.5. Equilibrium properties

In equilibrium, banks are identical and all markets clear, such that total supply of bank funds equals total demand by intermediate goods firms, $L_t = \int_0^1 L_{i,t}di = \int_0^1 L_{j,t}dj$, aggregate deposit supply by households equals demand from banks, $D_t = \int_0^1 D_{i,t}di$, and interbank market positions satisfy $\int_0^1 F_{i,t}di = 0$. The aggregate stock of reserves is $M_t = \int_0^1 M_{i,t}di$, aggregate capital is $K_t = \int_0^1 K_{i,t}di$, and the total amount of money supplied in open market operation is $I^B_t = \int_0^1 I^B_{i,t}di$. Bond market clearing requires the total amount of treasuries B^T_t to satisfy

$B_t^T = B_t^C + B_t$, where B_t denotes aggregate bond holdings of banks $B_t = \int_0^1 B_{i,t} di$. Using that aggregate reserves satisfy $I_t^B = M_t - M_{t-1}$, the reserve requirement (9) for a representative bank can be rewritten as $\varrho D_t \leq M_t$. Defining $S_t = M_t + B_t$ as the total stock of public sector liabilities held by banks, the capital requirement (11) can be rewritten in aggregate terms as

$$(1 + \phi_t) D_t \leq L_t + S_t. \tag{25}$$

The central bank balance sheet (24) together with bond market clearing implies $B_t^T = M_t + B_t$. Hence, the total stock of public sector liabilities held by banks S_t equals the total supply of treasury securities B_t^T. The reason is that open market operations imply any change in bank reserve holdings to be associated with an equally-sized inverse change in treasury holdings, $\Delta M_t = -\Delta B_t$, as required by the central bank balance sheet (24). Given that total public sector liabilities are relevant for the capital requirement (see 25), a complete description of the competitive equilibrium requires an explicit specification for the supply of S_t,

$$S_t = \nu_t^B S_{t-1}. \tag{26}$$

Instead of imposing a particular endogenous supply rule, we adopt an agnostic stance and treat the growth rate ν_t^B as exogenous. This relates to the exogenous supply specifications of reserves and bank assets in Ennis (2018), Diba and Loisel (2021) or Piazzesi et al. (2022). We provide supportive evidence in Appendix A3 by assessing several alternative specifications. For the analysis of equilibrium determination (see Section 3), we further consider a widely applied fiscal policy specification leading to an alternative supply specification for S_t based on its identity to B_t^T. The full set of equilibrium conditions is given in Appendix A1.

When there is a positive spread between the main policy rate (i.e., the Federal Funds rate) and the IOR, reserve holdings are costly. Then, the multiplier on the reserve requirement (9) is positive (see 13), and banks' money demand is well-defined by the binding reserve requirement (see 11). In this case, monetary policy accommodates money demand, such that money supply adjusts endogenously. If, however, IOR is set equal to the policy rate, reserve holdings are costless and the reserve requirement (9) is slack, such that reserves are decoupled from the allocations and prices. Bank operations are further constrained by the capital requirement (11). According to (19), monetary policy is decisive for the relevance of this constraint. Precisely, its multiplier $\varkappa_t$ is positive if the expected policy rate R_{t+1}^M and thereby the current market rate R_t (see 15) is lower than the inverse of shareholders' stochastic discount factor in nominal terms. If they are identical, $\mathbb{E}_t \Lambda_{t,t+1} \pi_{t+1}^{-1} R_t = 1$, banks are indifferent between paying dividends or retaining profits today, such that building up equity is costless. The multiplier $\varkappa_t$ then equals zero (see 15), indicating that the capital requirement is slack. If interest rates are lower, retaining profits to build up equity is costly, such that the multiplier $\varkappa_t$ is positive (see 15) and the capital requirement binds.

Corollary 1. *Consider a competitive equilibrium with profit-maximizing banks.*

1. *If the policy rate R_t^M is set above (equal to) the IOR, the reserve requirement (9) is binding (slack).*
2. *If the market rate R_t is below (equal to) the inverse of agents' valuation of future payoffs, $\mathbb{E}_t \Lambda_{t,t+1} \pi_{t+1}^{-1}$, the capital requirement (11) is binding (slack).*

Proof. The claim made in part 1 immediately follows from (13) and complementary slackness, while the claim made in part 2 follows from (15) and complementary slackness. ■

The condition for a binding/slack reserve requirement can immediately be assessed for each state/period via observed data on the policy rate and IOR. Yet, the condition for a binding/slack capital requirement cannot as easily be assessed, given that the multiplier depends on various equilibrium objects, specifically, on the stochastic discount factor in nominal terms (see 19). We therefore provide an estimation of the full model allowing for an occasionally binding capital requirement (see Section 4). The household optimality condition for deposits (5) and the bank optimality condition for deposits (18) further imply the following relation between the multiplier ϑ_t^H on the household liquidity constraint (2), the multiplier ϑ_t^B on the reserve requirement (9), and the multiplier $\varkappa_t$ on the capital requirement (11)

$$\mu \vartheta_t^H / \lambda_t = \kappa_D + \rho \vartheta_t^B + (1 + \phi_t) \varkappa_t. \tag{27}$$

According to (27), the household liquidity constraint (2) is binding even if both constraints that banks face are non-binding, such that households always hold deposits just at the minimum level. If these constraints are binding, the additional non-pecuniary costs are simply passed through by banks to the depositors in form of a lower deposit rate (see 18).

The reserve requirement and the capital requirement evidently differ with regard to the balance sheet items that limit the creation of deposits. Specifically, the reserve requirement imposes a constraint on deposits exclusively in terms of reserve holdings M_t (see 9). Thereby, a binding reserve requirement constitutes a well-defined money demand relation. In contrast, a binding capital requirement relates deposits to bank assets, i.e., loans L_t and public sector liabilities $S_t = M_t + B_t$ (see 25). Thus, the latter rather than reserves alone alter the relation between deposits and loans. Precisely, any change in bank reserve holdings is accompanied by an inverse change in eligible assets (see 8), such that the impact of a change in money supply on banks' total assets is neutralized.

Proposition 1. *Suppose that IOR equals the policy rate. Then, changes in the supply of reserves do neither affect the equilibrium allocation nor prices, regardless of whether the capital requirement (11) is slack or binding.*

Proof. When IOR equals the policy rate, the reserve requirement (9) is slack (see Corollary 1) and reserves are solely related to decisions and restrictions of the private sector via total public sector liabilities $S_t = M_t + B_t$ entering the potentially binding capital requirement. According to (26), the supply of total public sector liabilities S_t, which – by the central bank balance sheet identity $M_t = B_t^C$ – are equal to B_t^T, is independent of reserves M_t. A change in reserve supply does therefore exclusively affect the composition of S_t by causing an equally-sized opposite change in bank treasuries holdings, $M_t = B_t^T - B_t$. ■

Proposition 1 establishes that money is irrelevant for the equilibrium allocation and prices under a slack reserve requirement (9), even if the capital requirement (11) is binding. This property differs from Ennis (2018), Diba and Loisel (2021), and Piazzesi et al. (2022), and is consistent with the lack of inflation hikes in post-2008 US data under increases in reserves induced by QE at the ZLB. Deposits and loans are however related to banks' holdings of public sector liabilities S_t (see 25), while changes in money supply exclusively alter the composition of S_t.

3. Monetary policy under binding capital requirements

In this section, we examine implications of capital requirements for monetary policy effects in an analytical way. It is well-established that the sequence of policy rates followed a Taylor-type feedback rule under pre-GFC monetary policy, while the reserve requirement (9) was binding due the non-existence of IOR. The performance of this type of New Keynesian model with liquidity-constrained agents is well-established, and its local equilibrium determinacy is known to depend on the Taylor principle (see e.g. Ravenna and Walsh, 2006). Here, we focus on main properties of post-2008 monetary policy where the equality of IOR and FFR has led to a slackening of the reserve requirement (see Proposition 1), while the capital requirement has been binding, as will be confirmed by the estimations in Section 4. We, firstly, derive local equilibrium determinacy properties and, secondly, examine impulse responses to productivity and cost push shocks.

To facilitate the derivation of analytical results, we introduce some simplifying assumptions, mainly by reducing the set of endogenous state variables: Firstly, we ignore habit formation $h = 0$, such that the first-order condition (4) simplifies to, $c_t^{-1} = \lambda_t + \vartheta_t^H$. Secondly, we abstract from capital formation and consider a linear production function ($\alpha = 0$), i.e., $y_t = a_t n_t$. As assumed before, external financing is required for funding the costs of production. Given that we abstract from capital formation, we assume that external funds are equal to a constant fraction $\xi > 0$ of production:

$$l_t = \xi y_t. \tag{28}$$

Thirdly, we consider a simple feedback rule for the policy rate, $R_t^M / R^M = (\pi_t/\pi)^{\gamma_{r,\pi}}$, with

$\gamma_{r,\pi} \geq 0$. In addition, we restrict parameter values to ensure that the capital requirement establishes an unambiguous relation between the supply of public sector liabilities S_t and real activity. Precisely, the capital requirement is assumed to satisfy the parameter restriction $\phi > \mu\xi - 1$, which is clearly satisfied according to our analysis of post-2008 data in Section 4.[5] Finally, we set those stochastic variables equal to their steady state values, which have solely been introduced to enhance the model's fit to the data.

Assumption 1. *Agents' preferences (1) and the production function (20) satisfy* $h = 0$ *and* $\alpha = 0$*, firms' loan demand is given by (28), instead of (21), the policy rate satisfies* $R_t^M/R^M = (\pi_t/\pi)^{\gamma_{r,\pi}}$*, and the capital requirement* $\phi > \mu\xi - 1$*, while* $\psi_t^P = \psi_t^N = 1$*,* $\phi_t = \phi$*, and* $\nu_t^B = \nu^B$*.*

Based on the set of equilibrium conditions for the simplified version, we apply a linear approximation of the equilibrium conditions at a steady state of the economy, where the real interest rate is sufficiently low such that the multiplier on the capital requirement is strictly positive (see Corollary 1). According to Proposition 1, money is irrelevant under $R_t^R = R_t^M$ when the reserve requirement is slack. We can therefore neglect the sequence of reserves for the analysis in this section. Let variables without a time index denote steady state values and variables with a hat denote percentage deviations from a steady state. In the neighborhood of this steady state, a rational expectations equilibrium (REE) under a slack reserve requirement and a binding capital requirement is a set of sequences $\{\widehat{\pi}_t,\ \widehat{s}_t,\ \widehat{\lambda}_t\}_{t=0}^{\infty}$ that converge to the steady state and satisfy $\widehat{R}_t^M = \gamma_{r,\pi}\widehat{\pi}_t$ (see Appendix A2),

$$\widehat{\pi}_t = \beta\mathbb{E}_t\widehat{\pi}_{t+1} - \Pi_a\widehat{a}_t - \Xi\widehat{\lambda}_t + \Pi_s\widehat{s}_t - \kappa_p^{-1}\widehat{\eta}_t, \tag{29}$$

$$\mathbb{E}_t\widehat{\lambda}_{t+1} - \mathbb{E}_t\widehat{\pi}_{t+1} + \widehat{R}_{t+1}^M = \digamma_\lambda\widehat{\lambda}_t + \digamma_s\widehat{s}_t, \tag{30}$$

$$\widehat{s}_t = -\widehat{\pi}_t + \widehat{s}_{t-1}, \tag{31}$$

where $\Pi_s = \Xi\sigma_n$, $\digamma_\lambda = 1 + \frac{\varkappa}{1-\varkappa}\kappa_\varkappa^{-1} > 1$, $\Pi_a = \Xi(1+\sigma_n)$, $\Xi = \frac{\eta-1}{\kappa_p} > 0$, $\digamma_s = \frac{\varkappa}{1-\varkappa}\sigma\kappa_\varkappa^{-1} > 0$, and $\kappa_\varkappa = \varkappa\frac{1+\phi}{\mu}/(1+\varkappa\frac{1+\phi}{\mu}) \in (0,1)$, where $\widehat{a}_t$ and $\widehat{\eta}_t$ satisfy $\mathbb{E}_t\widehat{a}_{t+1} = \rho\widehat{a}_t$ and $\mathbb{E}_t\widehat{\eta}_{t+1} = \rho\widehat{\eta}_t$. Output and consumption are further determined by $\widehat{y}_t = \widehat{c}_t = \widehat{s}_t$. This set of conditions differs from a basic New Keynesian model by two elements: Firstly, the Euler equation (15) deviates from those of a textbook version of the New Keynesian model by the multiplier $\varkappa_t$ on the capital requirement, leading to (30). Secondly, the supply of total public sector liabilities (see 31) matters in this economy, because they shift the relation between deposits and loans via the capital requirement (see 25). Therefore, $\widehat{s}_t$ enters the aggregate supply constraint (29) and (30). As a consequence, local equilibrium determinacy does not rely on the well-known Taylor principle. Nominal public sector liabilities in fact support the determination of inflation, similar to an economy with non-satiated money demand where the central bank controls the money growth rate, as shown by Diba and Loisel (2021) for an interest rate peg.

[5] The left-hand side takes the value 0.099, whereas the right-hand side equals -0.998.

Proposition 2. *Suppose that Assumption 1 holds. A REE under a slack reserve requirement and a binding capital requirement is uniquely determined if*

$$\gamma_{r,\pi} < 1 + \frac{\digamma_s + (1 + \digamma_\lambda)\,\sigma_n}{2} + \frac{(1 + \digamma_\lambda)\,(1 + \beta)}{\Xi}. \tag{32}$$

Proof. See Appendix A2 ■

According to Proposition 2, equilibrium determinacy is ensured if the inflation feedback does not exceed an upper bound specified by the RHS of inequality (32), which includes the case where the interest rate is pegged $\gamma_{r,\pi} = 0$, for example, at the ZLB. The upper bound is in fact not restrictive under plausible parameter values, for example, based on the calibration informed by the estimation results in Section 4, the bound is computed to be 10.86. In Appendix B, we further examine equilibrium determinacy for a typical fiscal policy feedback rule (see Leeper, 1991 and Bohn, 1998), which leads to an alternative specification for the supply of s_t based on the identity to b_t^T. There, we show that the equilibrium is uniquely determined and stable under a binding capital requirement if the feedback of debt on the fiscal surpuls is smaller than the net real rate, which is consistent with empirical evidence for post-2008 data provided by Bianchi and Melosi (2017, 2022), Gomez-Cram et al. (2024), or Barro and Bianchi (2025).

The set of conditions (29)-(31) reveals that a positive productivity shock $\widehat{a}_t > 0$ and a cost-reducing shock $\widehat{\eta}_t > 0$ have symmetric effects on inflation $\widehat{\pi}_t$, public liabilities $\widehat{s}_t$ and the multiplier $\widehat{\lambda}_t$ due to the property that they exclusively enter (29) with identical signs. Since $\widehat{s}_t = \widehat{c}_t$ and $\widehat{c}_t = \widehat{y}_t$ further hold in equilibrium, the impact of these shocks on output are also symmetric. Hence, to qualitatively assess the effects of productivity and cost push shocks on output and inflation, it suffices to examine only one of them. Like for the determinacy analysis, we thereby do not need to examine regimes at and above the ZLB in a separate way.

