Bank of England

Monetary policy, state-dependent bank capital requirements and the role of non-bank financial intermediaries

Staff Working Paper No. 1,156

November 2025

Manuel Gloria and Chiara Punzo

Staff Working Papers describe research in progress by the author(s) and are published to elicit comments and to further debate. Any views expressed are solely those of the author(s) and so cannot be taken to represent those of the Bank of England or any of its committees, or to state Bank of England policy.

Bank of England

Staff Working Paper No. 1,156

Monetary policy, state-dependent bank capital requirements and the role of non-bank financial intermediaries

Manuel Gloria[(1)] and Chiara Punzo[(2)]

Abstract

We develop a DSGE model that incorporates state-dependent commercial bank capital requirements as a source of non-linearity. The presence of non-bank financial institutions (NBFI) amplifies the contractionary effects of monetary policy, primarily through the asset price channel. The amplification effect is strongest in the left tail of the GDP distribution and remains pronounced under zero lower bound conditions. The short-run vulnerabilities exposed by NBFIs contrast with their long-run benefits: a greater share of NBFI lending is associated with higher welfare.

Key words: Non-bank financial institutions, financial frictions, bank capital, macroprudential policy, monetary policy, GDP-at-risk.

JEL classification: E32, E58, G23.

---

(1) Bank of England. Email: manuel.gloria@bankofengland.co.uk
(2) Bank of England. Email: chiara.punzo@bankofengland.co.uk

The views expressed in this paper are those of the authors, and not necessarily those of the Bank of England or its committees. For helpful discussions and comments, we would like to thank Nicolo Bandera, Kristina Bluwstein, Ambrogio Cesa-Bianchi, Andrea Ferrero, Massimo Giovannini, Richard Harrison, Simon Lloyd, Lorenza Rossi, Mauricio Salgado Moreno, Sophie Stone and Matthew Waldron, and seminar and conference participants at the Bank of England, Basel Committee on Banking Supervision – Bank for International Settlements Research Workshop, Central Bank of Ireland-University College Dublin Workshop on Macro-Finance and financial stability policies, 17th Annual Dynare Conference.

The Bank's working paper series can be found at www.bankofengland.co.uk/working-paper/staff-working-papers

Bank of England, Threadneedle Street, London, EC2R 8AH
Email: enquiries@bankofengland.co.uk

©2025 Bank of England
ISSN 1749-9135 (on-line)

1 Introduction

Recent years have witnessed a rapid ascent in the scholarly and policy relevance of commercial bank capital requirements as a core instrument of macroprudential policy. While traditional dynamic stochastic general equilibrium (DSGE) models have typically encoded these requirements within linear frameworks - assuming either always-binding constraints (as in Iacoviello (2015)) or symmetric penalties for deviations from target capital ratios (as in Gerali et al. (2010)) - recent developments in the linear literature have underscored the inherently non-linear nature of bank behaviour under regulatory pressure. Models employing global solutions techniques have highlighted the role of occasionally binding constraints and the asymmetric effects they induce on financial dynamics (see Corbae and D'Erasmo (2021), Van der Ghote (2021), Elenev et al. (2021), Lang and Menno (2025), Schroth (2021), among others)[1].

This paper contributes to the ongoing dialogue by constructing a structural microfounded DSGE model that incorporates state-dependent commercial bank capital requirements as a source of non-linearity. Drawing inspiration from Gerali et al. (2010), we retain the conceptualisation of capital requirements as adjustment costs but crucially depart from the symmetric specification: in our model, the quadratic cost is activated only when a bank's capital ratio falls below a regulatory threshold, and is otherwise dormant[2]. This design allows loan-deposit spreads to become sensitive to capital shortfalls but not to surpluses - an asymmetry well-supported by empirical evidence, such as Bichsel et al. (2022), which finds that the effect of surplus capital on lending spreads is an order of magnitude smaller than that of a deficit.

Our financial sector comprises two distinct types of intermediaries: regulated commercial banks and non-bank financial institutions (NBFIs), commonly referred to as *shadow banks*. Commercial banks operate under capital requirements and benefit from government guarantees, such as deposit insurance schemes, which help mitigate risk and ensure stability. In contrast, NBFIs are exempt from such regulatory oversight and instead rely on market discipline to maintain credibility and attract funding. This market discipline implies that NBFIs must operate in accordance with an incentive compatibility constraint, ensuring that their actions align with the expectations and confidence of savers and investors, as in the framework of Gertler and Karadi (2011).The competitive landscape is further differentiated by the banks' market power in setting interest rates, in contrast to the perfect

[1]A notable departure within the New-Keynesian literature is found in Karmakar (2016), which introduces asymmetric bank capital requirements through a non-linear penalty function.

[2]It is reasonable to anticipate that when banks maintain capital levels above regulatory requirements, they may seek to offset the associated costs by increasing lending spreads charged to borrowers. However, we contend that this effect is likely to be asymmetric. While a bank facing a capital shortfall must promptly address regulatory constraints, a bank with excess capital is under no such immediate pressure to act.

competition assumed for NBFIs[3]. Entrepreneurs in our model access funding from both sectors, subject to externally imposed loan-to-value ratios, and - departing from Gebauer and Mazelis (2023), following Gertler and Karadi (2011) - we model NBFI lending as long-term bonds in the spirit of Sims and Wu (2021), rather than as claims priced identically to capital[4].

We deploy this framework to analyse both short- and long-run responses of the economy to monetary policy shocks. First, we isolate the contribution of asymmetric capital requirements and that of NBFIs to the transmission channel of a policy rate increase. Second, following Aikman et al. (2021), we measure tail risk by simulating the models multiple times, averaging across simulations, and plotting the output distribution over time, comparing our baseline model with a version without shadow banks. Considering that stress scenarios, captured by the tail risk approach, have often coincided in recent decades with policy rates close to zero, we repeat the analysis to account for a zero lower bound on the policy rate. Finally, we complement these analyses with a welfare evaluation of NBFI activity over the long term.

Our findings reveal that the presence of NBFIs amplifies the contractionary effects of monetary policy, primarily through the asset price channel: tighter policy reduces the market value of bonds held by NBFIs, diminishing their net worth and lending capacity. This effect outweighs the lending competition channel highlighted by Gebauer and Mazelis (2023), as declining bond prices impose leverage constraints that prevent NBFIs from offsetting reductions in bank credit. Notably, the amplification effect is strongest in the left tail of the GDP distribution, and remains pronounced under zero lower bound conditions. These results suggest that NBFIs may pose systemic risks by magnifying adverse shocks, especially in periods of financial distress - emphasising the need for monetary authorities to monitor feedback loops between monetary policy and financial stability.

The short-run vulnerabilities exposed by NBFIs contrast with their long-run benefits: a greater share of NBFI lending is associated with higher welfare, as lower regulatory burdens free resources from adjustment costs. This trade-off resonates with the findings of Adrian et al. (2020), but our model locates its origin in the structural composition of the financial system rather than endogenous risk-taking. In summary, our analysis delineates the nuanced interplay between financial regulation, monetary policy, and the evolving role of NBFIs - highlighting a fundamental tension between short-term stability and long-term efficiency in modern financial systems.

[3]Viewed from a macroeconomic lens, the NBFI sector comprises a rich array of highly specialized and diverse institutions whose activities often mirror those of traditional banks. This sector encompasses entities such as money market funds, hedge funds, private credit funds, investment funds, and direct lending funds, among others.

[4]By distinguishing the behaviour of bond prices from that of capital and investment, we gain a clearer analytical framework to examine how monetary policy, and financial shocks propagate through bond markets. This separation proves particularly beneficial for isolating the mechanisms at play. Consequently, our model emphasises that NBFI leverage responds chiefly to movements in bond prices rather than fluctuations in capital values.

To structure our analysis, we begin with a review of the relevant literature on shadow banking in macro-finance models before presenting the complete DSGE framework in Section 3. Section 4 outlines our calibration methodology. In Section 5, we examine the effects of monetary policy shocks, detailing the model's predictions in both qualitative and quantitative dimensions. Through simulation exercises, we explore how asymmetric capital requirements and the presence of NBFIs alter the transmission mechanisms of monetary policy. Further, we investigate the influence of NBFIs on the distribution of expected GDP, with particular attention to their quantitative impact on the centre and left tail of the distribution. Finally, we assess welfare outcomes in a counterfactual setting where these asymmetries are absent. The paper concludes with Section 6.