Proposition 3. *Suppose that Assumption 1 holds and that (32) is satisfied. Under a slack reserve requirement and a binding capital requirement, a negative productivity shock $\widehat{a}_t < 0$ and a cost-push-shock $\widehat{\eta}_t < 0$ lead to a decline in output and an increase in inflation on impact if*

$$\rho > (1 - \rho_s)\,\frac{\digamma_\lambda}{\digamma_\lambda - \rho_s} \tag{33}$$

or if $\rho < (1 - \rho_s)\,\frac{\digamma_\lambda}{\digamma_\lambda - \rho_s}$ *and* $\gamma_{r,\pi} < 1 + \frac{\digamma_s \frac{\digamma_\lambda}{\digamma_\lambda - \rho_s}}{(1-\rho_s)\frac{\digamma_\lambda}{\digamma_\lambda - \rho_s} - \rho}$, *where* $\rho_s \in (0, 1)$.

Proof. See Appendix A2 ■

Proposition 3 reveals that the direction of the effects of productivity and cost-push shocks is not affected by the inflation feedback $\gamma_{r,\pi}$. In fact, a productivity (cost-push) shock leads to an increase (decrease) in output and a decline (increase) in inflation if the autocorrelation coefficient ρ is sufficiently large, i.e., if (33) is satisfied. The sign of the output responses to both types of shocks are not opposed between policy rates at or above the ZLB, which is predicted by the basic new Keynesian model (see Eggertsson, 2011, 2012). When (33) holds, both types of shocks therefore lead to intuitive responses regardless of the ZLB. Using the parameter values based on US data (see Section 4), the RHS of (33) is given by 0.648, whereas the estimated autocorrelation coefficients equal $\rho_a = 0.825$ and $\rho_\eta = 0.808$ and therefore clearly satisfy (33).[6]

4. Quantitative results

In the first part of this Section, we estimate the full model as given in Appendix A1 for post-2008 US data, indicating that capital requirements have been almost permanently binding since the GFC. In the second part, we examine the transmission of macroeconomic shocks.

4.1. Evidence on binding capital requirements

Figure 1 and Corollary 1 indicate that the reserve requirement (9) has been slack since 2008, when the US Federal Reserve set IOR equal to the policy rate $R_t^R = R_t^M$. Figure 1 further shows how the capital-to-asset ratio increased since 2008 and went down in 2020, which relates to the gradual implementation of Basel II and III since the GFC, and the relaxation of capital requirements at the onset of the COVID-19 pandemic. We perceive this pattern as suggestive of capital requirements to be binding since 2008. This can, however, only be validated by assessing the multiplier on the capital requirement and therefore the relation between the real interest rate and the stochastic discount factor (see Corollary 1).

To assess the relevance of capital requirements, the possibility of occasionally binding capital requirements is accounted for in form of switches between regimes (like Benigno et al., 2025), where the regimes refer to slack or binding capital requirements. To focus on our main novel argument and to facilitate identification, we thereby abstract from other policy regime switches that might have occurred simultaneously. Specifically, we disregard regime switches between a state-contingent feedback rule for the policy rate to a fixed policy rate at the ZLB. According to Proposition 2, the model is uniquely determined even under a peg, which allows specifying the sequence of policy rates by the realized sequence in the data. For the identification of regime switches, we focus on the information on the multiplier of the capital requirement. We abstain from imposing pre-specified values for the capital requirement ratio and let the leverage ratio be determined by observed data. The reason for this strategy is that bank regulation has been implemented as a combination of capital requirements related to assets with different risk weights, state-contingent capital buffers, and additional leverage ratio requirements. Moreover, regulatory standards according to Basel II and III, and the Dodd-Frank Wall Street Reform were gradually introduced over time, such that time-invariant capital ratios would be misspecified.

[6] For the computation of the upper bound, we used that the unique stable eigenvalue of the simplified model equals $\rho_s = 0.760$.

4.1.1. Two Markov chains

In this subsection, we describe details of the regime-switching specification. We introduce a two-state Markov chain that governs the tightness of the capital requirement, denoted as $\mathcal{S}_t^{lev} = \{S, B\}$ where S indicates that the capital requirement is slack, and B indicates that it is binding. For the two-state Markov chain $\mathcal{S}_t^{lev}$ governing the relevance of the capital requirement, we introduce the following matrix of transition probabilities,[7]

$$\mathbb{Q}_t^{lev} = \begin{bmatrix} 1 - prob_t^{S,B} & prob_t^{S,B} \\ prob_t^{B,S} & 1 - prob_t^{B,S} \end{bmatrix},$$

where $prob_t^{S,B}$ denotes the probability of transitioning from state S in period t to state B in period $t+1$, with $1 - prob_t^{S,B}$ denoting the probability of remaining in state S. The terms $prob_t^{B,S}$ and $1 - prob_t^{B,S}$ are defined analogously. These probabilities are specified as logistic functions, ensuring that they are bounded between 0 and 1. Let $\bar{\varkappa}$ be the steady-state value of the multiplier under a binding capital requirement, i.e., $\bar{\varkappa} = 1 - \beta R^M(B)/\pi > 0$, and $\widetilde{\varkappa}_t$ be the distance of the multiplier $\varkappa_t$ from this steady state value, $\widetilde{\varkappa}_t = \varkappa_t - \bar{\varkappa}$. The endogenous transition probabilities are assumed to satisfy

$$prob_t^{S,B} = \frac{1}{1 + \mathcal{O}_{s,b} \exp(-\theta_{s,b} \varkappa_t)}, \tag{34}$$

$$prob_t^{B,S} = \frac{1}{1 + \mathcal{O}_{b,s} \exp(\theta_{b,s} \widetilde{\varkappa}_t)}, \tag{35}$$

where $\mathcal{O}_{s,b}$ and $\mathcal{O}_{b,s}$ are scaling parameters for the transition probabilities and the parameters $\theta_{s,b}$ and $\theta_{b,s}$ measure the sensitivity of switches. Equation (34) implies that the probability of transitioning from a slack to a binding capital requirement increases with the multiplier $\varkappa_t$. Likewise, equation (35) implies that the probability of transitioning to a slack capital requirement increases when the multiplier $\varkappa_t$ falls below the steady state value $\bar{\varkappa}$ such that $\widetilde{\varkappa}_t$ gets negative, indicating that the constraint imposed by the capital requirement is less tight. For the complementary slackness condition for the capital requirement we introduce a regime-switching indicator $\mathbf{z}(\mathcal{S}_t^{lev})$, which takes the values $\mathbf{z}(S) = 1$ and $\mathbf{z}(B) = 0$,

$$\mathbf{z}(\mathcal{S}_t^{lev})\varkappa_t + \left(1 - \mathbf{z}(\mathcal{S}_t^{lev})\right)(\epsilon_t - \phi_t) = 0, \tag{36}$$

where ϵ_t denotes the observed capital-to-deposit ratio $\epsilon_t = e_t/d_t$. For state S, the first term in (36) implies that the multiplier $\varkappa_t$ is equal to zero. For state B, the second term in (36) demands the endogenous capital-to-deposit ratio ϵ_t to be equal to the policy-imposed capital-to-deposit ratio ϕ_t. Hence, the policy-imposed leverage requirement ratio ϕ_t will be determined

[7] We adopt regime-dependent steady states as perturbation points, following Binning and Maih (2017) and Barthélemy and Marx (2017), which naturally impose a non-negative Lagrange multiplier, offering a useful approximation for analyzing capital regulation.

as an outcome of the model estimation.

A second Markov chain is introduced to capture the heightened macroeconomic uncertainty observed during the GFC and the COVID-19 pandemic. For this, we follow Sims and Zha (2006), Liu et al. (2011), and Benigno et al. (2025) and allow for heteroskedasticity in the standard deviations of all structural shocks. Specifically, we allow for regime-dependent standard deviations for the structural shocks. For this, we define two regimes $\mathcal{S}_t^{vol} \in \{L, H\}$ with the transition matrix

$$\mathbb{Q}^{vol} = \begin{bmatrix} 1 - prob^{L,H} & prob^{L,H} \\ prob^{H,L} & 1 - prob^{H,L} \end{bmatrix},$$

where $prob^{L,H}$ ($prob^{H,L}$) is the exogenous probability of transitioning from a low (high) volatility state L (H) to a high (low) volatility state H (L)[8]. Hence, our model comprises four regimes denoted by $\mathcal{S}_t = \mathcal{S}_t^{lev} \times \mathcal{S}_t^{vol}$, which are governed by a combined transition matrix $\mathbb{Q}_{t,t+1} = \mathbb{Q}_t^{lev} \otimes \mathbb{Q}^{vol}$. Finally, the model incorporates the following shocks expressed as AR(1) processes: TFP a_t, consumption preference ψ_t^P, IST ψ_t^X, labor supply ψ_t^N, cost-push ψ_t^η, equity-to-deposit ratio ϕ_t, and a stochastic process of public sector liabilities supply ν_t^B.

4.1.2. Estimation results

The first-order perturbation solution is obtained using the functional iteration method proposed by Chang et al. (2021), which accommodates nonlinear regime-switching models with multiple steady states and endogenous transition matrices. Posterior mode maximization and posterior simulation are implemented with the RISE toolbox. Bayesian estimation is conducted using U.S. quarterly data spanning from 2009Q1 to 2024Q4. Observed quantities are seasonally adjusted as well as adjusted for population growth and expressed in terms of growth rates. We consider an exogenous balanced growth path bgp, which will be identified by the estimation. For the estimation, we use time series for the nominal FFR $R_{t,data}^M$, CPI inflation $\pi_{t,data}$, the Tier-1 capital-to-deposit ratio $\epsilon_{t,data}$, per capita real GDP growth $\Delta \log y_{t,data}$, non-durable goods real consumption growth $\Delta \log c_{t,data}$, real fixed capital investment growth$\Delta \log x_{t,data}$, and real wage growth $\Delta \log w_{t,data}$.

A subset of parameters is calibrated, using empirical means or information from other studies.[9] The discount factor is set to $\beta = 0.99628$, which equals average ratio of inflation to the Federal Funds rate based on pre-2008 data (1994Q1–2008Q4). The (annual) inflation target is set at 2% and the steady-state Federal Funds rate at 1.1%, reflecting the post-2008Q4 sample

[8]For identification purposes, we impose a restriction $\varsigma_{i,(L)} < \varsigma_{i,(H)}$, for $i \in \{a, p, x, n, \eta, b\}$ with the ordering consistent with the sequence of shocks introduced above, ensuring that the standard deviation of shock i in the low-volatility regime is strictly smaller than in the high-volatility regime.

[9]We use the following data sources (from the FRED database): non-durable goods consumption (PCEND), M3 monetary aggregate (MABMM301USM189S), total loans to non-financial firms from depository institutions (BLNECLBSNNCB), and net worth of non-financial firms (TNWMVBSNNCB).

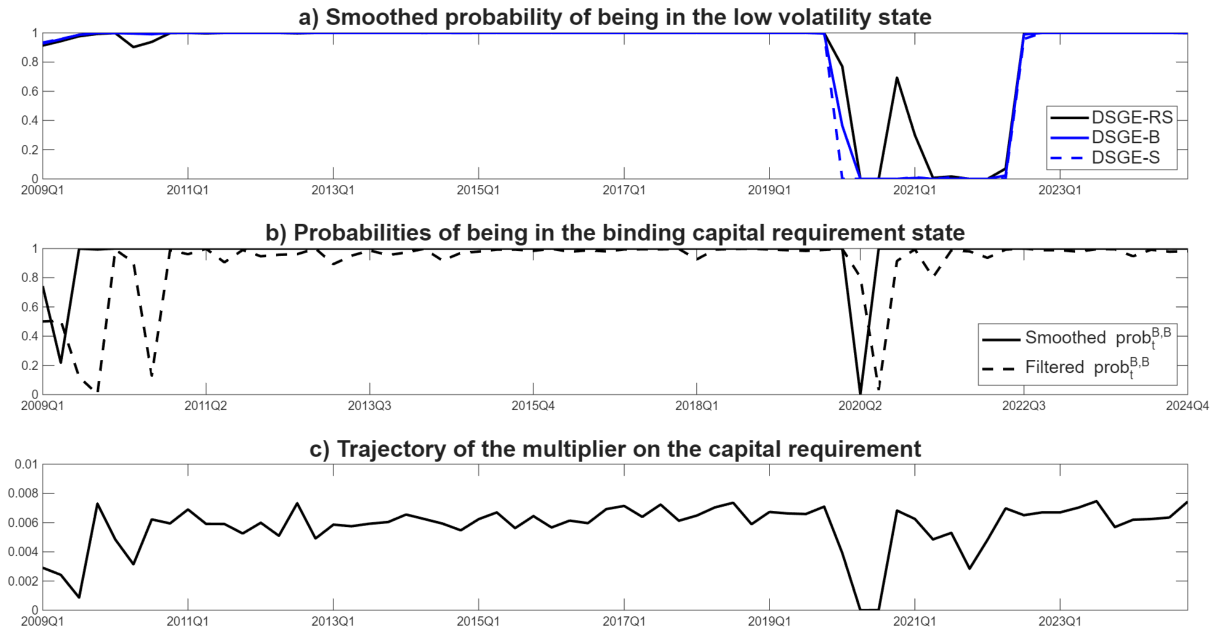

Figure 2: The black line in the top panel represents the probability of being in a low-volatility regime. In the middle panel, the black line represents the smoothed probability of being in a binding capital requirement regime, while the dashed line plots the filtered probabilities using information only up to time t. The black line in the bottom panel depicts the expected trajectory of the capital requirement multiplier. The initial point of the filtering procedure is set to the ergodic mean.

mean. For the utility function, the weight $\chi = 2.94$ is calibrated such that steady-state labor supply equals one-third of available time in state S. The steady-state consumption-to-deposit ratio is set at $\mu = 0.22$, based on the sample mean of nondurable consumption relative to broad money (M3). The marginal cost of deposits, $\kappa_D = 0.12\%$, is calibrated to match a 0.5% annual deposit–bond spread, consistent with Ulate (2021). The steady state equity-to-deposit ratio is set at $\epsilon = 9.9\%$, which equals the average after 2009Q3. The marginal monitoring cost $\kappa_L = 0.625\%$ matches the sample mean of the spread between the prime loan rate and the Federal Funds rate. The firms' share of external finance, $\xi = 0.1$, equals the sample mean of the ratio of non-financial firms' debt to net worth. Capital depreciates at $\delta = 0.025$ quarterly. Finally, the parameters $\theta_{b,s}$ and $\theta_{s,b}$ in (34) and (35) are set at 2000, following Binning and Maih (2017).

The remaining parameters are estimated under weakly informative priors. Following Bjørnland et al. (2018), we use 90 percent quantile intervals, allowing the data to primarily shape the posterior distributions.[10] For the scaling parameters $\mathcal{O}_{s,b}$ and $\mathcal{O}_{b,s}$ of the transition probabilities (34) and (35), we choose an identical and loose distribution, capturing the uncertainty about the switch between binding or slack capital requirements. We find that the data provides informative signals for a large majority of the estimated parameters (for the full set of priors and posteriors see Table A.3 in Appendix). For the parameters governing the heteroskedas-

[10]The posterior mode is searched using the stochastic global optimizer, `bee_gate`, available in the RISE toolbox (see Chang et al., 2021), followed by refinement with a derivative-based local optimizer.

Table 1: Model comparison

	DSGE-RS	DSGE-B	DSGE-S
Log MDD (Laplace)	1392.75	1326.26	1317.28

ticity $\varsigma_{i,(\mathcal{S}_t^{vol})}$, for $i \in \{a, x, n, p, \eta, b\}$, we find clear differences between high- and low-volatility states. The model further accounts for the transitory nature of the disruptions caused by the COVID-19 pandemic, as reflected in the first panel of Figure 2 and the relatively high transition probability of $prob^{H,L} = 9.48\%$, which is three times as high as the probability of moving from low to high volatility regime. The posterior modes of the scaling parameters $\mathcal{O}_{s,b}$ and $\mathcal{O}_{b,s}$ are estimated at 26.78 and 27.45, which imply steady-state transition probabilities of 3.60% from state S to state B and 3.51% for the opposite direction.

The second panel of Figure 2 displays the model-implied smoothed probability of being in state B, which measures the ex-post likelihood that the capital requirement is binding, conditional on the full sample of observed data. The results indicate that the capital requirement becomes binding shortly after the onset of the Global Financial Crisis (2009Q2). The temporary decline in the probability of staying in the B-state at the beginning of the COVID-19 pandemic (2020Q2) coincides with the easing of capital requirements. The third panel of Figure 2 plots the expected trajectory of the multiplier $\varkappa_t$ associated with the capital requirement and corroborates this interpretation. Outside the pandemic episode, the multiplier remains strictly positive, confirming that the capital requirement is binding for most of the sample. At the onset of the COVID-19 pandemic – when regulatory capital requirements were temporarily relaxed – the multiplier approaches zero, indicating a reduction in the effective cost of equity creation.

To further assess the validity of our model, we estimate two alternative model specifications: one where the capital requirement is always binding (DSGE-B), and another where it is always slack (DSGE-S), which is essentially a standard New Keynesian model with linear banking costs. The fit of the three model versions is formally assessed by the comparison of the marginal data density (MDD) at the posterior mode, reported in Table 1, and computed by Laplace approximation. The regime-switching specification with an occasionally binding capital requirement (DSGE-RS) attains the highest marginal data density (1392.75) of all specification. The DSGE-B and DSGE-S specifications yield substantially lower MDD values, equal to 1326.26 and 1317.28. Thus, our estimates suggest that a specification where capital requirements are allowed to bind occasionally, providing the best statistical representation of the observed data.

In Appendix A4, we provide posterior estimates for these specifications in Table A.3, which are related to parameter values common in the literature (see e.g., Gilchrist et al., 2017). Appendix A4 further presents Table A.4, which reports ergodic horizon-conditional variance decompositions. For the benchmark specification (DSGE-RS), we find that TFP shocks, invest-

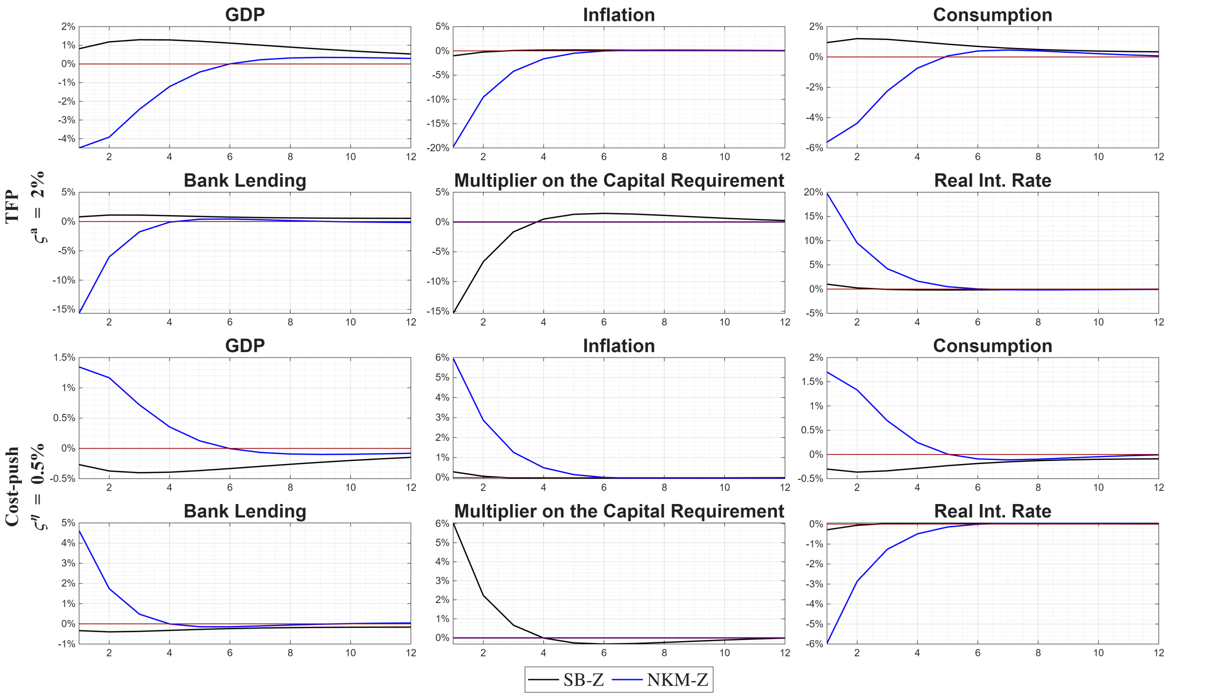

Figure 3: Impulse responses to a 2% TFP shock and a cost-push shock (modelled as a 20% reduction in the elasticity of substitution), comparing the benchmark model (SB-Z: black solid line) and a NK-type specification (NKM-Z: blue solid line) under the ZLB. The vertical axis reports percentage deviations from the steady state.

ment specific productivity shocks, and labor supply shocks account for almost ninety percent of output fluctuations, whereas that the contribution of nominal public sector liability shocks is almost negligible.

4.2. Transmission of macroeconomic shocks

In this section, we present impulse responses to macroeconomic shocks under different regimes, parameterized using estimates for the regime-switching specification. We firstly assess responses to supply side shocks, i.e., productivity and cost push shocks, at and above the ZLB, confirming the findings presented in Proposition 3. We secondly examine the transmission of fiscal shocks, which shows that a binding capital requirement causes fiscal multipliers not be substantially affected by policy rates at the ZLB. Different versions of the model will be abbreviated with three letters, where the first informs about whether the reserve requirement is slack (S) or binding (B), the second about the capital requirement, and the third about the policy rate being at the ZLB (Z) or above (N). For example, the pre-2008 regime will be abbreviated with ”BS-N” and ZLB regime after 2008 with ”SB-Z”. For the counterfactual policy regime where both requirements are slack we will use ”NKM”.

4.2.1. Supply side shocks

Figure 3 shows impulse responses to productivity and cost-push shocks for the estimated model at the ZLB. The black solid line shows impulse responses for our benchmark model (SB-Z),

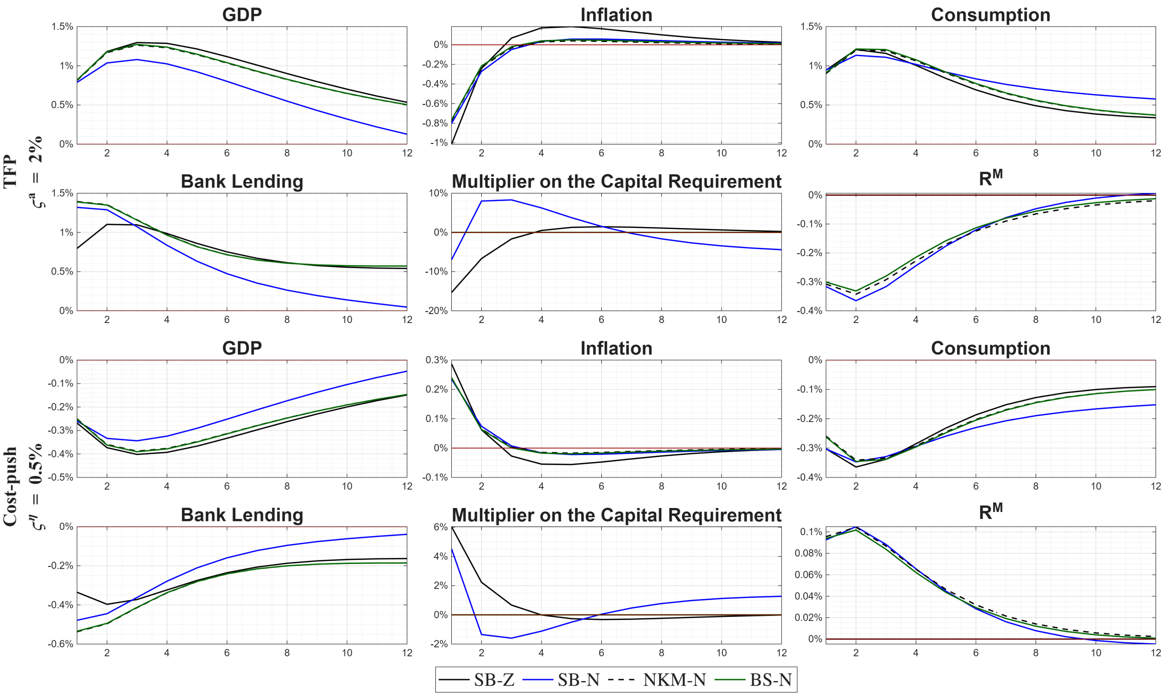

Figure 4: Impulse responses to a 2% TFP shock and a cost-push shock (modelled as a 20% reduction in the elasticity of substitution) in the benchmark models (SB-Z: black solid line; SB-N: blue solid line), a NK-type specification (NKM-N: black dashed line), and a model version with a binding reserve requirement (BS-N: green solid line). The vertical axis reports percentage deviations from the steady state.

where the central bank sets IOR equal to the policy rate such that the reserve requirement is slack and the relatively low real interest rate induces the capital requirement to be binding. The first two rows show responses to a productivity shock, and the last two rows show responses to a cost-push shock. Consistent with conventional expectations, productivity (cost-push) shocks raise (reduce) aggregate output and reduce (raise) inflation, while consumption and bank lending increase.

The blue solid line refers to a counterfactual model version at the ZLB, where the reserve and the capital requirement are assumed to be slack (NKM-Z) such that neither reserves nor total public sector liabilities are relevant for the allocation. This version thus relates to a standard New Keynesian model. In contrast to the benchmark model, which is locally determined under a peg (see Proposition 2), a New Keynesian model is known to be locally indetermined under a peg. A typical strategy to ensure equilibrium uniqueness is to apply an interest rate rule that satisfies the Taylor-principle and to introduce an adverse shock, which is sufficiently large to induce that the central bank sets the interest rate at the ZLB. To keep the analysis as transparent as possible and to abstract from the impact of expected duration at the ZLB, we abstain from this strategy and assume that the policy rate is pegged at zero, while we apply the minimum state variable solution for NKM.

Apparently, the NKM-Z specification predicts that output falls (increases) at the ZLB in response to a productivity (cost-push) shock. These well-established counterintuitive predictions of the New Keynesian model (see Eggertsson, 2011, 2012) are based on the property that the real interest rate increases (falls) in response to a productivity (cost-push) shock, raising agents' willingness to save more (less). This impact of the monetary policy rate on aggregate demand dominates the impact of the shock on the supply side. In the benchmark model with a binding capital requirement, the impact of the real policy rate on agents' intertemporal choices is muted by the multiplier on the capital requirement (see 19), such that the supply side effects dominate and intuitive output effects of both shocks prevail.

Figure 4 displays impulse responses to productivity and cost-push shocks for four model versions: the benchmark model at the ZLB and above the ZLB (SB-Z and SB-N), the New-Keynesian-type model (NKM-N), and a specification with a binding reserve requirement and slack capital requirement (BS-N). For the specifications (-N), where the policy rate is above the ZLB, we assume that the main policy rate follows a standard Taylor rule,

$$R_t^M/R^M = \left(R_{t-1}^M/R^M\right)^{\rho_r} \left[(\pi_t/\pi)^{\gamma_{r,\pi}} \left(y_t/y_t^*\right)^{\gamma_{r,y}}\right]^{1-\rho_r}, \tag{37}$$

where $\gamma_{r,\pi} \geq 0$ and $\gamma_{r,y} \geq 0$ denote the feedback coefficients to changes in inflation and in the output gap, which is measured by output deviation from its flexible price level y_t^*. Values for the coefficients in (37) are taken from Smets and Wouters (2007): $\rho_r = 0.81$, $\gamma_{r,\pi} = 2.03$ and $\gamma_{r,y} = 0.08$. A comparison of the four versions shows that they lead to similar impulse responses under both types of supply side shocks, except for the slightly dampened and shorter-lived output responses predicted by the SB-N version. Overall, these results suggest that the ZLB (or, more generally, interest rate pegs) does not substantially affect the transmission of supply side shocks under binding capital requirements. In fact, the versions with slack capital requirements (NKM-N and BS-N) exhibit broadly similar, though slightly more pronounced, output responses, which corresponds to the impulse responses in Piazzesi et al. (2022). These findings indicate that binding capital requirements have no systematic amplification effects of supply side shocks above the ZLB. Notably, this property differs from the predictions of models where leverage constraints endogenously arise due to the presence of financial frictions (see e.g. Gertler and Karadi, 2011), which have been omitted in our analysis to isolate the effects of the regulatory capital requirement.

4.2.2. Government spending shocks

To demonstrate that capital requirements are also relevant for demand shocks, we further introduce government expenditures g_t, which are assumed to be fully financed through lump-sum taxation, for convenience. Government expenditures follow an AR(1) process: $g_t/g = (g_{t-1}/g)^{\gamma_g}$ $\exp(\varsigma^g \epsilon_t^g)$.[11] Figure 5 presents the impulse responses to a positive government expenditure shock

[11] We apply an empirical supported value (18%) for the steady-state output share g/y.

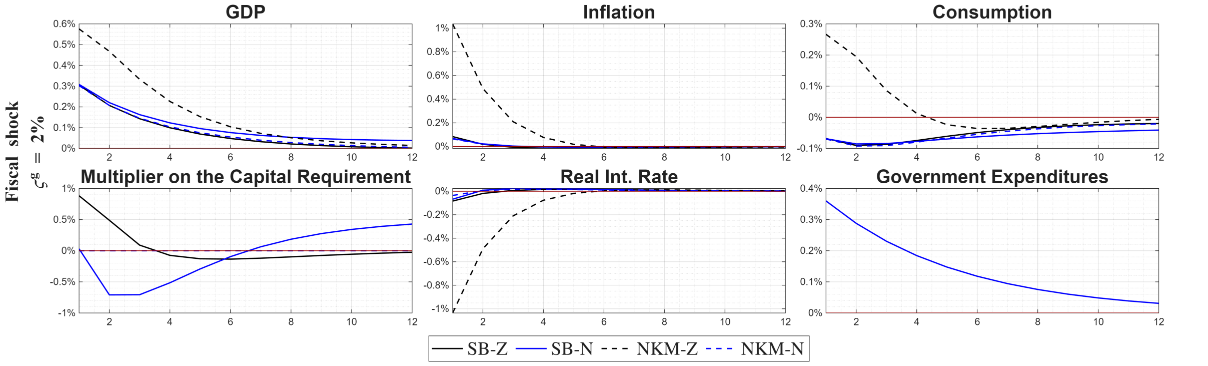

Figure 5: Impulse responses to a 2% increase in government expenditures with autocorrelation $\gamma_g = 0.8$ in the benchmark models (SB-Z: black solid line; SB-N: blue solid line) and in two NK-type specifications (NKM-Z: black dashed line; NKM-N: blue dashed line). The vertical axis reports percentage deviations from the steady state, while the response of government expenditures is adjusted by the steady-state ratio g/y.

for four specifications of the model (SB-Z, NKM-Z, SB-N, and NKM-N).