2 Review of Literature on Shadow Banking in Macro-Finance Models

The landscape of dynamic macro-financial modelling has seen significant advances in its treatment of shadow banking, with diverse approaches reflecting the evolving complexity of financial intermediation outside the regulatory perimeter. Among the most closely related contributions to our work is Gebauer and Mazelis (2023), who conceptualize shadow banks as Non-Bank Financial Institutions (NBFIs) largely distinct from traditional banks, characterized by high specialization and micro-level heterogeneity. From a macroeconomic perspective, these institutions replicate many activities of regulated banks yet evade macroprudential oversight precisely due to their heterogeneity. Their framework yields empirical-consistent credit dynamics for commercial and shadow banks in response to tighter monetary policy amd demonstrates that shifts in macroprudential policy can induce credit leakage towards unregulated intermediaries. Notably, it cautions that neglecting changes in credit compositions may undermine policy efficacy. Counterfactually, their analysis for the euro area suggests that a regulator focused solely on commercial bank credit may better stabilize real economic activity than one accounting for both commercial and shadow bank credit.

Other notable DSGE approaches model shadow banks as issuers of Asset Backed Securities (ABS). Works such as Meeks et al. (2017) and Fève et al. (2019) depart from the standard Real Business Cycle (RBC) architecture, introducing a financial sector comprising traditional and shadow banks. Both categories intermediate credit between saving households and borrowing firms, but only traditional banks - funded by deposits - comply with capital regulation. A central friction in these models is the inability of banks to fully pledge balance-sheet assets as collateral, constraining the funding available from external creditors. ABS issuance offers a circumvention: shadow banks raise funds in wholesale markets by securitizing loans, operating largely outside regulatory scrutiny. The relative fungibility and tradability of ABS, which are subject to lighter regulatory requirements than conventional loans, incentivizes traditional banks to substitute loans with ABS and thereby increase leverage.

In Meeks et al. (2017), shadow banking is shown to enhance credit intermediation efficiency by easing financial frictions related to limited asset pledgeability. The model assumes that traditional banks can more readily *divert* loan assets for private gain, while shadow banks do so less frequently - a nuance that shapes their intermediary roles. Fève et al. (2019) highlight regulatory asymmetries: shadow banks, unburdened by capital constraints, can intermediate more efficiently than regulated counterparts. Their empirical work demonstrates that regulatory tightening for traditional banks prompts intermediation to migrate to the shadow sector, weakening the regulator's stabilizing influence. Consistent with Buchak et al. (2018), data shows that shadow banks penetrate markets where bank regulation is most stringent. Focusing on historical counterfactuals, Fève et al. (2019) reveal that a countercyclical capital buffer applied solely to traditional loans would have exacerbated the boom-bust cycle of the 2007-2008 financial crisis in the US, while broader regulation encompassing both types of credit would have yielded better macroeconomic outcomes.

Some studies take alternative modelling stance. For instance, Verona et al. (2013) forego securitization and direct interaction between intermediaries, instead positing two entrepreneur classes served by commercial and investment banks. Safer firms access bond financing, while riskier ones rely on bank loans. Their model predicts pronounced boom-bust cycles following prolonged monetary policy accomodation. Bandera and Stevens (2024) explores the monetary implications of the Bank of England's asset purchases during the October 2022 gilt market crisis, focusing on the interplay between Liability Driven Investment (LDI) funds and pension funds. Their findings underscore that central banks can address financial stability concerns without easing the overall policy stance. Importantly, these models eschew competitive or substitution dynamics between intermediary types, setting them apart from our framework.

The aforementioned DSGE literature forms part of a broader inquiry into the welfare and financial stability implications of shadow banking. Ordoñez (2018) explores the potential welfare gains from securitization that sidesteps inefficient regulation, presenting a model wherein shadow banking may outperform regulated banking if reputational mechanisms effectively discipline risk-taking. This reasonates with Plantin (2014), who contends that the presence of a shadow sector can be desirable when regulation constrains banking efficiency, though via different mechanisms. Most research, however, spotlights the financial stability risks introduced by shadow banks. Gorton and Metrick (2010) emphasize the role of maturity transformation and vulnerability to creditor runs in precipitating crises, as shadow banking channels rely on highly rated, long-term securitized bonds as collateral for short-term, money-like claims. The proliferation of such claims, driven by institutional demand, accentuates systemic risk. Gennaioli et al. (2013) further show that diversification, while mitigating intermediary-specific risks, amplifies exposures to aggregate tail risks by pooling loans to support *riskless* debt issuance. Under rational expectations, this expansion is Pareto-improving and stable (Ross (1976)); yet excessive balance-sheet expansion renders the system vulnerable to systemic shocks.

The following section details the unique features of our model and articulates its departures from Gebauer and Mazelis (2023), situating our contribution within this dynamic literature.

3 The Model

As previously noted, our baseline framework follows the model set out by Gebauer and Mazelis (2023). Though this model is linear, it draws a clear distinction between two segments of the financial sector: a regulated, monopolistically competitive commercial banking sector (in the tradition of Gerali et al. (2010)), and a shadow banking system operating in a perfectly competitive market for investment funding (as described by Sims and Wu (2021)). Our approach departs from their framework in two significant ways, detailed below: we introduce state-dependent capital requirements, and we modify the financial instrument through which entrepreneurs obtain NBFI funding.

In our model, the financial sector comprises commercial banks and shadow banks. Both types of intermediaries collect households savings and lend to entrepreneurs, but their structures differ markedly. Firstly, commercial banks face regulatory capital requirements, whereas shadow banks are not obliged to hold a minimum share of equity against their assets. As a result, commercial banks benefit from government backstop like deposit insurance, which shadow banks lack. This distinction means that while commercial banks offer households a safe depository, shadow banks depend entirely on the confidence of savers. Although not regulated by macroprudential policy, shadow banks are still subject to discipline imposed by the market.

To capture shadow banks' reliance on market funding, we incorporate the Sims and Wu (2021) incentive compatibility constraint: shadow bankers can choose to divert a portion of the funds they manage, defaulting on the rest and ceasing their intermediation activities. If the value gained from such diversion exceeds the expected returns from continued operations, shadow bankers have an incentive to exit the market, leaving investors with losses. Households are aware of this risk and thus restrict the amount of funding they provide, ensuring the shadow banker remains motivated to continue rather than default. Consequently, saving with shadow banks involves greater risk for households, which results in a positive spread between the interest rates offered by shadow banks and those by commercial banks.

Secondly, commercial banks possess market power in setting both loan and deposit rates, and they adjust these rates only partially in response to policy shifts. In contrast, shadow banks are assumed to operate under perfect competition. On the lending side, entrepreneurs seeking funds from commercial banks must adhere to an externally imposed loan-to-value ratio, limiting the amount they can borrow to a portion of the collateral (physical capital) they own. A separate, externally set portion of their remaining collateral can be used for borrowing from shadow banks.

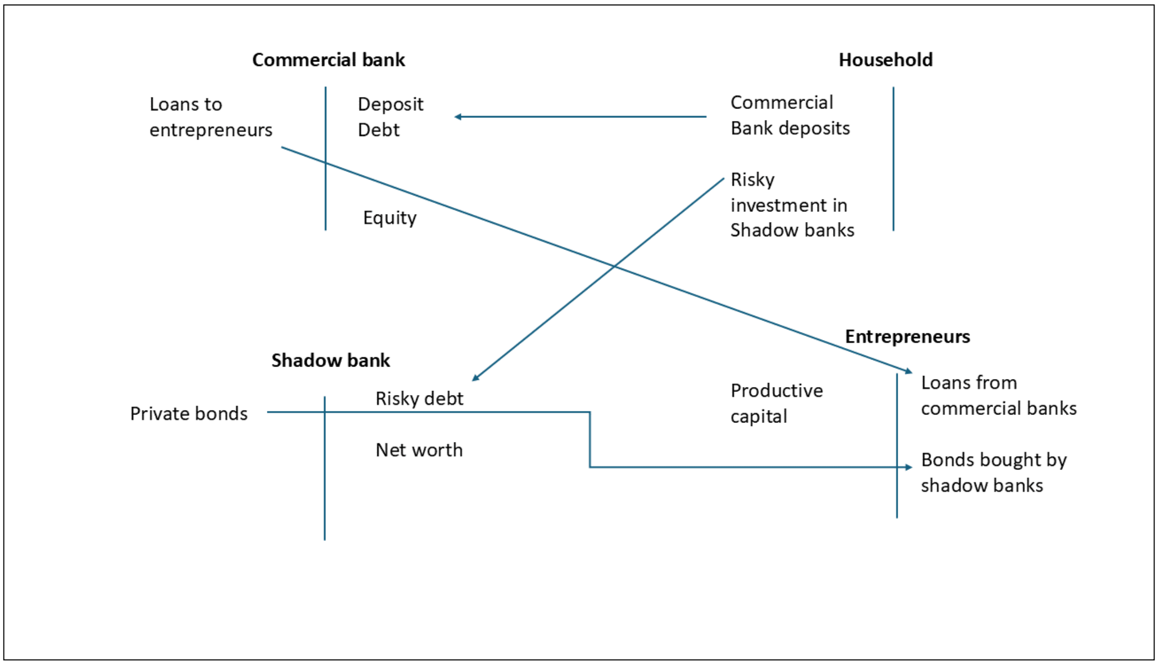
Thirdly, since there is no default in the commercial banking sector, commercial banks are modelled as infinitely lived institutions, whereas we allow for shadow banks to enter and exit the market.