According to a basic New Keynesian model above the ZLB, government spending tends to raise inflation and to partially crowd-out consumption and investment, such that the fiscal multiplier is less than one. This is confirmed by the blue dashed lines (NKM-N), where the fiscal multiplier equals the relation of the output and the government expenditure responses. The overall pattern of the NKM-N responses are closely related to the impulse responses for the versions with a binding capital requirement above and at the ZLB (SB-Z and SB-N). When the capital requirement is slack, the responses are however markedly different at the ZLB, revealing an impact multiplier clearly above one (see NKM-Z). This outcome is well-established (see e.g., Christiano et al., 2011) and relies on the inflationary impact of the fiscal shock, which implies a reduction of the real interest rate at the ZLB. Like for the supply side shocks, the real interest rate is decisive for aggregate demand under a slack capital requirement, such that consumption and also investment are crowded-in. Under a binding capital requirement, the real interest rate effect is muted, such that the impact multiplier rather takes normal than extreme values.

5. Conclusion

Our paper develops a medium-scale macroeconomic model with banks that incorporates key features of U.S. monetary policy before and after the GFC. The model allows the central bank to control the Federal Funds Rate (FFR), interest on reserves (IOR), and the supply of reserves. It captures the transition from a pre-2008 regime characterized by binding reserve requirements and zero IOR to a post-2008 environment with satiated money demand and IOR equal to the FFR. In addition, the model introduces a regulatory capital requirement that constrains bank deposit creation.

We estimate the model using a regime-switching structure that allows for the capital requirement to bind occasionally. The estimation reveals that the capital requirement has been binding since 2008, except for the onset of the COVID-19 pandemic, when capital requirements were temporary relaxed. We show that a binding capital requirement can fundamentally affect macroeconomic dynamics, especially at the ZLB. We show analytically that local equilibrium determinacy is not threatened by interest rate pegs when standard New Keynesian models predict indeterminacy. Notably, binding capital requirements do not restore relevance of reserves at the ZLB, which is consistent with missing inflation hikes after a surge in reserve supply since 2008. Unlike standard models, a monetary policy regime under binding capital requirements is associated with conventional output and inflation responses to productivity and cost-push shocks at the ZLB. The analysis of the transmission of macroeconomic shocks shows that policy rates at the ZLB do not induce reversals of output responses to supply side shocks compared policy rates above the ZLB. There, binding capital requirements rather dampen than amplify responses to macroeconomic shocks.

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References

Arce, O., G. Nuno, D. Thaler, and C. Thomas (2020). A large central bank balance sheet? Floor vs corridor systems in a New Keynesian environment. *Journal of Monetary Economics 114*, 350–367.

Barro, R. J. and F. Bianchi (2025). Fiscal Influences on Inflation in OECD Countries, 2020–2023. *The Economic Journal 136*(674), 626–654.

Barthélemy, J. and M. Marx (2017). Solving endogenous regime switching models. *Journal of Economic Dynamics and Control 77*, 1–25.

Begenau, J. (2020). Capital requirements, risk choice, and liquidity provision in a business-cycle model. *Journal of Financial Economics 136*(2), 355–378.

Benigno, G. and P. Benigno (2021). Interest, reserves, and prices. *Federal Reserve Bank of New York Staff Reports* (971).

Benigno, G., A. Foerster, C. Otrok, and A. Rebucci (2025). Estimating macroeconomic models of financial crises: An endogenous regime-switching approach. *Quantitative Economics 16*(1), 1–47.

Bianchi, F. (2013). Regime Switches, Agents' Beliefs, and Post-World War II U.S. Macroeconomic Dynamics. *The Review of Economic Studies 80*(2), 463–490.

Bianchi, F. and C. Ilut (2017). Monetary/Fiscal policy mix and agents' beliefs. *Review of Economic Dynamics 26*, 113–139.

Bianchi, F. and L. Melosi (2017). Escaping the Great Recession. *American Economic Review 107*(4), 1030–1058.

Bianchi, F. and L. Melosi (2022). Inflation as a fiscal limit. FRB of Chicago Working Paper No. 2022-37, Available at SSRN: https://ssrn.com/abstract=4205158.

Bianchi, J. and S. Bigio (2022). Banks, Liquidity Management, and Monetary Policy. *Econometrica 90*(1), 391–454.

Binning, A. and J. Maih (2017). Modelling occasionally binding constraints using regime-switching. Norges Bank Working Paper No. 23/2017, ISBN 978-82-8379-007-8.

Bjørnland, H. C., V. H. Larsen, and J. Maih (2018). Oil and macroeconomic (in) stability. *American Economic Journal: Macroeconomics 10*(4), 128–151.

Bohn, H. (1998). The Behavior of U. S. Public Debt and Deficits. *The Quarterly Journal of Economics 113*(3), 949–963.

Chang, Y., J. Maih, and F. Tan (2021). Origins of monetary policy shifts: a new approach to regime switching in DSGE models. *Journal of Economic Dynamics and Control 133*, 104235.

Christiano, L., M. Eichenbaum, and S. Rebelo (2011). When is the government spending multiplier large? *Journal of Political Economy 119*(1), 78–121.

Diba, B. and O. Loisel (2021). Pegging the interest rate on bank reserves: a resolution of New Keynesian puzzles and paradoxes. *Journal of Monetary Economics 118*, 230–244.

Eggertsson, G. B. (2011). What fiscal policy is effective at zero interest rates? *NBER Macroeconomics Annual 25*(1), 59–112.

Eggertsson, G. B. (2012). Was the new deal contractionary? *American Economic Review 102*(1), 524–555.

Ennis, H. M. (2018). A simple general equilibrium model of large excess reserves. *Journal of Monetary Economics 98*, 50–65.

Ennis, H. M. and T. McMillan (2023). Fed Balance Sheet Normalization and the Minimum Level of Ample Reserves. *Richmond Fed Economic Brief 23*(07).

Gertler, M. and P. Karadi (2011). A model of unconventional monetary policy. *Journal of Monetary Economics 58*(1), 17–34.

Gertler, M. and N. Kiyotaki (2015). Banking, liquidity, and bank runs in an infinite horizon economy. *American Economic Review 105*(7), 2011–2043.

Gilchrist, S., R. Schoenle, J. Sim, and E. Zakrajšek (2017). Inflation Dynamics during the Financial Crisis. *American Economic Review 107*(3).

Gomez-Cram, R., H. Kung, and H. N. Lustig (2024). Government debt in mature economies: Safe or risky? Available at SSRN: https://ssrn.com/abstract=4935930.

Guerrieri, L. and M. Iacoviello (2017). Collateral constraints and macroeconomic asymmetries. *Journal of Monetary Economics 90*, 28–49.

Ihrig, J., Z. Senyuz, and G. Weinbach (2020). The Fed's "Ample Reserves" Approach to Implementing Monetary Policy. Finance and Economics Discussion Series 2020-022.

Leeper, E. M. (1991). Equilibria under 'active' and 'passive' monetary and fiscal policies. *Journal of Monetary Economics 27*(1), 129–147.

Lenel, M., M. Piazzesi, and M. Schneider (2019). The short rate disconnect in a monetary economy. *Journal of Monetary Economics 106*, 59–77.

Liu, Z., D. F. Waggoner, and T. Zha (2011). Sources of macroeconomic fluctuations: A regime-switching DSGE approach. *Quantitative Economics 2*(2), 251–301.

Malherbe, F. (2020). Optimal capital requirements over the business and financial cycles. *American Economic Journal: Macroeconomics 12*(3), 139–174.

Mendicino, C., K. Nikolov, J. Suarez, and D. Supera (2020). Bank capital in the short and in the long run. *Journal of Monetary Economics 115*, 64–79.

Michaillat, P. and E. Saez (2021). Resolving New Keynesian Anomalies with Wealth in the Utility Function. *The Review of Economics and Statistics 103*(2), 197–215.

Piazzesi, M., C. Rogers, and M. Schneider (2022). Money and banking in a New Keynesian model. Unpublished, Stanford University.

Piazzesi, M. and M. Schneider (2022). Credit lines, bank deposits or CBDC? Competition and efficiency in modern payment systems . Unpublished, Stanford University.

Ravenna, F. and C. E. Walsh (2006). Optimal monetary policy with the cost channel. *Journal of Monetary Economics 53*(2), 199–216.

Rotemberg, J. J. (1982). Sticky Prices in the United States. *Journal of Political Economy 90*(6), 1187–1211.

Sims, C. A. and T. Zha (2006). Were There Regime Switches in U.S. Monetary Policy? *American Economic Review 96*(1).

Sims, E. and J. C. Wu (2021). Evaluating central banks' tool kit: Past, present, and future. *Journal of Monetary Economics 118*, 135–160.

Smets, F. and R. Wouters (2007). Shocks and frictions in US business cycles: A Bayesian DSGE approach. *American Economic Review 97*(3), 586–606.

Ulate, M. (2021). Going Negative at the Zero Lower Bound: The Effects of Negative Nominal Interest Rates. *American Economic Review 111*(1), 1–40.

Walter, J. R. (2019). US Bank Capital Regulation: History and Changes Since the Financial Crisis. *Economic Quarterly* (1Q), 1–40.

Wu, J. C. and F. D. Xia (2016). Measuring the macroeconomic impact of monetary policy at the zero lower bound. *Journal of Money, Credit and Banking 48*(2-3), 253–291.

A Appendix

A1 Rational expectations equilibrium

A REE is a set of sequences of quantities $\{y_t,\ c_t,\ x_t,\ n_t,\ k_t,\ d_t,\ l_t,\ b_t,\ s_t,\ m_t,\ i_t^B,\ \epsilon_t,\ e_t\}$, prices $\{w_t,\ mc_t,\ \eta_t,\ q_t,\ \pi_t,\ \lambda_t,\ \vartheta_t^H,\ \vartheta_t^B,\ \varkappa_t,\ \widetilde{\varkappa}_t,\ \Lambda_{t,t+1},\ R_t^L,\ R_t^D,\ R_t^M,\ R_t^R,\ R_t^F,\ R_t\}$, and probabilities $\{prob_t^{S,B},\ prob_t^{B,S}\}$ satisfying,

$$\psi_t^P(\mathcal{C}_t)^{-1} - \beta h \mathbb{E}_t \psi_{t+1}^P (\mathcal{C}_{t+1})^{-1} = \lambda_t + \vartheta_t^H, \tag{A.1}$$

$$\lambda_t w_t = \chi \psi_t^N n_t^{\sigma_n}, \tag{A.2}$$

$$\mu \vartheta_t^H / \lambda_t + \mathbb{E}_t \Lambda_{t,t+1} \pi_{t+1}^{-1} R_t^D = 1, \tag{A.3}$$

$$\mu d_t \geq c_t, \quad \text{if } \vartheta_t^B = 0, \quad \text{or} \quad \mu d_t = c_t, \quad \text{if } \vartheta_t^B > 0, \tag{A.4}$$

$$\Lambda_{t,t+1} = \beta \lambda_{t+1} / \lambda_t, \tag{A.5}$$

$$\vartheta_t^B = R_t^M - R_t^R, \tag{A.6}$$

$$\vartheta_t^B = R_t^F - R_t^R, \tag{A.7}$$

$$\varkappa_t = 1 - \mathbb{E}_t \Lambda_{t,t+1} \pi_{t+1}^{-1} R_t, \tag{A.8}$$

$$1 = \varkappa_t + \mathbb{E}_t \Lambda_{t,t+1} \pi_{t+1}^{-1} R_{t+1}^M, \tag{A.9}$$

$$1 = \varkappa_t + \mathbb{E}_t \Lambda_{t,t+1} \pi_{t+1}^{-1} \left(R_{t+1}^L - \kappa_L \right), \tag{A.10}$$

$$1 = (1 + \phi_t) \varkappa_t + \kappa_D + \varrho \vartheta_t^B + \mathbb{E}_t \Lambda_{t,t+1} \pi_{t+1}^{-1} R_t^D, \tag{A.11}$$

$$m_{t-1} \pi_t^{-1} + i_t^B - \varrho d_t \geq 0, \quad \text{if } \vartheta_t^B = 0, \quad \text{or} \quad m_{t-1} \pi_t^{-1} + i_t^B - \varrho d_t = 0, \quad \text{if } \vartheta_t^B > 0, \tag{A.12}$$

$$l_t = \xi q_t k_t, \tag{A.13}$$

$$k_t = (1 - \delta) k_{t-1} + x_t, \tag{A.14}$$

$$y_t = a_t k_{t-1}^{\alpha} n_t^{1-\alpha}, \tag{A.15}$$

$$(1 - \alpha) mc_t y_t = w_t n_t, \tag{A.16}$$

$$R_t^L \pi_t^{-1} = \left[\alpha mc_t y_t / k_{t-1} + q_t (1 - \delta) \right] / q_{t-1}, \tag{A.17}$$

$$q_t \psi_t^X = 1 + \frac{\kappa_I}{2} \left(\frac{x_t}{x_{t-1}} - 1 \right)^2 + \kappa_I \left(\frac{x_t}{x_{t-1}} - 1 \right) \frac{x_t}{x_{t-1}} - \kappa_I \mathbb{E}_t \Lambda_{t,t+1} \left(\frac{x_{t+1}}{x_t} - 1 \right) \left(\frac{x_{t+1}}{x_t} \right)^2 \frac{\psi_t^X}{\psi_{t+1}^X}, \tag{A.18}$$

$$\eta_t - 1 = \eta_t mc_t - \kappa_p \left(\frac{\pi_t}{\pi} - 1 \right) \left(\frac{\pi_t}{\pi} \right) + \kappa_p \mathbb{E}_t \Lambda_{t,t+1} \frac{y_{t+1}}{y_t} \left(\frac{\pi_{t+1}}{\pi} - 1 \right) \left(\frac{\pi_{t+1}}{\pi} \right), \tag{A.19}$$

$$\eta_t = \eta (\psi_t^{\eta})^{-\kappa_p}, \tag{A.20}$$

$$c_t + \left[\Psi \left(\frac{x_t}{x_{t-1}} \right) + 1 \right] \frac{x_t}{\psi_t^X} + \frac{\kappa_p}{2} \left(\frac{\pi_t}{\pi} - 1 \right)^2 y_t = y_t, \tag{A.21}$$

$$m_t = m_{t-1} \pi_t^{-1} + i_t^B, \tag{A.22}$$

$$s_t = m_t + b_t, \tag{A.23}$$

$$\epsilon_t = e_t/d_t, \tag{A.24}$$

$$e_t = l_t + s_t - d_t, \tag{A.25}$$

$$m_t/m_{t-1} = \pi/\pi_t, \tag{A.26}$$

$$s_t/s_{t-1} = \nu_t^B/\pi_t, \tag{A.27}$$

$$\nu_t^B/\nu^B = \exp\left(\varsigma_b \epsilon_t^B\right), \tag{A.28}$$

$$a_t = (a_{t-1})^{\rho_a} \exp\left(\varsigma_a \epsilon_t^A\right), \tag{A.29}$$

$$\psi_t^P = (\psi_{t-1}^P)^{\rho_p} \exp\left(\varsigma_p \epsilon_t^P\right), \tag{A.30}$$

$$\psi_t^X = (\psi_{t-1}^X)^{\rho_x} \exp\left(\varsigma_x \epsilon_t^X\right), \tag{A.31}$$

$$\psi_t^N = (\psi_{t-1}^N)^{\rho_n} \exp\left(\varsigma_n \epsilon_t^N\right), \tag{A.32}$$

$$\psi_t^\eta = (\psi_{t-1}^\eta)^{\rho_\eta} \exp\left(\varsigma_\eta \epsilon_t^\eta\right), \tag{A.33}$$

$$\phi_t/\phi = (\phi_{t-1}/\phi)^{\rho_\phi} \exp(\varsigma^\phi \epsilon_t^\phi), \tag{A.34}$$

$$R_t^M/R^M = \left(R_{t-1}^M/R^M\right)^{\rho_r} \left[(\pi_t/\pi)^{\gamma_{r,\pi}} (y_t/y_t^*)^{\gamma_{r,y}}\right]^{1-\rho_r}, \quad \text{if } R_t^M > 0, \quad \text{or} \quad R_t^M = 1, \tag{A.35}$$

$$\widetilde{\varkappa}_t = \varkappa_t - \bar{\varkappa}, \tag{A.36}$$

$$prob_t^{S,B} = \left[1 + \mathcal{O}_{s,b} \exp(-\theta_{s,b} \varkappa_t)\right]^{-1}, \tag{A.37}$$

$$prob_t^{B,S} = \left[1 + \mathcal{O}_{b,s} \exp(\theta_{b,s} \widetilde{\varkappa}_t)\right]^{-1}, \tag{A.38}$$

$$\mathbf{z}(\mathcal{S}_t^{lev}) \varkappa_t + \left(1 - \mathbf{z}(\mathcal{S}_t^{lev})\right)(\epsilon_t - \phi_t) = 0, \tag{A.39}$$

the transversality conditions, given exogenous sequences $\{a_t, \psi_t^P, \psi_t^X, \psi_t^N, \psi_t^\eta, \phi_t\}$, $b_{-1} > 0$, $b_{-1}^T > 0$, and $m_{-1} > 0$. This definition applies to the general framework. The model implementations considered below incorporate regime-specific features to selected equilibrium conditions, while preserving the underlying equilibrium concept. For the specifications NKM-N and NKM-Z used in Section 4.2, both the reserve requirement (A.12) and the capital requirement (A.39) are slack, and the money-related variables and conditions (A.22)-(A.28) are omitted. In the BS-N specification, interest on reserves is not implemented ($R_t^R = 1$), while the reserve requirement (A.12) is binding. In the SB-N and SB-Z specifications, the capital requirement (A.39) is binding, while the nominal interest rate follows a state-contingent feedback rule in the former and is pegged in the latter, as specified in (A.35). For the regime-switching version estimated in Section 4, the reserve requirement (A.12) is always slack, whereas the capital requirement (A.39) is occasionally binding. In addition, the nominal interest rate (A.35) is specified in a data-driven process as $R_t^M/R^M = \exp\left(\varsigma_r \epsilon_t^R\right)$, and the standard deviations of the shocks in (A.28)–(A.33) are allowed to be heteroskedastic, i.e., $\varsigma_{i,(\mathcal{S}_t^{vol})}$, for $i \in \{a, x, n, p, \eta, b\}$.

Steady state of the model To solve for the steady state of the model, we impose that all variables are constant over time. The exogenous processes are normalized such that, in steady state, $a_t = \psi_t^P = \psi_t^X = \psi_t^N = \psi_t^\eta = 1$, while $\nu^B = \pi$. To preserve the invariance of deep parameters across regimes, we allow the steady states of certain variables to be regime-dependent. Taking the inflation target π and the discount factor β as given, the banks' optimality condition (A.9) together with $\Lambda = \beta$ implies $R^M = \pi/\beta$ for the NKM-N and BS-N specifications. For the NKM-Z specification, where $R^M = 1$, we follow Bianchi and Melosi (2017) and set $\beta' = 1/\pi$. For the SB-N and SB-Z specifications, R^M is calibrated to match the average level observed in the post-crisis period (see Section 4.1.2), which implies that the multiplier on the capital requirement satisfies $\varkappa = 1 - \beta R^M \pi^{-1}$. The loan rate is then given by $R^L = R^M + \kappa_L$ according to (A.10). Firms' optimality conditions (A.16–A.17) together with the production function (A.15) imply

$$mc = \frac{\eta - 1}{\eta}, \quad \frac{y}{k} = \frac{R^L \pi^{-1} - (1-\delta)q}{\alpha mc}, \quad \frac{k}{n} = \left(\frac{y}{k}\right)^{\frac{1}{\alpha-1}}, \quad \frac{y}{n} = \left(\frac{k}{n}\right)^{\alpha}, \tag{A.40}$$

where $q = 1$. Capital accumulation (A.14) and market-clearing (A.21) further imply,

$$\frac{x}{n} = \delta\frac{k}{n}, \quad \frac{l}{n} = \xi\frac{k}{n}, \quad w = (1-\alpha)\, mc\frac{y}{n}, \quad \frac{c}{n} = \frac{y}{n} - \frac{x}{n}. \tag{A.41}$$

Combining the first-order conditions for deposits of households (A.3) and banks (A.11), yields $\vartheta^H/\lambda = [\kappa_D + (1+\phi)\varkappa]/\mu$, in the SB cases, $\vartheta^H/\lambda = \kappa_D/\mu$, in the NKM cases, and $\vartheta^H/\lambda = (\kappa_D + \varrho\vartheta^B)/\mu$, in the BS case where $\vartheta^B = R^M - 1$. Household optimal conditions on consumption and labor (A.1)-(A.2) imply,

$$n = \left[\frac{w\,(1-\beta h)\left((1-h)\frac{c}{n}\right)^{-1}}{\chi\,(1+\vartheta^H/\lambda)}\right]^{\frac{1}{(\sigma^n+1)}}. \tag{A.42}$$

Combining (A.42) with (A.40)-(A.41) yields the steady-state values of $\{c,\ y,\ x,\ l,\ k,\ w,\ \vartheta^H,\ \lambda\}$. The steady-state values of deposits, public sector liabilities, and equity are determined by $d = \mu^{-1}c$, $s = (1+\epsilon)d - l$, and $e = l + s - d$. The steady-state levels of reserves and banks' holdings of treasury securities are calibrated to match the corresponding ratio observed in the data. In the BS-N specification, reserves satisfy $m = \varrho d$.

A2 Appendix to Section 3

Suppose that Assumption 1 holds. Then, the resource constraint reduces to

$$c_t = \Phi_t y_t, \text{ where } \Phi_t = 1 - \frac{\kappa_p}{2}\left(\frac{\pi_t}{\pi} - 1\right)^2, \tag{A.43}$$

where Φ_t is an inefficiency wedge between consumption and inflation. Using aggregate production, $y_t = a_t n_t$, and (A.43), to substitute out working time in (6), gives

$$\lambda_t = \chi c_t^{\sigma_n} a_t^{-\sigma_n} \Phi_t^{-\sigma_n} w_t^{-1}. \tag{A.44}$$

Consider $R_t^R = R_t^M \Rightarrow \vartheta_t^B = 0$ (see A.6) and $\varkappa_t > 0$, such that reserve requirement is slack and the capital requirement binds, $(1+\phi)\, d_t = l_t + s_t$. According to (A.3) and (A.11), the household liquidity constraint binds, $c_t = \mu d_t$. Further, using loan demand (28) and the resource constraint (A.43), the binding capital requirement implies

$$c_t = \mu_t^{lev} s_t, \tag{A.45}$$

where $\mu_t^{lev} = 1/\left(\frac{1+\phi}{\mu} - \frac{\xi'}{\Phi_t}\right) > 0$. Under Assumption 1, the household optimality condition (4) simplifies to $c_t^{-1} = \lambda_t + \vartheta_t^H$. Substituting out the multiplier ϑ_t^H with (27) for $\vartheta_t^B = 0$, yields

$$c_t^{-1} = \lambda_t \left(1 + \varkappa_t \frac{(1+\phi)}{\mu}\right). \tag{A.46}$$

Further, labor demand (A.16) simplifies to $w_t/a_t = mc_t$. Using the latter and $\widehat{\Phi}_t = 0$, we log-linearize (15), (22), (26), (A.44), (A.45), (A.46) at the steady state, leading to

$$\begin{aligned}
\mathbb{E}_t\widehat{\lambda}_{t+1} - E_t\widehat{\pi}_{t+1} - \widehat{\lambda}_t + \widehat{R}_t &= -\frac{\varkappa}{1-\varkappa}\widehat{\varkappa}_t, &\text{(A.47)}\\
\widehat{\pi}_t &= \beta\mathbb{E}_t\widehat{\pi}_{t+1} + \Xi(\widehat{w}_t - \widehat{a}_t) - \widehat{\eta}_t/\kappa_p, &\text{(A.48)}\\
\widehat{s}_t &= \widehat{s}_{t-1} - \widehat{\pi}_t, &\text{(A.49)}\\
\widehat{\lambda}_t &= \sigma_n\widehat{c}_t - \sigma_n\widehat{a}_t - \widehat{w}_t, &\text{(A.50)}\\
\widehat{c}_t &= \widehat{s}_t, &\text{(A.51)}\\
-\widehat{c}_t &= \widehat{\lambda}_t + \kappa_\varkappa\widehat{\varkappa}_t, &\text{(A.52)}
\end{aligned}$$

where $\Xi = \frac{\eta-1}{\kappa_p}$ and $\kappa_\varkappa = \frac{\varkappa\frac{1+\phi}{\mu}}{1+\varkappa\frac{(1+\phi)}{\mu}} \in (0,1)$. Substituting out $\widehat{w}_t$ with (A.50), and $\widehat{c}_t$ with (A.51) in (A.48), gives

$$\widehat{\pi}_t = \beta\mathbb{E}_t\widehat{\pi}_{t+1} + \Pi_s\widehat{s}_t - \Xi\widehat{\lambda}_t - \Pi_a\widehat{a}_t - \widehat{\eta}_t/\kappa_p. \tag{A.53}$$

Combining (A.51) and (A.52) to $-\sigma\widehat{s}_t = \widehat{\lambda}_t + \kappa_\varkappa\widehat{\varkappa}_t$, and using the latter to substitute out $\widehat{\varkappa}_t$ in (A.47), gives

$$\mathbb{E}_t\widehat{\lambda}_{t+1} - \mathbb{E}_t\widehat{\pi}_{t+1} + \widehat{R}_t = F_s\widehat{s}_t + F_\lambda\widehat{\lambda}_t, \tag{A.54}$$

where $\Pi_a = \Xi\,(1+\sigma_n) > 0$, $\Pi_s = \Xi\sigma_n > 0$, $F_s = \frac{\varkappa}{1-\varkappa}\kappa_\varkappa^{-1} > 0$ and $F_\lambda = 1 + \frac{\varkappa}{1-\varkappa}\kappa_\varkappa^{-1} > 1$. Hence, (A.49), (A.53), and (A.54) constitute a 3x3 system in $\{\widehat{\pi}_t\ \widehat{s}_t,\ \widehat{\lambda}_t\}$ for a sequence for $\widehat{R}_t$ given by monetary policy.

Proof of Proposition 2. Since there is one predetermined state variable $\{\widehat{s}_t\}$ and two non-predetermined variables $\{\widehat{\lambda}, \widehat{\pi}_t\}$, the REE is stable and locally determined if and only if there are two unstable and one stable eigenvalue. Substituting out $\widehat{R}_t^M$ with $\widehat{R}_t^M = \gamma_{r,\pi}\widehat{\pi}_t$ and summarizing the system (29)-(31) by

$$\begin{pmatrix} \beta & 0 & \Pi_s \\ 0 & 0 & 1 \\ \gamma_{r,\pi}-1 & 1 & -\digamma_s \end{pmatrix} \begin{pmatrix} \widehat{\pi}_{t+1} \\ \widehat{\lambda}_{t+1} \\ \widehat{s}_t \end{pmatrix} = \begin{pmatrix} 1 & \Xi & 0 \\ -1 & 0 & 1 \\ 0 & \digamma_\lambda & 0 \end{pmatrix} \begin{pmatrix} \widehat{\pi}_t \\ \widehat{\lambda}_t \\ \widehat{s}_{t-1} \end{pmatrix} + \begin{pmatrix} \Pi_a \\ 1/\kappa_p \\ 0 \end{pmatrix} \begin{pmatrix} \widehat{a}_t \\ \widehat{\eta}_t \\ 0 \end{pmatrix},$$

we define the matrix $\mathbb{A}$ as

$$\mathbb{A} = \begin{pmatrix} \beta & 0 & \Pi_s \\ 0 & 0 & 1 \\ \gamma_{r,\pi}-1 & 1 & -\digamma_s \end{pmatrix}^{-1} \begin{pmatrix} 1 & \Xi & 0 \\ -1 & 0 & 1 \\ 0 & \digamma_\lambda & 0 \end{pmatrix}.$$

Characteristic polynomial of $\mathbb{A}$ is given by $G(X) = X^3 - \frac{\beta+\Xi+\Pi_s-\Xi\gamma_{r,\pi}+\beta\digamma_\lambda+1}{\beta}X^2 + \frac{\Xi+\digamma_\lambda-\Xi\gamma_{r,\pi}+\Xi\digamma_s+\beta\digamma_\lambda+\Pi_s\digamma_\lambda+1}{\beta}X - \frac{\digamma_\lambda}{\beta}$ with

$$G(0) = -\frac{\digamma_\lambda}{\beta} < -1, \quad G(1) = \frac{\Xi\digamma_s + \Pi_s(\digamma_\lambda - 1)}{\beta} > 0,$$
$$G(-1) = -\frac{\Xi\digamma_s + (1+\digamma_\lambda)(2(1+\beta)+\Pi_s) + 2\Xi(1-\rho_\pi)}{\beta}.$$

Hence, $G(-1)$ is negative for $\gamma_{r,\pi} < 1 + \frac{\Xi\digamma_s+(1+\digamma_\lambda)(2(1+\beta)+\Pi_s)}{2\Xi}$, or using $\Pi_s = \Xi\sigma_n$,

$$\gamma_{r,\pi} < 1 + \frac{\digamma_s + (1+\digamma_\lambda)\sigma_n}{2} + \frac{(1+\digamma_\lambda)(1+\beta)}{\Xi}. \tag{A.55}$$

Given that $G(0) = -\digamma_\lambda/\beta < -1$, there exists at least one unstable eigenvalue. Further, $G(1) > 0$ implies that there is at least one stable eigenvalue between zero and one. For $G(-1) < 0$, the third eigenvalue is unstable. Hence, the system is locally stable and uniquely determined iff (A.55) is satisfied. ■