Our approach diverges from Gebauer and Mazelis (2023) in two principal respects. First, we introduce a state-dependent mechanism in the form of an occasionally binding constraint: commercial bank spreads only rise when capital positions become strained. In the original setup (Gerali et al. (2010)), the regulatory capital requirement for the wholesale branch imposes a quadratic cost for moving away from the required capital ratio, influencing the spread between loan and deposit rates. Instead, our model assumes that spreads only become sensitive to capital positions once a bank's effective capital buffer is depleted and its capital ratio drops below a certain threshold. This *deleveraging point* lies above the regulatory minimum and reflects precautionary behaviour, consistent with models (e.g., Karmakar (2016); Van den Heuvel (2008)) in which banks maintain excess capital to reduce the expected costs of future inadequacy. In such frameworks, banks with ample capital behave similarly to unconstrained banks, with small capital fluctuations having limited impact on lending. Other models acknowledging nonlinear relationships between credit supply and bank capital include He and Krishnamurthy (2019) and Holden et al. (2020).

Second, we change how entrepreneurs access NBFI funding. While Gebauer and Mazelis (2023), following Gertler and Karadi (2011), assume that the price of financial claims intermediated by banks equals the price of capital, we follow Sims and Wu (2021) and model NBFI lending as long-term bonds. This approach allows us to separately analyse bond prices dynamics from those of capital and investment.

An overview of the relationships among the key agents is provided in Figure 1. Following Sims and Wu (2021), households supply labor to unions and choose between consumption and saving through financial intermediaries. The production side features four types of firms: a competitive final goods producer aggregates output for consumption and investment; a continuum of retail firms, acting as monopolistic competitors subject to price stickiness, repackage wholesale output for resale; a representative investment goods firm purchases output and transforms it into new capital, with a

Figure 1: Overview of model relationships between agents involved in financial intermediation



convex adjustment cost; finally, a representative wholesale firm produces output using its own capital and labour hired from unions.

3.1 Households

Households are assumed to behave identically, and the representative agent maximizes the following expected utility function:

$$\max_{c_t^P, h_t, d_t^{C,P}, d_t^{S,P}} E_0 \sum_{t=0}^{\infty} \beta_t^P \left[\ln(c_t^P - a^P c_{t-1}^P) - \frac{\chi h_t^{1+\eta}}{1+\eta} \right]$$

where c_t^P is consumption, h_t labour supplied, a^P regulates habit formation, η is the inverse of the Frisch labour elasticity and χ is a labour supply scaling parameter. Utility is maximized subject to the following budget constraint (in real terms):

$$c_t^P + d_t^{C,P} + d_t^{S,P} = mrs_t h_t + div_t - X + (1 + r_{t-1}^{C,D}) d_{t-1}^{C,P} \Pi_t^{-1} + (1 + r_{t-1}^{S,D}) d_{t-1}^{S,P} \Pi_t^{-1}$$

where the the flow of expenses includes current consumption, deposits to commercial banks $d_t^{C,P}$, risky investment in shadow banks $d_t^{S,P}$, and transfers paid to new shadow banks as startup net worth (X). Resources consist of wage earnings $mrs_t h_t$ (where mrs_t is the real remuneration a household receives from supplying labor to labor unions), gross interest income on last period deposits and dividends

div_t.[5] Π_t is the gross inflation rate.

The first order conditions for the household are:

$$\lambda_t^P = \frac{1}{c_t^P - \alpha^E c_{t-1}^P} - E_t \frac{\beta^P \alpha^P}{c_{t+1}^P - \alpha^P c_t^P} \tag{1}$$

$$\Lambda_{t-1,t}^P = \frac{\beta \lambda_t^P}{\lambda_{t-1}^P} \tag{2}$$

$$\chi h_t^\eta = \lambda_t^P mrs_t \tag{3}$$

$$1 = (1 + r_t^{C,D}) E_t \Lambda_{t,t+1} \Pi_{t+1}^{-1}. \tag{4}$$

Equation 1 defines the marginal utility of consumption, λ_t^P. The stochastic discount factor, $\Lambda_{t-1,t}^P$ is given by Equation 2. Equation 3 is a standard labor supply. The first order condition for deposits is Equation 4.

3.2 Labour Market

The labour market strictly follows Sims and Wu (2021), where a continuum of labour unions indexed by $h \in [0, 1]$ purchase labour from households at mrs_t and repackage it for sale to a representative labour packer. The labour packer combines differentiated labour $h_{h,d,t}$ into a final labour bundle available for production $h_{d,t}$ via a CES technology with elasticity of substitution $\epsilon_t^w > 1$. Labour unions set nominal wages charged to the labour packer, but in each period face a constant probability $1 - \phi_w$ of adjusting the previous period wage, with $\phi_w \in [0, 1]$. When setting wages, therefore, they must take into account the possibility of not being able to adjust their nominal wage for some time. It can be shown that, by maximizing the present discounted value of real profits, the labour union chooses the following reset wage:

$$w_t^{\#} = \frac{\epsilon_t^w}{\epsilon_t^w - 1} \frac{f_{1,t}}{f_{2,t}} \tag{5}$$

where:

$$f_{1,t} = mrs_t w_t^{\epsilon_t^w} h_{d,t} + \phi_w \Pi_t^{-\gamma_w \epsilon_t^w} E_t \Lambda_{t,t+1} \Pi_{t+1}^{\epsilon_t^w} f_{1,t+1} \tag{6}$$

and:

$$f_{2,t} = w_t^{\epsilon_t^w} h_{d,t} + \phi_w \Pi_t^{\gamma_w \left(1-\epsilon_t^w\right)} E_t \Lambda_{t,t+1} \Pi_{t+1}^{\epsilon_t^w - 1} f_{2,t+1} \tag{7}$$

and where γ_w regulates the possibility of indexing nominal wages to inflation. Integrating the

[5] From labour unions, banks, retailers and capital producers.

demand curve faced by the union we get:

$$h_t = h_{d,t} \upsilon_t^w \tag{8}$$

where the measure of wage dispersion υ_t^w can be written as:

$$\upsilon_t^w = (1-\phi_w)\left(\frac{w_t^{\#}}{w_t}\right)^{-\epsilon_t^w} + \phi_w \left(\Pi_{t-1}\right)^{-\gamma_w \epsilon_t^w} \left(\Pi_t\right)^{\epsilon_t^w} w_t^{\epsilon_t^w} w_{t-1}^{-\epsilon_t^w} \upsilon_{t-1}^w \tag{9}$$

The evolution of the aggregate real wage, finally, can be expressed as:

$$w^{1-\epsilon_t^w} = (1-\phi_w)\left(w_t^{\#}\right)^{1-\epsilon_t^w} + \phi_w \left(\Pi_{t-1}\right)^{\gamma_w (1-\epsilon_t^w)} \left(\Pi_t\right)^{\epsilon_t^w - 1} w_{t-1}^{1-\epsilon_t^w} \tag{10}$$

3.3 Entrepreneurs

Entrepreneurs use labour provided by households as well as capital to produce intermediate goods that retailers purchase in a competitive market. Similar to households, they behave identically and maximize the following utility function:

$$\max_{c_t^E, h_{d,t}, k_t, l_t^{C,E}, b_t^{S,E}} E_0 \sum_{t=0}^{\infty} \beta_t^E \left[\ln(c_t^E - a^E c_{t-1}^E)\right]$$

where c_t^E is consumption, and a^E regulates habits formation. They obtain funds by getting one-period loans supplied by commercial banks (as in Gerali et al. (2010)), l_t^{CE}, and by issuing long-term bonds purchased by shadow banks. As in Sims and Wu (2021), we assume that bonds are modelled as perpetuities with decreasing coupon payments, with κ denoting the decay parameter ($0 \leq \kappa \leq 1$). This setup allows to define new bond issuances and coupon payments at time t without keeping track of the entire sequence of past issues. New bond issuances at time t cf_t are equal to:

$$cf_t = b_t^{SE} - \kappa b_{t-1}^{SE}$$

where b_t^{SE} are coupon liabilities at time t. Furthermore, this setup implies the following inverse mathematical relationship between the bond price q_t^S and the interest rate $r_t^{S,E}$.

$$1 + r_t^{S,E} = \frac{1 + \kappa q_t^S}{q_{t-1}^S} \tag{11}$$

Utility is therefore maximized subject to the following budget constraint:[6]

$$c_t^E + w_t h_{d,t} + (1+r_{t-1}^{CE}) l_{t-1}^{CE} \Pi_t^{-1} + (1+r_t^{SE}) q_{t-1}^S b_{t-1}^{SE} \Pi_t^{-1} + q_t^K k_t = p_t^E y_t^E + l_t^{CE} + q_t^S b_t^{S,E} + q_t^K (1-\delta^k) k_{t-1} \tag{12}$$

where q_t^k and δ^k represent respectively the price and the depreciation rate of capital, and the relative price p_t^E can also be interpreted as the marginal cost for retailers. Output y_t^E is produced according to the standard Cobb-Douglas technology:

$$y_t^E = A_t (k_{t-1})^\alpha (h_{d,t})^{1-\alpha} \tag{13}$$

where α is the capital share and productivity A_t evolves exogenously. Entrepreneurs additionally face two key borrowing constraints that restrict the amount they can obtain from commercial banks and the volume of claims they can issue to shadow banks. Both limits hinge on the value of collateral held by the firm, that is directly tied to the entrepreneur's expected physical capital stock. For commercial bank loans, a regulatory loan-to-value (LTV) ratio, denoted m^C, governs the maximum borrowing amount. Since shadow banks typically charge higher interest rates than commercial banks, entrepreneurs prefer to exhaust their commercial bank borrowing capacity first before seeking additional financing from shadow banks.

Once the maximum allowable amount from commercial banks has been reached, entrepreneurs can secure further funds from shadow banks by leveraging any remaining capital not pledged as collateral to commercial banks. The proportion of this capital available for shadow bank borrowing is represented by m^S. As a result, the two borrowing constraints can be expressed as follows:

$$(1+r_t^{CE}) l_t^{CE} \leq m^C E_t[q_{t+1}(1-\delta^k) k_t \Pi_{t+1}] \tag{14}$$

$$(1+r_{t+1}^{SE}) q_t^S b_t^{SE} \leq m^S E_t[q_{t+1}^K (1-\delta^k) k_t \Pi_{t+1}] \tag{15}$$

where the LTV ratio for commercial bank, m^C, and the bond-to-value (BTV) ratio for shadow bank m^S are calibrated according to the data. Drawing on the approach of Iacoviello (2005), we assume that the borrowing constraints bind around the steady state, effectively eliminating uncertainty from the model. Consequently, entrepreneurs in equilibrium face binding borrowing constraints, meaning that both Equations 14 and 15 hold with equality.

Entrepreneurs maximize utility subject to 12, 13, 14, and 15. The resulting first order conditions

[6] The derivation of the budget constraint with long-term bonds with decaying coupon payments can be found in Appendix A.

are:

$$\lambda_t^E = \frac{1}{c_t^E - \alpha^E c_{t-1}^E} - \frac{\beta^E \alpha^E}{c_{t+1}^E - \alpha^E c_t^E} \tag{16}$$

$$w_t = (1-\alpha)\, p_t^E A_t (k_{t-1})^{\alpha} (l_{d,t})^{-\alpha} \tag{17}$$

$$\beta_t^E \lambda_{t+1}^E \left[\alpha p_{t+1}^E A_{t+1} (k_t)^{(\alpha-1)} (l_{d,t+1})^{1-\alpha} + (1-\delta^k) q_{t+1}\right] + \left[m^C \delta_t^C + m^S \delta_t^S\right] (1-\delta^k) q_{t+1} = q_t \lambda_t^E \tag{18}$$

$$\lambda_t^E = (\beta^E \lambda_{t+1}^E + \delta_t^C) \frac{(1 + r_t^{C,E})}{\Pi_{t+1}} \tag{19}$$

$$\lambda_t^E = (\beta^E \lambda_{t+1}^E + \delta_t^S) \frac{(1 + r_{t+1}^{S,E})}{\Pi_{t+1}} \tag{20}$$

where δ_t^C and δ_t^S are the Lagrange multipliers on the collateral constraints. Equation 16 defines marginal utility of consumption; equations 17, 18, 19 and 20 represent respectively the demand for labour, capital, commercial bank and shadow bank lending.

3.4 Retailer Firms

The retailer firms sector also strictly follows Sims and Wu (2021), where a continuum of firms indexed by $f \in [0, 1]$ purchase wholesale output from entrepreneurs at p_t^E and resell it to a representative competitive final goods firm. The retailers combines intermediate output $y_{f,t}^E$ into a retail good $y_{f,t}$ via a CES technology with elasticity of substitution $\epsilon_t^p > 1$. Retailers set prices charged to the final good firms, but in each period face a constant probability $1 - \phi_p$ of being able to adjust their price, with $\phi_p \in [0, 1]$. When setting prices, therefore, they must take into account the possibility of not being able to adjust their prices for some time. It can be shown that, by maximizing the present discounted value of real profits, the retailer chooses the following reset price:

$$\Pi_t^{\#} = \frac{\epsilon_t^p}{\epsilon_t^p - 1} \frac{x_{1,t}}{x_{2,t}} \tag{21}$$

where:

$$x_{1,t} = p_{,t}^E Y_t + \phi_p \Pi_t^{-\gamma_p \epsilon_t^p} E_t \Lambda_{t,t+1} \Pi_{t+1}^{\epsilon_t^p} x_{1,t+1} \tag{22}$$

and:

$$x_{2,t} = Y_t + \phi_p \Pi_t^{\gamma_p (1-\epsilon_t^p)} E_t \Lambda_{t,t+1} \Pi_{t+1}^{\epsilon_t^p - 1} x_{2,t+1} \tag{23}$$

and where γ_p regulates the indexation to lagged inflation. Integrating the demand curve faced by the retailers we get:

$$y_t^E = \upsilon_t^p Y_t \tag{24}$$

where the measure of price dispersion υ_t^p can be written as:

$$\upsilon_t^p = (1-\phi_p)\left(\Pi_t^{\#}\right)^{-\epsilon_t^p} + \phi_p\left(\Pi_{t-1}\right)^{-\gamma_p \epsilon_t^p}\left(\Pi_t\right)^{\epsilon_t^p}\upsilon_{t-1}^p \tag{25}$$

The evolution of the aggregate price index, finally, can be expressed as:

$$1 = (1-\phi_p)\left(\Pi_t^{\#}\right)^{1-\epsilon_t^p} + \phi_p\left(\Pi_{t-1}\right)^{\gamma_p\left(1-\epsilon_t^p\right)}\left(\Pi_t\right)^{\epsilon_t^p-1} \tag{26}$$

3.5 Capital Producers

A representative capital producer buys last period underpreciated capital from the entrepreneur at real price q_t^k and I_t units of final good at nominal price P_t to increase the stock of effective capital which is then sold back to entrepreneur. It therefore maximizes:

$$\max_{I_t, k_t} E_0 \sum_{t=0}^{\infty} \beta_t^P \left[q_t^k k_t - (1-\delta^k) q_t k_{t-1} - I_t\right]$$

subject to a capital evolution equation which includes quadratic investment adjustment costs:

$$k_t = (1-\delta^k)k_{t-1} + \left[1 - \frac{\kappa_i}{2}\left(\frac{I_t}{I_{t-1}}\right)^2\right] I_t \tag{27}$$

The resulting equilibrium condition for investment is:

$$1 = q_t^k\left[1 - \frac{\kappa_i}{2}\left(\frac{I_t}{I_{t-1}} - 1\right)^2 - \kappa_i\left(\frac{I_t}{I_{t-1}} - 1\right)\frac{I_t}{I_{t-1}}\right] + E_t \Lambda_{t,t+1} q_{t+1}^k \kappa_i \left(\frac{I_{t+1}}{I_t} - 1\right)\left(\frac{I_{t+1}}{I_t}\right)^2 \tag{28}$$

where in absence of adjustment costs the real price of capital would be equal to one.

3.6 Commercial Banks

In line with Gerali et al. (2010), we model commercial banks as a banking group made of three separate branches: a wholesale unit responsible of managing the aggregate capital position of the group, and two retail units responsible of setting retail interest rates while collecting deposits from households and extending loans to entrepreneurs. Unlike previous models, our approach to the wholesale unit's optimization problem allows for asymmetric capital adjustment costs, adding nuance to how banks manage their resources.