Proof of Proposition 3. Suppose that (32) is satisfied and productivity $\widehat{a}_t$ follows an AR(1) process, $\widehat{a}_t = \rho\widehat{a}_{t-1} + \varepsilon_{a,t}$ with $\rho \in (0,1)$. Further neglecting cost push shocks $\widehat{\eta}_t = 0$, the fundamental solution to the system (29)-(31) with $\widehat{R}_t^M = \gamma_{r,\pi}\widehat{\pi}_t$ can be written as

$$\widehat{\pi}_t = \delta_{\pi,s}\widehat{s}_{t-1} + \delta_{\pi,a}\widehat{a}_t, \tag{A.56}$$
$$\widehat{\lambda}_t = \delta_{\lambda,s}\widehat{s}_{t-1} + \delta_{\lambda,a}\widehat{a}_t, \tag{A.57}$$
$$\widehat{s}_t = \rho_s\widehat{s}_{t-1} + \delta_{s,a}\widehat{a}_t, \tag{A.58}$$

where we know that $\rho_s \in (0,1)$, since the unique stable root of the system (29)-(31) lies between one and zero. To identify the six unknown coefficients in (A.56)-(A.58), replace the endogenous variables with the fundamental solutions. Substituting out $\mathbb{E}_t\widehat{\pi}_{t+1}$, $\widehat{\pi}_t$, $\mathbb{E}_t\widehat{\lambda}_{t+1}$, $\widehat{\lambda}_t$ and $\widehat{s}_t$ with the fundamental solutions (A.56)-(A.58) in (29), and using $\mathbb{E}_t\varepsilon_{a,t+1}=0$, yields

$$[(\delta_{\pi,s}+\Xi\delta_{\lambda,s})-\beta\delta_{\pi,s}\rho_s-\Pi_s\rho_s]\,\widehat{s}_{t-1}=[\beta\delta_{\pi,s}\delta_{s,a}+\beta\delta_{\pi,a}\rho+\Pi_s\delta_{s,a}-(\delta_{\pi,a}+\Xi\delta_{\lambda,a}+\Pi_a)]\,\widehat{a}_t,$$

which can only be satisfied if the following equalities hold

$$\begin{aligned} &i.)\quad (1-\beta\rho_s)\,\delta_{\pi,s}=\Pi_s\rho_s-\Xi\delta_{\lambda,x},\\ &ii.)\quad (\beta\delta_{\pi,s}+\Pi_s)\,\delta_{s,a}=(1-\beta\rho_a)\,\delta_{\pi,a}+\Xi\delta_{\lambda,a}+\Pi_a. \end{aligned}$$

Substituting out $\widehat{\pi}_t$ and $\widehat{s}_t$ with the fundamental solutions (A.56)-(A.58) in (31), yields $(\delta_{s,a}+\delta_{\pi,a})\,\widehat{a}_t=(1-\rho_s-\delta_{\pi,s})\,\widehat{s}_{t-1}$, which can only be satisfied if the following equalities hold

$$\begin{aligned} &iii.)\quad \delta_{\pi,s}=(1-\rho_s)>0,\\ &iv.)\quad -\delta_{\pi,a}=\delta_{s,a}. \end{aligned}$$

Substituting out $\mathbb{E}_t\widehat{\pi}_{t+1}$, $\widehat{\pi}_t$, $\mathbb{E}_t\widehat{\lambda}_{t+1}$, $\widehat{\lambda}_t$ and $\widehat{s}_t$ with the fundamental solutions (A.56)-(A.58) in (30) and using $\mathbb{E}_t\varepsilon_{a,t+1}=0$, yields

$$\begin{aligned} 0 \;=\;& (\delta_{\lambda,s}\rho_s-(1-\gamma_{r,\pi})\,\delta_{\pi,s}\rho_s-F_s\rho_s-F_\lambda\delta_{\lambda,s})\,\widehat{s}_{t-1}\\ &+(\delta_{\lambda,s}\delta_{s,a}+\delta_{\lambda,a}\rho-(1-\gamma_{r,\pi})\,\delta_{\pi,s}\delta_{s,a}-(1-\gamma_{r,\pi})\,\delta_{\pi,a}\rho-F_s\delta_{s,a}-F_\lambda\delta_{\lambda,a})\,\widehat{a}_t, \end{aligned}$$

which can only be satisfied if the following equalities hold

$$\begin{aligned} &v.)\quad \delta_{\lambda,s}=-\frac{\rho_s}{F_\lambda-\rho_s}\left((1-\gamma_{r,\pi})\,\delta_{\pi,s}+F_s\right)<0,\\ &vi.)\quad (\delta_{\lambda,s}-(1-\gamma_{r,\pi})\,\delta_{\pi,s}-F_s)\,\delta_{s,a}=(F_\lambda-\rho_a)\,\delta_{\lambda,a}+(1-\rho_\pi)\,\delta_{\pi,a}\rho. \end{aligned}$$

The unknown coefficients in (A.56)-(A.58) can be determined by the equations $i.)-vi.)$. Substituting out $\delta_{\pi,s}=(1-\rho_s)$ and $\delta_{s,a}$ with $iii.)$ and $iv.)$ in $ii.)$, yields

$$\delta_{\pi,a}=-\frac{\Xi}{(\beta\,(1-\rho_s)+\Pi_s)+(1-\beta\rho)}\delta_{\lambda,a}-\frac{\Pi_a}{(\beta\,(1-\rho_s)+\Pi_s)+(1-\beta\rho)}. \tag{A.59}$$

Substituting out $\delta_{\pi,s}$, $\delta_{s,a}$ and $\delta_{\lambda,s}$ with $iii.)$, $iv.)$ and $v.)$ in $vi.)$, further yields

$$\delta_{\pi,a}=\frac{(F_\lambda-\rho)}{(1-\gamma_{r,\pi})\left((1-\rho_s)\frac{F_\lambda}{F_\lambda-\rho_s}-\rho\right)+F_s\frac{F_\lambda}{F_\lambda-\rho_s}}\delta_{\lambda,a}. \tag{A.60}$$

Hence, the coefficients $\delta_{\pi,a}$ and $\delta_{\lambda,a}$ have the same sign if

$$F_s\frac{F_\lambda}{F_\lambda-\rho_s}>(1-\gamma_{r,\pi})\left(\rho-(1-\rho_s)\,\frac{F_\lambda}{F_\lambda-\rho_s}\right). \tag{A.61}$$

For $\rho < (1-\rho_s)\frac{\digamma_\lambda}{\digamma_\lambda - \rho_s}$, the inequality (A.61) is satisfied if

$$\gamma_{r,\pi} < 1 + \frac{\digamma_s \frac{\digamma_\lambda}{\digamma_\lambda - \rho_s}}{(1-\rho_s)\frac{\digamma_\lambda}{\digamma_\lambda - \rho_s} - \rho}. \tag{A.62}$$

For $\rho > (1-\rho_s)\frac{\digamma_\lambda}{\digamma_\lambda - \rho_s}$, the inequality (A.61) requires $\gamma_{r,\pi} > 1 - \digamma_s \frac{\digamma_\lambda}{\digamma_\lambda - \rho_s} / (\rho - (1-\rho_s)\frac{\digamma_\lambda}{\digamma_\lambda - \rho_s})$, which is satisfied for $\gamma_{r,\pi} \geq 0$, $\rho \in (0,1)$, and $\rho_s \in (0,1)$, given that the second term on the RHS is larger than one. To see this, use that

$$\digamma_s \frac{\digamma_\lambda}{\digamma_\lambda - \rho_s} \Big/ \left(\rho - (1-\rho_s)\frac{\digamma_\lambda}{\digamma_\lambda - \rho_s}\right) > 1 \;\Leftrightarrow\; H(\rho_s) > \rho,$$

where $H(\rho_s) = \digamma_s \frac{\digamma_\lambda}{\digamma_\lambda - \rho_s} + (1-\rho_s)\frac{\digamma_\lambda}{\digamma_\lambda - \rho_s}$ and $H'(\rho_s) = \digamma_\lambda \frac{\digamma_s - \digamma_\lambda + 1}{(\digamma_\lambda - \rho_s)^2} > 0$, such that $H(\rho_s) > H(0) = \digamma_s + 1$. Finally, substitute out $\delta_{\pi,a}$ in (A.59) with (A.60), yielding

$$\begin{aligned}\delta_{\lambda,a} \;\; &= \;\; -\left[\frac{(\digamma_\lambda - \rho)}{(1-\gamma_{r,\pi})\left((1-\rho_s)\frac{\digamma_\lambda}{\digamma_\lambda - \rho_s} - \rho\right) + \digamma_s \frac{\digamma_\lambda}{\digamma_\lambda - \rho_s}} + \frac{\Xi}{(\beta(1-\rho_x) + \Pi_s) + (1-\beta\rho)}\right]^{-1} \\ &\quad \cdot \frac{\Pi_a}{(\beta(1-\rho_s) + \Pi_s) + (1-\beta\rho)}.\end{aligned}$$

The term in the square brackets is positive if (A.62) is satisfied. Then, $\delta_{\lambda,a}$ as well as $\delta_{\pi,a}$ (see A.60) are negative, such that $\delta_{s,a}$ is positive according to *iv.*). ■

A3 Supply of public sector liabilities

In this Appendix, we empirically assess the growth rate of public sector liabilities $S_t = M_t + B_t$ (see (26)). Firstly, we provide a description of the data used in the regression analysis for the specification of public sector liabilities. In particular, for Specification-1, S_t is defined as reserves (WRESBAL) plus bills issued by the public sector (from the Fiscal database), excluding holdings by the central bank (BOGZ1FL713061113Q), foreigners (BOGZ1FL263061110Q), and the non-financial sector (BOGZ1FL143061113Q). For Specification-2, S_t is defined as total treasury securities held by the domestic financial sector (FBTSAAQ027S) minus holdings of the central bank (BOGZ1FL713061103Q) plus reserve balances. For Specification-3, S_t is defined as short-term treasuries securities held by the domestic financial sector (BOGZ1FL794022415Q) minus open market papers (FBOMPAQ027S) and minus holdings of the central bank (BOGZ1FL713061113Q), plus reserve balances.

The data are from 2009Q1 to 2024Q4, which is consistent with the sample for the regime-switching estimation in Section 4. To examine the supply of public sector liabilities, we consider a specification for the growth rate which allows for various contingencies:

$$\hat{\nu}_t^B = a_1 \hat{\nu}_{t-1}^B + a_2 \hat{m}_t + a_3 \hat{\pi}_t + a_4 \hat{y}_t + a_5 \mathcal{D}_t + \varepsilon_t, \tag{A.63}$$

Table A.1: Regression Results

	Specification-1			Specification-2			Specification-3		
	OLS	2SLS	GMM	OLS	2SLS	GMM	OLS	2SLS	GMM
$\widehat{\nu}^B_{t-1}$	0.007	-0.913	-0.087	0.060	-0.415	-0.257	0.065	-0.160	-0.148
	(0.101)	(2.228)	(2.236)	(0.109)	(0.932)	(0.852)	(0.103)	(0.841)	(0.615)
$\widehat{m}_t$	0.097	0.191	0.111	0.050	0.042	0.037	0.102	0.067	0.111
	(0.058)	(0.360)	(0.342)	(0.033)	(0.100)	(0.075)	(0.064)	(0.194)	(0.167)
$\widehat{\pi}_t$	-2.458	-14.90	-7.497	-1.665*	-6.154	-5.343*	-2.262	-9.221	-9.052
	(1.574)	(19.11)	(18.01)	(0.894)	(4.810)	(2.949)	(1.728)	(8.417)	(6.102)
$\widehat{y}_t$	-0.153	-0.665	-0.065	-0.180	-0.384	-0.309	-0.168	-0.138	-0.154
	(0.373)	(2.090)	(1.791)	(0.213)	(0.578)	(0.654)	(0.410)	(0.957)	(0.964)
$\mathcal{D}_t$	0.313***	0.287	0.457	0.130***	0.145	0.159*	0.337***	0.446**	0.444***
	(0.057)	(0.501)	(0.461)	(0.032)	(0.110)	(0.088)	(0.063)	(0.182)	(0.163)
R^2	0.450			0.374			0.446		
p-value (J-stat)		0.497	0.602		0.714	0.797		0.242	0.409

Notes: *** Indicates that the t-values of coefficients (standard error in parentheses) are significant at the 1% level; ** at the 5% level; and * at the 10% level. Instrument variables used in 2SLS and GMM are $\widehat{\nu}^B_{t-2}$, $\widehat{m}_{t-1}$, $\widehat{\pi}_{t-1}$, $\widehat{y}_{t-1}$, the shadow rate, and the log-deviation of per capita nominal government expenditure growth.

where $\hat{\nu}^B_t$ and $\hat{m}_t$ denote the log-deviations of ν^B_t and m_t from the respective sample average (denoted by a bar), i.e., $\hat{\nu}^B_t = \log(\nu^B_t/\bar{\nu}^B)$ and $\hat{m}_t = \log(m_t/\bar{m})$. Inflation deviations from the target value are given by $\hat{\pi}_t = \log(\pi_t/\pi)$, while the output gap is defined as deviations of real GDP from its potential level (GDPPOT): $\hat{y}_t = \log(y_t/y^*_t)$. The dummy variable $\mathcal{D}_t$ accounts for the initial phase of the COVID-19 pandemic.[12]

Table A.1 presents sets of regression results based on the three specifications for the growth rate of S_t, which indicate that the coefficients with respect to reserve balances, inflation, and the output gap are not statistically significant. The significant coefficient on the dummy variable captures exceptional effects at the start point of COVID-19. To address a potential endogeneity, particularly the possibility that output gap and reserve balance may be affected by public sector liabilities, we conduct robustness analyses using two-stage least squares (2SLS) estimations. For the instrument selection, we use the first lag of endogenous variables, the shadow rate (Wu and Xia, 2016) and the growth of government expenditures. The Hansen J-statistic shows that the instruments are valid and the model is well specified. Overall, the results remain qualitatively unchanged, showing that $\hat{\nu}^B_t$ is not significantly related to reserves or macroeconomic indicators.

$$\log \nu^B_t = \mathtt{b}_0 + \mathtt{b}_1 \log \nu^B_{t-1} + \mathtt{b}_2 \hat{m}_t + \mathtt{b}_3 \log \pi_t + \mathtt{b}_4 \hat{y}_t + \mathtt{b}_5 \mathcal{D}_t + \varepsilon_t. \tag{A.64}$$

We further consider an alternative regression specification (A.64) in which both ν^B_t and inflation are expressed in logs rather than in deviations from average (target value for inflation).

[12] Specifically, we set $\mathcal{D}_t$ to 1 at 2020Q1-Q2, ensuring that the estimation results reflect structural relationships rather than short-term fluctuations driven by disruptions at the onset of the COVID-19 pandemic.

Table A.2: Regression Results

	Specification-1			Specification-2			Specification-3		
	OLS	2SLS	GMM	OLS	2SLS	GMM	OLS	2SLS	GMM
$\log \nu^B_{t-1}$	-0.021	0.324	0.355	0.042	0.213	0.159	0.035	0.206	0.179
	(0.100)	(0.304)	(0.352)	(0.110)	(0.337)	(0.337)	(0.102)	(0.290)	(0.308)
$\widehat{m}_t$	0.080	-0.080	-0.067	0.044	-0.046	-0.054	0.085	-0.100	-0.107
	(0.057)	(0.109)	(0.095)	(0.033)	(0.054)	(0.051)	(0.063)	(0.105)	(0.088)
$\log \pi_t$	-1.170	2.002	2.207	-1.216	-0.819	-0.898	-0.890	1.210	1.061
	(1.707)	(5.791)	(4.561)	(0.983)	(2.744)	(3.359)	(1.873)	(5.552)	(5.341)
$\widehat{y}_t$	-0.595	-0.467	-0.442	-0.337	-0.374	-0.438	-0.644	-0.720	-0.733
	(0.443)	(0.999)	(0.751)	(0.257)	(0.483)	(0.557)	(0.488)	(0.979)	(0.940)
$\mathcal{D}_t$	0.325***	0.626***	0.607***	0.134***	0.226***	0.238***	0.350***	0.582***	0.598***
	(0.056)	(0.157)	(0.127)	(0.032)	(0.071)	(0.067)	(0.062)	(0.141)	(0.129)
$\mathtt{b}_0$	0.011	-0.024	-0.028	0.022**	0.012	0.014	0.008	-0.017	-0.014
	(0.017)	(0.049)	(0.036)	(0.010)	(0.024)	(0.024)	(0.019)	(0.047)	(0.040)
R^2	0.478			0.387			0.473		
p-value (J-stat)		0.841	0.658		0.636	0.491		0.849	0.759

Notes: *** Indicates that the t-values of coefficients (in parentheses) are significant at the 1% level; ** at the 5% level; and * at the 10% level. Instrument variables used in 2SLS and GMM are $\log \nu^B_{t-2}$, $\widehat{m}_{t-1}$, $\log \pi_{t-1}$, $\widehat{y}_{t-1}$, the shadow rate, the log-deviation of per capita nominal government expenditure growth, and a constant term.

We further include a constant term in all regressions to ensure unbiased estimations. Table A.2 presents the estimation results using the same three specifications for ν^B_t as before. Consistent with the findings above, the growth rate of public sector liabilities is not significantly influenced by reserve supply, inflation, or the output gap.

A4 Appendix to the model estimation

The empirical analysis draws primarily on macroeconomic data from the Federal Reserve Economic Data (FRED) database for the U.S. economy. The observed sequences for the nominal policy rate and inflation used in the Bayesian estimation are the nominal effective Federal Funds rate (FEDFUNDS) and the quarter-over-quarter change in the consumer price index (CPIAUCSL). The codes in parentheses refer to the corresponding identifiers in the FRED database and are consistently used throughout this section. Per capita data are derived by adjusting raw values with the population level (POPTHM). Non-seasonally adjusted raw data are processed using the X-12 seasonal adjustment method conducted in Eviews12. Consumption is measured by personal non-durable goods consumption expenditures (PCEND), and the final output is measured by gross domestic product (GDP). The real growth rate of wages is calculated using hourly earnings (USAHOUREAQISMEI), adjusted for CPI inflation. The leverage ratio is constructed using the Tier 1 leverage ratio, which is defined as Tier 1 Capital (QBPBSLEVK) divided by total assets (QBPBSTAS) for FDIC-regulated banks. The raw investment data is sourced from the OECD database, which is represented by gross fixed capital formation

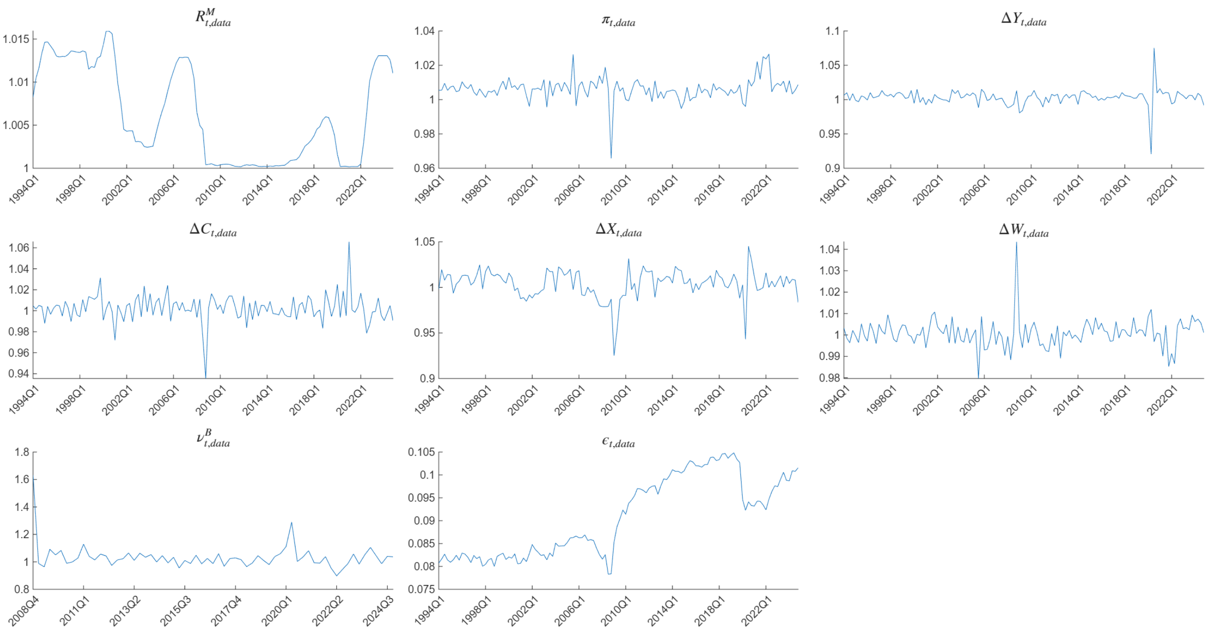

Figure A.1: Data used in the model estimation

for the total economy. The nominal growth rate of per capita public sector liabilities refers to specification-2 defined in the previous section (see Appendix A3), The processed data are presented in Figure A.1.

The connection between model variables and observed data is established through the following measurement equations (A.65). In particular, we allow for an additional estimated drift term, $\bar{\nu}$, to capture deviations in the mean growth rate of nominal public sector liabilities relative to the balanced growth path, while measurement errors capture other relevant unmodeled features.

$$\begin{bmatrix} \log R^M_{t,data} \\ \log \pi_{t,data} \\ \log \epsilon_{t,data} \\ \Delta \log x_{t,data} \\ \Delta \log w_{t,data} \\ \Delta \log y_{t,data} \\ \Delta \log c_{t,data} \\ \log \nu^B_{t,data} \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 0 \\ \log bgp \\ \log bgp \\ \log bgp \\ \log bgp \\ \log bgp + \log \bar{\nu} \end{bmatrix} + \begin{bmatrix} \log R^M_t \\ \log \pi_t \\ \log \epsilon_t \\ \log x_t - \log x_{t-1} \\ \log w_t - \log w_{t-1} \\ \log y_t - \log y_{t-1} \\ \log c_t - \log c_{t-1} \\ \log \nu^B_t \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ \varsigma^y_{data} \varepsilon^y_{t,data} \\ \varsigma^c_{data} \varepsilon^c_{t,data} \\ \varsigma^\nu_{data} \varepsilon^\nu_{t,data} \end{bmatrix} \quad \text{(A.65)}$$

Table A.3 presents the full set of prior and posterior distributions for the estimated parameters across three model specifications, each initialized with identical starting values to ensure comparability. The initial values for mode maximization are chosen to align with commonly used values in the literature (see e.g., Bjørnland et al., 2018; Gertler and Karadi, 2011). To ensure robustness in identifying a high-density region of the posterior distribution, the global optimizer

Table A.3: Prior and Posterior Distribution of Parameters

Parameters	Prior		Posterior (DSGE-RS)					Posterior (DSGE-B)				Posterior (DSGE-S)			
	initial	distribution	mode	mean	5%	95%	PSRF	mode	mean	5%	95%	mode	mean	5%	95%
$100(bgp^4-1)$	1.5	G(1,2)	0.966	1.009	0.736	1.277	1.001	0.948	1.056	0.739	1.366	1.286	1.254	1.098	1.404
h	0.7	B(0.55,0.85)	0.437	0.420	0.358	0.483	1.002	0.461	0.443	0.342	0.542	0.130	0.146	0.130	0.163
σ^n	0.276	B(0.22,0.32)	0.255	0.255	0.208	0.302	1.000	0.257	0.258	0.210	0.306	0.271	0.274	0.231	0.318
α	0.333	B(0.2,0.4)	0.292	0.290	0.248	0.332	1.006	0.331	0.319	0.211	0.424	0.184	0.185	0.144	0.226
κ_I	5	N(3,8)	3.452	3.662	2.449	4.858	1.015	1.897	2.104	1.164	3.112	2.261	2.295	2.123	2.536
ϖ	0.65	B(0.55,0.75)	0.513	0.499	0.423	0.576	1.002	0.512	0.490	0.415	0.565	0.506	0.499	0.441	0.557
η	6	N(4,8)	6.257	6.315	4.459	8.177	1.004	6.096	6.086	4.061	8.169	5.523	5.438	4.945	5.878
ρ_a	0.85	B(0.75,0.95)	0.825	0.819	0.713	0.920	1.009	0.824	0.811	0.700	0.913	0.928	0.929	0.912	0.945
ρ_η	0.85	B(0.75,0.95)	0.808	0.829	0.748	0.923	1.005	0.805	0.855	0.760	0.959	0.930	0.932	0.917	0.947
ρ_x	0.5	B(0.25,0.75)	0.724	0.699	0.579	0.820	1.013	0.810	0.711	0.571	0.862	0.830	0.832	0.762	0.897
ρ_n	0.5	B(0.25,0.75)	0.917	0.921	0.896	0.946	1.001	0.916	0.923	0.899	0.952	0.844	0.825	0.787	0.867
ρ_p	0.5	B(0.25,0.75)	0.499	0.589	0.355	0.864	1.007	0.535	0.611	0.327	0.872	0.936	0.933	0.911	0.954
ρ_ϕ	0.5	B(0.25,0.75)	0.821	0.817	0.743	0.893	1.000	0.828	0.822	0.747	0.900				
$100\varsigma_\phi$	2	G(1,10)	1.531	1.585	1.314	1.845	1.000	1.561	1.615	1.338	1.878				
$100\varsigma_r$	0.1	IG(0.01,0.5)	0.434	0.443	0.376	0.509	1.001	0.429	0.438	0.368	0.506	0.429	0.441	0.373	0.506
$100\varsigma_{a,L}$	2	G(0.5,5)	0.757	0.753	0.500	1.006	1.005	0.764	0.752	0.512	0.995	0.637	0.648	0.564	0.731
$100\varsigma_{a,H}$	2	G(0.5,5)	1.640	1.806	0.755	2.758	1.064	0.971	1.327	0.671	1.991	0.898	1.002	0.683	1.350
$100\varsigma_{b,L}$	2	G(0.5,5)	0.149	0.164	0.087	0.240	1.001	0.133	0.164	0.079	0.246	0.100	0.115	0.039	0.200
$100\varsigma_{b,H}$	2	G(0.5,5)	1.678	1.991	1.197	2.792	1.023	3.308	3.675	2.406	4.908	3.235	3.281	2.632	4.001
$100\varsigma_{\eta,L}$	2	G(0.5,5)	0.219	0.239	0.071	0.390	1.001	0.195	0.209	0.043	0.364	0.303	0.305	0.225	0.383
$100\varsigma_{\eta,H}$	2	G(0.5,5)	0.818	1.137	0.321	1.912	1.026	0.795	1.075	0.293	1.814	0.719	3.281	0.434	1.090
$100\varsigma_{x,L}$	2	G(0.5,5)	1.293	1.428	0.939	1.912	1.002	0.742	0.936	0.572	1.317	0.790	0.807	0.671	0.939
$100\varsigma_{x,H}$	2	G(0.5,5)	7.447	8.001	5.638	10.31	1.007	1.348	1.868	0.919	2.819	1.359	1.264	0.881	1.550
$100\varsigma_{n,L}$	2	G(0.5,5)	0.114	0.132	0.036	0.222	1.002	0.131	0.155	0.042	0.258	0.197	0.203	0.151	0.262
$100\varsigma_{n,H}$	2	G(0.5,5)	4.812	5.135	3.402	6.810	1.002	4.639	4.868	3.148	6.648	3.435	3.397	2.757	4.103
$100\varsigma_{p,L}$	2	G(0.5,5)	0.266	0.283	0.081	0.468	1.004	0.271	0.273	0.063	0.467	0.110	0.121	0.097	0.146
$100\varsigma_{p,H}$	2	G(0.5,5)	1.524	2.257	0.691	3.765	1.008	1.087	1.772	0.259	3.372	0.727	0.799	0.575	1.000
$prob^{L,H}$	0.05	B(0.02,0.08)	3.73%	4.37%	1.85%	6.83%	1.000	3.42%	3.95%	1.57%	6.25%	3.04%	3.69%	1.43%	5.86%
$prob^{H,L}$	0.10	B(0.05,0.15)	9.48%	10.6%	5.44%	15.6%	1.000	8.77%	9.78%	4.91%	14.5%	8.73%	9.19%	4.99%	13.3%
$\mathcal{O}_{s,b}$	27	N(22,32)	26.78	26.82	21.86	31.78	1.002								
$\mathcal{O}_{b,s}$	27	N(22,32)	27.45	27.61	22.72	32.44	1.001								
$100\varepsilon^{\nu}_{t,data}$	2	G(0.5,5)	5.113	5.221	4.414	6.016	1.001	5.992	6.099	5.173	7.011	5.986	6.229	5.384	7.040
$100\varepsilon^{c}_{t,data}$	2	G(0.5,5)	1.265	1.329	1.082	1.573	1.000	1.559	1.619	1.323	1.915	1.621	1.622	1.450	1.769
$100\varepsilon^{y}_{t,data}$	2	G(0.5,5)	0.637	0.673	0.519	0.823	1.001	0.635	0.674	0.482	0.862	0.675	0.651	0.582	0.723
$100(\bar{\nu}^4-1)$	3.5	G(1.5,5.5)	3.183	3.557	1.606	5.431	1.004	3.052	3.540	1.566	5.521	3.033	2.886	2.049	3.764
Log MDD (Laplace)			1392.75					1326.25				1317.29			

Notes: Abbreviations for prior distributions include B (Beta), N (Normal), G (Gamma), and IG (Inverse Gamma). Values in parentheses indicate the lower and upper bounds of the 90% confidence interval for the quantile prior. The log marginal data density is computed using the Laplace approximation. Given that $\kappa_p = (\eta-1)\varpi/(1-\varpi)/(1-\beta\varpi)$ under first order approximation, we estimate the Calvo parameter ϖ as a proxy.

(`bee_gate`) is run multiple times. The mode with the highest posterior density is subsequently refined using a local optimization algorithm (`fmincon`), and the resulting estimate is used for posterior simulation. Posterior statistics are obtained using a random-walk Metropolis-Hastings algorithm. We run four parallel Markov chains and discard the first 10% of draws as burn-in. The remaining samples are thinned by retaining one out of every five draws, resulting in 500,000 effective posterior draws used for posterior inference and simulation. The scale parameters are tuned to achieve acceptance rates of approximately 0.3. We assess convergence using several diagnostics, including trace plots, recursive mean plots, and the potential scale reduction factor (PSRF, Gelman–Rubin) statistic. The PSRF values for the benchmark model are reported in the Table A.3.