3.6.1 Wholesale Unit

Wholesale units operate under perfect competition and have to obey a balance-sheet identity of the form:

$$l_t^C = k_t^C + d_t^C \tag{29}$$

where l_t^C are the funds they provide to the retail branch (equal to entrepreneurs loans), d_t^C are wholesale deposit provided by the retail branch and k_t^C is the net worth. The bank chooses loans, deposits and net worth, which is accumulated out of retained earnings according to:

$$\Pi_t k_t^C = (1 - \sigma^C) k_{t-1}^C + j_{t-1}^C \tag{30}$$

where j_t^C are commercial bank profits (from all branches) and σ^C measures resources used in managing bank capital. The mechanism described by Gerali et al. (2010) is based on the idea that the wholesale branch incurs a penalty whenever its capital ratio deviates from a predetermined target, denoted as ν^c. This penalty directly influences the branch's marginal cost structure. Specifically, when the capital ratio drops below the target, the marginal cost of lending rises, which in turn creates a positive spread between the loan and deposit rates. Importantly, in the original formulation, this penalty is symmetric: the same cost applies whether the capital ratio is below or above the target.

We propose a modification to this approach. In our version, the marginal cost of lending only increases when the capital ratio falls short of the target; no penalty applies if the capital ratio exceeds the threshold. In essence, credit supply becomes sensitive to the bank's capital position only when its effective capital buffer is depleted and the capital ratio dips below the designated threshold $\bar{k}$.

The problem for the wholesale unit is to maximize the discounted sum of real cash flows:

$$\max_{l_t^C, d_t^C} E_0 \sum_{t=0}^{\infty} \Lambda_{0,t}^P \left[(1 + r_t^C) l_t^C - l_{t+1}^C \pi_{t+1} - (1 + r_t^D) d_t^C + d_{t+1}^C \pi_{t+1} + k_t^C - k_{t+1}^C \pi_{t+1} - adj_{w,t} \right] \tag{31}$$

subject to:

$$k_t^C = l_t^C - d_t^C$$

and to:

$$adj_{w,t} = \begin{cases} \frac{\kappa^C}{2} \left(\frac{k_t^C}{l_t^C} - \nu^C \right)^2 k_t^C & \text{if } \frac{k_t^C}{l_t^C} \leq \bar{k} \\ 0 & otherwise \end{cases}$$

where r_t^C and r_t^D are respectively the rate charged to the retail loan branch and the funding rate paid to the retail deposit branch, and κ^C regulates the size of the adjustment costs. We define $\bar{k}$ as the sum of the regulatory capital requirement ν^C and an additional buffer Δ, where Δ represents the threshold above the regulatory target at which banks begin to have an incentive to deleverage.[7] This formulation of adjustment costs ensures that banks do not pay capital requirement costs when their capital position is solid, and drives the asymmetry of our model. By using 29 to subsitute capital into the objective function, and by following Gerali et al. (2010) in assuming that the wholesale deposit rate r_t^D is equal to the policy rate r_t, we obtain that the equilibrium condition is state dependent, meaning that it varies according to the capital position of the bank. Specifically, if the capital position is solid, adjustment costs are switched-off, and we obtain:[8]

$$r_t^C = r_t$$

If the capital ratio is below target, the first-order condition links the spread between rates on wholesale loans and deposits to the capital position, that is,

$$r_t^C = r_t - \kappa^C \left(\frac{k_t^C}{l_t^C} - \nu^C \right) \left(\frac{k_t^C}{l_t^C} \right)^2 \tag{32}$$

3.6.2 Retail Units

The retail branches framework strictly follows Gerali et al. (2010), where loans and deposit contracts bought by entrepreneurs and households are a composite constant elasticity of substitution basket of slightly differentiated financial products with elasticity $\epsilon^{C,E}$ and $\epsilon^{C,D}$, respectively. This implies that the retail units of bank i face a demand curve for their products which depends on the overall volume of loans and deposits demanded and on the interest rates charged by the two branches relatively to the loan and deposit interest rate indexes. The retail loan unit of bank i obtains wholesale funds $l_{i,t}^C$ at the rate r_t^C, differentiate them at no cost and resell them to entrepreneurs applying a markup at rate $r_{i,t}^{C,E}$. The retail deposit branch collects deposit $d_{i,t}^{C,P}$ from households, applying a markdown and remunerating them at $r_{i,t}^{C,D}$, and passes the raised funds on to the wholesale unit at rate r_t. The two branches maximize their profits over $r_{i,t}^{C,E}$ and $r_{i,t}^{C,D}$ subject to the demand functions, to $l_{i,t}^C = l_{i,t}^{CE}$ and $d_{i,t}^{C,P} = d_{i,t}^C$, and to quadratic adjustment costs for changing interest rates over time. After imposing the symmetric equilibrium, it can be shown that the optimization problem results in the two following

[7] Since the model is solved with perturbation methods, the use of Δ here should be considered as a way to capture precautionary savings in reduced form (Karmakar (2016)).

[8] We can assume that the wholesale deposit rate is equal to the policy rate since banks have access to unlimited finance from a lending facility at the central bank.

equilibrium conditions:

$$\kappa^B(\pi_t^{C,E}-1)\pi_t^{C,E}=\kappa^B\beta\frac{\lambda_{t+1}^P}{\lambda_t^P}\frac{l_{t+1}^{C,E}}{l_t^{C,E}}(\pi_{t+1}^{C,E}-1)\pi_{t+1}^{C,E}+1-\epsilon^{C,E}+\epsilon^{C,E}\frac{r_t^C}{r_t^{C,E}} \tag{33}$$

$$\kappa^D(\pi_t^{C,D}-1)\pi_t^{C,D}=\kappa^D\beta\frac{\lambda_{t+1}^P}{\lambda_t^P}\frac{d_{t+1}^{C,P}}{d_t^{C,P}}(\pi_{t+1}^{C,D}-1)\pi_{t+1}^{C,D}-1+\epsilon^{C,D}-\epsilon^{C,D}\frac{r_t}{r_t^{C,D}} \tag{34}$$

where $\pi_t^{C,E}=\frac{r_t^{C,E}}{r_{t-1}^{C,E}}$ and $\pi_t^{C,D}=\frac{r_t^{C,D}}{r_{t-1}^{C,D}}$ are the gross growth rate of retail interest rates on loans and deposits, and κ^B and κ^D regulates the size of the quadratic adjustment costs. Finally, we can define overall bank profits as the sum of net earnings from the wholesale unit and the two retail branches. Deleting intragroup transactions yields (in real terms):

$$j_t^C=r_t^{C,E}l_t^{C,E}-r_t^{C,D}d_t^{C,P}-adj_t \tag{35}$$

where adj_t includes adjustment costs of both the wholesale and the retail branches.

3.7 Shadow Banks

Shadow banks are modelled following Sims and Wu (2021), such that in each period, a constant fraction (1-σ^s) of firms exits the market, returning their accumulated net worth to households. To maintain continuity, these departing firms are replaced by an equal number of new intermediaries, each starting operations with seed capital X also supplied by households. As described in Gebauer and Mazelis (2023), shadow banks perform the same intermediation functions as commercial banks. However, the model assumes that, although households view deposits at either type of bank as perfectly interchangeable, shadow banks extend credit to entrepreneurs not via one-period loan contracts, but through long-term private bonds, structured as outlined in Section 3.3.

The balance sheet of the NBFI is therefore:

$$q_t^S b_{j,t}^{SE}=k_{j,t}^S+d_{j,t}^{S,P}$$

where net worth $k_{j,t}^S$ evolves according to:

$$k_{j,t}^S=(r_t^{S,E}-r_{t-1}^{S,D})q_{t-1}^S b_{j,t-1}^{SE}+(1+r_{t-1}^{S,D})k_{j,t-1}^S$$

The intermediary value function can be written as:

$$V_{j,t}^{S} = \max\left\{(1-\sigma^{S})E_t\Lambda_{t,t+1}k_{j,t+1}^{S} + \sigma^{S}E_t\Lambda_{t,t+1}V_{j,t+1}^{S}\right\}$$

However, as in Sims and Wu (2021), the financial intermediary is subject to a costly enforcement problem, in that the shadow banker can choose in each period to divert a fraction θ^S of assets and default. Since in case of default savers can only recover a fraction $1-\theta^S$ of their deposits, in order for them to be willing to invest in shadow banks, the following incentive compatibility constraint must be satisfied:

$$V_{j,t}^{S} \geq \theta^{S}(q_t^{S}b_{j,t}^{SE}).$$

The NBFI maximizes the value function over private bonds and deposits, subject to the incentive compatibility constraint. By using the balance sheet and the net worth accumulation equation to substitute for net worth in the value function, and by guessing that the value function is linear in net worth, it is shown in Sims and Wu (2021) that we obtain the following aggregate equilibrium condition:

$$\Lambda_{t,t+1}\Omega_{t+1}\Pi_{t+1}^{-1}(r_{t+1}^{S,E} - r_t^{S,D}) = \theta^{S}\frac{\lambda_t^{S}}{1+\lambda_t^{S}} \tag{36}$$

where λ_t^S is the lagrange multiplier of the incentive constraint and:

$$\Omega_t = 1-\sigma^{S} + \sigma^{S}\theta^{S}\phi_t^{S} \tag{37}$$

ϕ_t^S is an endogenous leverage ratio, and it is equal to:

$$\phi_t^{S} = \frac{(1+\lambda_t^{S})\Lambda_{t,t+1}\Omega_{t+1}\Pi_{t+1}^{-1}(1+r_t^{S,D})}{\theta^{S}} \tag{38}$$

Eq. 36 shows that the tighter the constraint (the higher λ_t^S) the higher will be the spread required by the NBFI. Since we assume the constraint is always binding, by aggregating across institutions we obtain that:

$$q_t^{S}b_t^{SE} = \phi_t^{S}k_t^{S} \tag{39}$$

and:

$$q_t^{S}b_t^{SE} = k_t^{S} + d_t^{S,P} \tag{40}$$

Total net worth evolves as the sum of the retained earnings from the fraction σ^S of surviving bankers and the transfers that new bankers receive, X, as follows:

$$k_t^S = \sigma^S \Pi_{t+1}^{-1} [(r_t^{S,E} - r_{t-1}^{S,D}) q_t^S b_t^{SE} + (1 + r_{t-1}^{S,D}) k_{t-1}^S] + X \tag{41}$$

Unlike in the commercial banking sector, where asset prices play a lesser role, here they have a direct impact on the accumulation of equity. As a result, when monetary policy tightens, the beneficial effect of wider spreads on NBFI capital can be diminished by the adverse movement in asset values. Finally, following Gebauer and Mazelis (2023), we assume that the possibility of NBFI default creates a non-negative spread between the interest rates on shadow bank deposits and those on commercial bank deposits, determined by the parameter τ^S.[9]

$$(1 + r_t^{S,D}) = \frac{(1 + r_t^{C,D})}{1 - \tau^S} \tag{42}$$

3.8 Monetary Policy and Market Clearing

The short-term interest rate is set according to the following Taylor rule:

$$\ln(1+r_t) = (1-\rho_R) \ln(1+r) + \rho_R \ln(1+r_{t-1}) + (1-\rho_R) \left[\phi_\pi (\ln \Pi_t - \Pi) + \phi_y (\ln Y_t - Y_{t-1})\right] + s^R \varepsilon_t^R \tag{43}$$

where s^R regulates the size of the normally distributed monetary policy shock ε_t^R.

The model is closed by the following resource constraint:

$$Y_t = C_t + I_t + adj.costs_t \tag{44}$$

where adjustment costs include both the wholesale (resources used in managing bank capital and cost of moving the leverage ratio away from the regulatory requirement) and the retail (cost of changing interest rates) units of the commercial banks' costs, and aggregate consumption is the sum of households and entrepreneurs consumption:

$$C_t = c_t^P + c_t^E \tag{45}$$

[9] In the Appendix of Gebauer and Mazelis (2023), the authors derive the microfoundations of this parameter, demonstrating that it is, in fact, equivalent to the probability of default.

4 Calibration

Table 1 presents the calibrated parameters, with most instances adopting the calibration outlined by Gebauer and Mazelis (2023).[10]

Table 1: Calibrated Parameters

Parameter	Value	Description	Reference
β^P	0.9943	Savers discount factor	Gebauer and Mazelis (2023)
a^P	0.77	Savers habit formation	Gebauer and Mazelis (2023)
η	1	Savers Frisch labour elasticity	Gebauer and Mazelis (2023)
β^E	0.975	Entrepreneurs discount factor	Gebauer and Mazelis (2023)
a^E	0.77	Entrepreneurs habit formation	Assumed to be equal to a^P
δ^K	0.025	Depreciation rate of capital	Gebauer and Mazelis (2023)
α^E	0.2	Capital share	Gebauer and Mazelis (2023)
m^C	0.2	Entrepreneurs LTV ratio, commercial banks	Authors' calculations
m^S	0.1	Entrepreneurs LTV ratio, shadow banks	Authors' calculations
ϕ^P	0.87	Price stickiness	Gebauer and Mazelis (2023)
ϕ^W	0.87	Nominal wage stickiness	Assumed to be equal to ϕ^P
ϵ^P	6	Price markup	Gebauer and Mazelis (2023)
ϵ^W	5	Nominal wage markup	Gebauer and Mazelis (2023)
κ^I	3.98	Investment adjustment costs	Gebauer and Mazelis (2023)
ν^C	0.08	Commercial banks capital to assets target ratio	Gebauer and Mazelis (2023)
Δ	0.02	Commercial banks buffer above regulatory capital ratio	Author's calculations
$r - r^{C,D}$	0.0035/4	Steady state policy rate - deposit rate spread	Gebauer and Mazelis (2023)
$r^{C,E} - r$	0.0240/4	Steady state loan rate - policy rate spread	Gebauer and Mazelis (2023)
$r^{S,D} - r^{C,D}$	0.0200/4	Steady state NBFI deposit rate - bank deposit rate spread	Gebauer and Mazelis (2023)
κ^C	10.05	Banks capital deviation costs	Gebauer and Mazelis (2023)
κ^B	8.34	Loan rate adjustment costs	Gebauer and Mazelis (2023)
κ^D	13.26	Deposit rate adjustment costs	Gebauer and Mazelis (2023)
σ^S	0.944	NBFI survival probability	Gebauer and Mazelis (2023)
ϕ^S	4	NBFI leverage	Gertler and Karadi (2011)
ρ^R	0.88	Policy rate persistence	Gebauer and Mazelis (2023)
ϕ^π	1.87	Taylor rule response to inflation	Gebauer and Mazelis (2023)
ϕ^y	0.24	Taylor rule response to GDP	Gebauer and Mazelis (2023)
ρ^A	0.42	Persistence of productivity shock	Gebauer and Mazelis (2023)
ρ^Z	0.87	Persistence of preference shock	Gebauer and Mazelis (2023)
ρ^Q	0.46	Persistence of investment efficiency shock	Gebauer and Mazelis (2023)
ρ^T	0.36	Persistence of deposit spread shock	Gebauer and Mazelis (2023)
ρ^M	0.94	Persistence of LTV shock	Gebauer and Mazelis (2023)
ρ^D	0.36	Persistence of bank deposit rate shock	Gebauer and Mazelis (2023)
ρ^B	0.63	Persistence of bank loan rate shock	Gebauer and Mazelis (2023)
ρ^P	0.36	Persistence of price markup shock	Gebauer and Mazelis (2023)
ρ^W	0.71	Persistence of wage markup shock	Gebauer and Mazelis (2023)
ρ^C	0.96	Persistence of bank capital shock	Gebauer and Mazelis (2023)
s^A	0.029	Stdev of productivity shock	Gebauer and Mazelis (2023)
s^R	0.001	Stdev of monetary policy shock	Gebauer and Mazelis (2023)
s^P	0.002	Stdev of price markup shock	Gebauer and Mazelis (2023)
s^Z	0.011	Stdev of preference shock	Gebauer and Mazelis (2023)
s^W	0.041	Stdev of wage markup shock	Gebauer and Mazelis (2023)
s^Q	0.002	Stdev of investment efficiency shock	Gebauer and Mazelis (2023)
s^T	0.007	Stdev of deposit spread shock	Gebauer and Mazelis (2023)
s^M	0.008	Stdev of LTV ratio shock	Gebauer and Mazelis (2023)
s^C	0.003	Stdev of bank capital shock	Gebauer and Mazelis (2023)
s^D	0.002	Stdev of bank deposit rate shock	Gebauer and Mazelis (2023)
s^B	0.002	Stdev of bank loan rate shock	Gebauer and Mazelis (2023)

[10]While Gebauer and Mazelis (2023) is estimated using euro area data, we intend to estimate our model with UK data in a future extension of this work.