Figure A.2 plots the model-implied structural shocks together with a two-standard-deviation band. The trajectories fluctuate predominantly within this band, indicating that the regime-

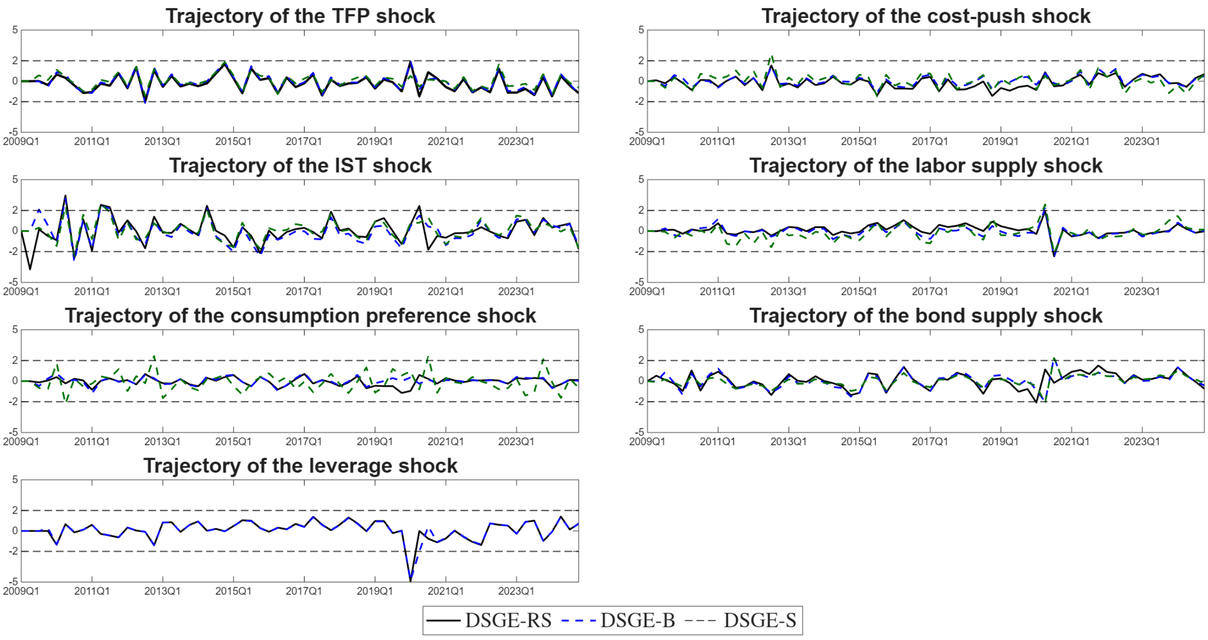

Figure A.2: Estimated model implied shocks. The figure plots the smoothed trajectories of model-implied shocks from the benchmark model (DSGE-RS; black solid line) and two alternatives (DSGE-B; blue dashed line; DSGE-S; green dashed line), together with a two-standard-deviation band (black dashed lines).

switching structure of heteroscedasticity provides a well-behaved representation of large fluctuations in the data during the pandemic period without systematically relying on excessive volatility. Figure A3 supplements the Figure 2 in the main text by reporting the 68% credible intervals around the smoothed regime probabilities of the benchmark specification.

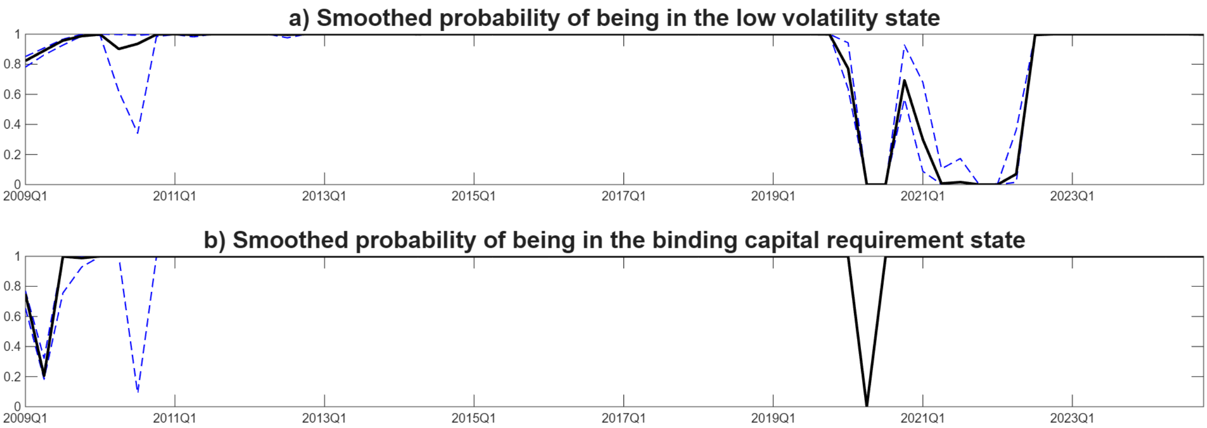

Figure A.3: The black line in the top panel shows the probability of being in the low-volatility regime evaluated at the posterior mode. In the bottom panel, the black line reports the smoothed probability of being in the binding capital requirement regime at the posterior mode, while the blue dashed lines indicate the 68% probability band constructed from retained parameter draws.

Table A.4 reports ergodic horizon-conditional variance decompositions for the benchmark specification (DSGE-RS) and for the counterfactual specification in which the constraint is always slack. In the benchmark economy, real shocks particularly TFP and labor supply disturbances account for the bulk of real fluctuations, while nominal private-sector liability (PSL) shocks contribute only modestly to output and consumption volatility.

Table A.4: Horizon-Conditional Variance Decomposition (Ergodic Averaging)

	DSGE-RS						DSGE-S					
Shock	h=1	4	8	12	20	∞	h=1	4	8	12	20	∞
Panel A. Output growth												
TFP	37.13	28.71	29.59	29.96	29.97	29.85	30.51	30.17	29.99	30.03	30.25	30.43
PSL	4.69	3.40	3.35	3.28	3.22	3.20	18.41	18.99	18.73	18.41	18.03	17.85
Cost-push	9.00	6.77	7.01	7.09	7.07	7.04	22.49	22.54	22.33	22.34	22.58	22.79
IST	15.76	32.45	31.88	31.61	31.38	31.24	1.72	2.42	2.42	2.51	2.61	2.61
Labor supply	29.05	25.53	25.08	25.04	25.42	25.72	22.17	21.34	22.02	22.26	22.18	21.98
Panel B. Inflation												
TFP	42.74	40.88	41.67	41.47	41.38	41.29	23.47	22.30	22.37	22.41	22.44	22.54
PSL	17.49	19.32	18.48	18.27	18.22	18.17	44.25	47.49	46.70	46.49	46.41	46.24
Cost-push	8.61	8.25	8.42	8.36	8.34	8.32	13.33	12.56	12.57	12.55	12.54	12.63
IST	0.06	1.45	1.72	2.32	2.52	2.60	0.03	0.13	0.18	0.29	0.34	0.36
Labor supply	30.99	29.99	29.63	29.47	29.43	29.51	18.62	17.20	17.86	17.94	17.93	17.89
Panel C. Consumption growth												
TFP	42.40	41.03	41.99	41.64	41.50	41.34	27.85	27.58	27.52	27.54	27.56	27.67
PSL	7.92	8.30	7.85	7.71	7.68	7.64	25.40	28.28	27.66	27.48	27.40	27.25
Cost-push	9.41	8.93	9.16	9.06	9.02	8.99	15.76	15.46	15.38	15.33	15.30	15.41
Preference	9.01	8.90	8.45	8.31	8.27	8.23	9.40	8.04	7.92	7.91	7.92	7.90
Labor supply	30.56	31.22	30.41	30.08	30.00	30.11	21.56	20.48	21.29	21.37	21.35	21.27

Notes: Entries report ergodic variance decomposition shares (in percent), computed by averaging across regimes according to the ergodic distribution. Horizons are $h = \{1, 4, 8, 12, 20, \infty\}$ quarters. Decompositions are computed for model-implied real output growth, inflation, and real consumption growth. Shares sum to 100 percent across all structural shocks.

B Appendix to equilibrium determinacy under a fiscal rule

To assess the robustness of the equilibrium determinacy results under a binding capital requirement, we refer to the equality of public sector liabilities $S_t = M_t + B_t$ and the total government bonds $B_t^T = B_t^C + B_t$. Accordingly, we can alternatively model the supply of S_t via an explicit specification of fiscal policy. For this, we follow large parts of the literature and apply a simple fiscal rule, which relates surpluses to the outstanding debt. Precisely, we follow Leeper (1991) and Bohn (1998) and assume that deviations of tax revenues from the steady state value respond positive to the deviations of total debt from the steady state value

$$(sr_t - sr) = \kappa_B (b_{t-1}^T - b^T), \tag{B.66}$$

where the real surplus satisfies $sr_t = \tau_t + div_t^{CB}$. Log-linearizing the government budget constraint $b_t^T + sr_t = R_{t-1} b_{t-1}^T \pi_t^{-1}$ at the steady state, $\widehat{b}_t^T = \frac{R}{\pi}\widehat{R}_{t-1} - \frac{R}{\pi}\widehat{\pi}_t + \frac{R}{\pi}\widehat{b}_{t-1}^T - \frac{sr}{b^T}\widehat{sr}_t$, and substituting out $\widehat{sr}_t$ with the log-linearized fiscal rule (B.66), $\frac{sr}{b}\widehat{sr}_t = \kappa_B \widehat{b}_{t-1}^T$, yields

$$\widehat{s}_t = \frac{R}{\pi}\left(\widehat{R}_{t-1} - \widehat{\pi}_t\right) + \left(\frac{R}{\pi} - \kappa_B\right)\widehat{s}_{t-1}, \tag{B.67}$$

where we further used the identity $b_t^T = s_t$. To avoid further complexities, we focus on the main case of interest, i.e. monetary policy at the ZLB, and restrict the analysis on the case of a pegged interest rate (like Diba and Loisel, 2022), such that $\widehat{R}_t^M = 0$ holds. A REE of the log-linearized version of the model under a slack reserve requirement and a binding capital requirement is then a set of sequences $\{\widehat{\pi}_t,\ \widehat{s}_t,\ \widehat{\lambda}_t\}_{t=0}^{\infty}$ that converge to the steady state and satisfy $\widehat{R}_t = 0$, (29), (30), and (B.67).

It can be shown that equilibrium determinacy prevails under a binding capital requirement and a constant policy rate, if fiscal policy is "active" or or "non-Ricardian", i.e. if the debt feedback κ_B is smaller than the net real rate $R\pi^{-1} - 1$, which is empirically supported for post-2008 data by Bianchi and Melosi (2017, 2022), Gomez-Cram et al. (2024), or Barro and Bianchi (2025). Notably, the parameter restriction $(\digamma_\lambda - 1)(1-\beta)\Xi^{-1} = 1.7 \times 10^{-3} < 1$ used in the following proposition, is clearly satisfied according to our estimates using post-2008 data.

Proposition 4. *Suppose that Assumption 1 holds. A REE under a slack reserve requirement, a binding capital requirement and an interest rate peg is uniquely determined if*

1. *fiscal policy satisfies*

$$\kappa_B < R\pi^{-1} - 1 \tag{B.68}$$

   for $(\digamma_\lambda - 1)(1-\beta)\Xi^{-1} < 1$, *or*

2. *fiscal policy satisfies*

$$\kappa_B \in \left(R\pi^{-1} - 1 - \frac{r\left(\digamma_x + \sigma_n\left(\digamma_\lambda - 1\right)\right)}{\left(\digamma_\lambda - 1\right)(1-\beta)\Xi^{-1} - 1},\ R\pi^{-1} - 1 \right) \tag{B.69}$$

   for $(\digamma_\lambda - 1)(1-\beta)\Xi^{-1} > 1$.

Proof of Proposition 2. Since there is one predetermined state variable $\{\widehat{s}_t\}$ and two non-predetermined variables $\{\widehat{\lambda}, \widehat{\pi}_t\}$, the REE is stable and locally determined if and only if there are two unstable and one stable eigenvalue. Using $\widehat{R}_{t-1} = 0$, the system (29), (30), and (B.67) can – under certainty – be written as

$$\begin{pmatrix} \beta & 0 & \Pi_x \\ 0 & 0 & 1 \\ -1 & 1 & -\digamma_x \end{pmatrix} \begin{pmatrix} \widehat{\pi}_{t+1} \\ \widehat{\lambda}_{t+1} \\ \widehat{x}_t \end{pmatrix} = \begin{pmatrix} 1 & \Xi & 0 \\ -\frac{R}{\pi} & 0 & \Omega \\ 0 & \digamma_\lambda & 0 \end{pmatrix} \begin{pmatrix} \widehat{\pi}_t \\ \widehat{\lambda}_t \\ \widehat{x}_{t-1} \end{pmatrix},$$

where $\Omega = R\pi^{-1} - \kappa_B$. The characteristic polynomial of the matrix $\mathbb{A}$

$$\mathbb{A} = \begin{pmatrix} \beta & 0 & \Pi_x \\ 0 & 0 & 1 \\ -1 & 1 & -\digamma_x \end{pmatrix}^{-1} \begin{pmatrix} 1 & \Xi & 0 \\ -\frac{R}{\pi} & 0 & \Omega \\ 0 & \digamma_\lambda & 0 \end{pmatrix}$$

is given by

$$H(X) = X^3 + \frac{-\Xi - \frac{R}{\pi}\Pi_x - \Omega\beta - \beta\digamma_\lambda - 1}{\beta} X^2 + \frac{\Omega + \digamma_\lambda + \Omega\Xi + \frac{R}{\pi}\Xi\digamma_x + \frac{R}{\pi}\Pi_x\digamma_\lambda + \Omega\beta\digamma_\lambda}{\beta} X - \Omega\frac{\digamma_\lambda}{\beta},$$

where

$$H(0) = -\frac{\Omega}{\beta}\digamma_\lambda, \;\; H(1) = \frac{(\digamma_\lambda - 1)(1-\beta)(1-\Omega) + \left(\frac{R}{\pi}\Xi\digamma_x - \Xi(1-\Omega) + \frac{R}{\pi}\Pi_x(\digamma_\lambda - 1)\right)}{\beta},$$

$$H(-1) = \frac{-(\digamma_\lambda + 1)(\beta+1)(\Omega+1) - \left(\Xi(\Omega+1) + \frac{R}{\pi}\Xi\digamma_x + \frac{R}{\pi}\Pi_x(\digamma_\lambda + 1)\right)}{\beta}.$$

Suppose that fiscal policy satisfies $\kappa_B < R\pi^{-1} - 1$, which is known as active fiscal policy (see Leeper, 1991). Then, $\Omega > 1$, such that $H(0) < -1$, since $\beta < 1$ and $\digamma_\lambda > 1$, and $H(-1) < 0$. Further, $H(1) > 0$ if

$$R\pi^{-1}(\digamma_x + \sigma_n(\digamma_\lambda - 1)) > \left((\digamma_\lambda - 1)(1-\beta)\Xi^{-1} - 1\right)\left(R\pi^{-1} - 1 - \kappa_B\right), \tag{B.70}$$

where we used $\Pi_x = \Xi\sigma_n$ and $\Omega = R\pi^{-1} - \kappa_B$. To assess the inequality (B.70), we consider two cases: For $(\digamma_\lambda - 1)(1-\beta)\Xi^{-1} < 1$, the RHS of (B.70) is strictly negative under $\kappa_B < R\pi^{-1} - 1$, such that (B.70) is unconditionally satisfied. For $(\digamma_\lambda - 1)(1-\beta)\Xi^{-1} > 1$, (B.70) is satisfied if

$$\kappa_B > (R\pi^{-1} - 1) - \frac{R\pi^{-1}(\digamma_x + \sigma_n(\digamma_\lambda - 1))}{(\digamma_\lambda - 1)(1-\beta)\Xi^{-1} - 1}. \tag{B.71}$$

Hence, for $\kappa_B < R\pi^{-1} - 1$, there exists at least one unstable eigenvalue, since $H(0) < -1$. Further, $H(1) > 0$ implies that there is at least one stable (and positive) eigenvalue lying between zero and one. For $H(-1) < 0$, the third eigenvalue is unstable. Hence, the system is locally stable and uniquely determined if either $(\digamma_\lambda - 1)(1-\beta)\Xi^{-1} < 1$ or (B.71) is satisfied. ∎