Steady state annualized deposit and loan spreads of 35 and 240 bps respectively entail $\epsilon^{C,D} = -6.55$ and $\epsilon^{C,E} = 2.10$. A steady state annualized spread between the two deposit rates of 200 bps implies a 0.5% default probability of NBFIs. It is assumed entrepreneurs can borrow up to 30% of the value of their physical capital, and the LTV and BTV ratios are chosen to match the fact that NBFIs account for one-third of total corporate lending.[11] Following Gertler and Karadi (2011), NBFIs leverage ϕ^S is equal to 4. This results in a fraction of divertable assets θ^S of 0.32.

To assess how frequently the occasionally binding bank capital constraint is activated in our model, we simulate the economy 1,000 times over 100 periods each. In every period and simulation, shocks are randomly drawn from normal distributions with mean zero and standard deviations calibrated as shown in Table 1. For a value of $\Delta = 0.02$, which implies that lending spreads become insensitive to capital levels once the regulatory capital ratio exceeds 10%, we find that the capital constraint binds, on average, in approximately 13.8% of periods. This means that in 86.2% of the time, the bank's capital position actively influences the interest rate spread. It is worth emphasizing that this result depends on calibrating all shocks in accordance with the approach of Gebauer and Mazelis (2023).

Table 2: Data v. Model

		C	I	π	r	l^C	d^C	r^{CE}	r^{CD}	b^S
Data	Correlation with Y	0.72	0.9	0.37	0.18	0.31	-0.32	0.07	-0.13	0
Model	Correlation with Y	0.91	0.91	0.37	-0.38	0.42	0.42	-0.19	-0.25	0.16
Data	Stdev X/ Stdev Y	0.6	2.11	0.45	1.28	2.18	1.5	0.85	0.43	4.79
Model	Stdev X/ Stdev Y	0.61	6.19	0.35	2.45	5.33	5.8	2.43	1.68	9.22

The data manipulation process is detailed in Appendix B of Gebauer and Mazelis (2023). All variables (except interest rates) are seasonally adjusted and deflated. GDP, consumption, investment, and loans and deposits from banks and NBFIs are detrended using log-differences and then demeaned. Interest rates and inflation are also demeaned. In our model, we construct corresponding observational variables to match these transformations and extract the relevant model moments.

To evaluate whether our model effectively captures the core features of the business cycle, we analysed the correlations between key variables and output, as well as their standard deviations relative to the standard deviation of output. This comparison was conducted using our model - which incorporates all shocks estimated by Gebauer and Mazelis (2023) - and corresponding euro area data. Table 2 presents these results.

When examining correlations, the model succeeds in reflecting the relationships between output and variables such as consumption, investment, inflation, bank loans, and bank deposit rates. However, it falls short in replicating the positive correlation between output and policy rates, as well as the positive link between output and loan rates. Additionally, it does not capture the negative correlation

[11]This figure, reported in Gebauer and Mazelis (2023), is consistent with UK data, according to Bank of England calculations.

observed between output and bank deposits. We suspect these discrepancies - particularly the negative correlation between output and both interest rates in the model - may stem from the relatively larger influence of supply shocks compared to demand shocks in the Gebauer and Mazelis (2023) estimation.

In terms of relative standard deviations, the model accurately indicates that consumption and inflation are less volatile than output, while investment, policy rates, bank loans, bank deposits, and NBFI loans exhibit greater volatility. Nonetheless, our model overstates the volatility of loan and deposit interest rates, presenting them as more volatile than output, whereas in the actual data, they are less volatile than output[12].

5 Results

In this section, we provide both qualitative and quantitative forecasts generated by our model, with a particular emphasis on how it responds to monetary policy shocks. The first two subsections explore impulse response functions, highlighting the ways in which asymmetric capital requirements and the presence of NBFIs shape the transmission of monetary policy. The third subsection investigates the influence of NBFIs on the distribution of expected GDP, focusing on their quantitative effects at the centre and left tail of the distribution. Lastly, we assess the welfare implications of NBFIs within a counterfactual economy where all asymmetries have been removed.

5.1 Impulse Response Analysis - the Role of Asymmetric Capital Requirements

What role do asymmetric capital requirements play in the transmission of monetary policy? To address this, Figure 2 presents impulse response functions following a 1% monetary policy shock, comparing two model setup: one with state-dependent macroprudential policy, and another - drawing on Gerali et al. (2010) - with symmetric adjustment costs.

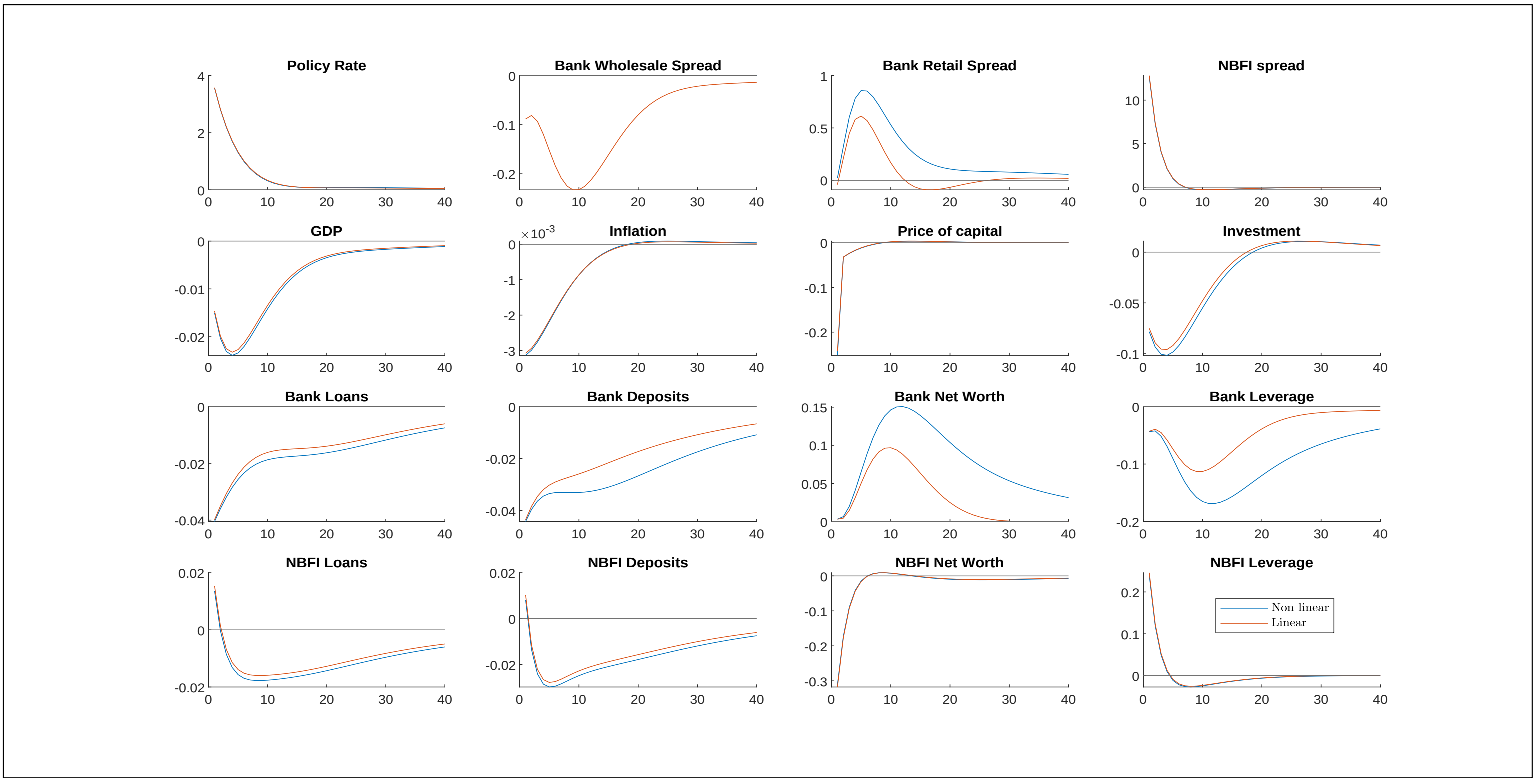
As is typical, a tighter monetary policy leads to a hump-shaped decline in output. Lending contracts as borrowing becomes more expensive, primarily due to higher interest rates. Bank intermediation spreads widen, reflecting the fact that monopolistically competitive banks increase lending rates to rebuild capital buffers, which accelerates deleveraging and reduces credit supply.

[12]It is technically possible to force the relative standard deviations of r^{CE} and r^{CD} below one by setting the parameters κ_b and κ_d to very high values (above 100), but we prefer to stick with the Gebauer and Mazelis (2023) estimates until we complete our own model estimation. A robustness check reveals that Gebauer and Mazelis (2023)model aligns closely with ours, sharing similar strengths and weaknesses in matching the data across categories. The main distinction - consistent with expectations - concerns the correlation between NBFI lending and output: our model shows a positive correlation, while Gebauer and Mazelis (2023) reports a negative one. This difference reflects the contrasting roles of NBFIs in the two models: dampening recessions in Gebauer and Mazelis (2023) but amplifying them in ours.

However, with symmetric macroprudential regulation, the increase in spreads is noticeably subdued. This is because the accumulation of capital heightens adjustment costs, discouraging banks from fully raising lending rates, even when market conditions might warrant it. Thus, banks are restrained in their ability to expand spreads.

By contrast, when macroprudential policy is asymmetric - meaning banks face no adjustment costs if capital levels exceed regulatory targets - lending rates can be raised more aggressively. Consequently, this leads to a sharper contraction in loans, output, and leverage, but also produces a larger rise in both capital and profits.

Figure 2: Interest Rate Shock: the contribution of occasionally binding capital requirements



Note: The policy rate and the two spreads are reported as annualized absolute deviations from their steady-state values. All other variables are expressed as percentage deviations. Specifically, since in our model the annualized policy rate is defined as $R_t^{ann} = R_t * 400$, a 0.01 standard deviation monetary policy shock corresponds to a 4% deviation in the annualized policy rate.

5.2 Impulse Response Analysis - the Role of NBFIs

What impact do non-bank financial institutions (NBFIs) have on the transmission of monetary policy? Figure 6 illustrates impulse response functions following a 1% monetary policy shock, contrasting two models with occasionally binding capital requirements: one featuring only banks (red lines), and the other incorporating shadow banks (blue lines).

In the model presented by Gebauer and Mazelis (2023), when conventional banks reduce lending, NBFIs step in to fill the gap. They do so by accepting slimmer intermediations spreads to capture greater market share - this phenomenon is known as the lending competition channel. However, our model introduces a crucial friction: the leverage of NBFIs is tied directly to the market value of private bonds. When monetary tightening occurs, bond prices decline, causing NBFI leverage to increase suddenly. This heightened leverage constrains NBFIs' ability to lower interest rates, even when the incentive exists. Consequently, both spreads and leverage rise, leading to a reduction in total NBFI lending, that in our framework depends on both the quantity and the price of bonds. Entrepreneurs, therefore, find themselves in a less favourable position compared to a scenario where only banks operate.

The dynamic is reflected in the total credit extended to entrepreneurs: somewhat counterintuitively, the contraction is more severe in the presence of both intermediaries. Thus, while NBFIs expand financing options under normal conditions, they intensify the credit squeeze during periods of monetary tightening. As a result, investment and output decline more steeply, and NBFIs end up amplifying the familiar mechanism of the financial accelerator[13].

How do these qualitative insights translate into quantitative outcomes? The following two subsections examine the influence of NBFIs on GDP and welfare, both in response to monetary shocks and over the long term.

5.3 GDP Distribution Analysis

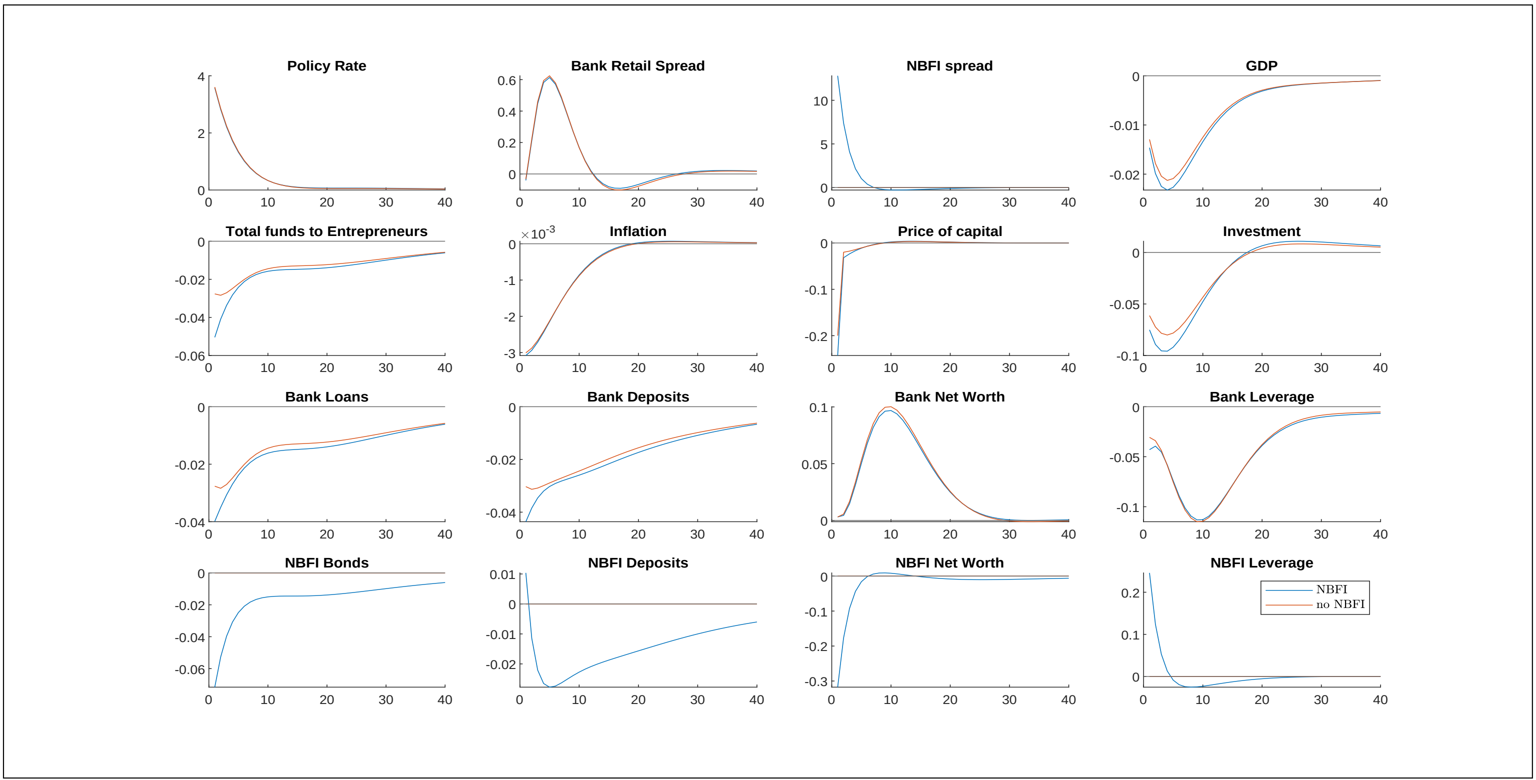
In this section, we explore the quantitative impact that shadow banks have within our model. As highlighted earlier, financial stability experts are concerned not just with the central case but also with rare, severe events - what is often called *left-tail risk*, such as financial crises or deep recessions. The asymmetrical structure of our model enables us to examine these extreme outcomes by accounting for non-normal distributions, allowing a meaningful analysis of the distribution's tails.

A key tool used by central banks to monitor financial stability is GDP-at-risk, typically defined as the fifth percentile of the expected GDP distribution. While much of the existing literature on GDP-at-risk relies on empirical analysis, our structural model provides a micro-founded, general equilibrium framework to investigate how GDP-at-risk evolves. In this section, we assess how the presence of non-bank financial institutions (NBFIs) influences both the median and the lower tail (fifth percentile) of the GDP distribution in response to monetary policy shocks.

To operationalise GDP-at-risk within our model, we follow the methodology of Aikman et al. (2021): we run a large number of simulations and, for every period, record the average macroeconomic

[13] Appendix C presents a comparison of impulse response functions between our model and that of Gebauer and Mazelis (2023), highlighting scenarios in which NBFIs can boost lending activity. For robustness, Appendix D investigates the impact of NBFIs when adjusting commercial bank lending in the steady state of the no-NBFI benchmark economy to ensure that total credit, investment, and GDP remain constant across both the baseline and the no-NBFI models.

Figure 3: Interest Rate Shock: the Contribution of NBFIs



Note: The policy rate and the two spreads are reported as annualized absolute deviations from their steady-state values. All other variables are expressed as percentage deviations. Specifically, since in our model the annualized policy rate is defined as $R_t^{ann} = R_t * 400$, a 0.01 standard deviation monetary policy shock corresponds to a 4% deviation in the annualized policy rate.

outcomes. GDP-at-risk is then defined as follows:

$$GaR^5(Y) = \sum_{n=1}^{N} \frac{1}{N} q^5(Y_n) \tag{46}$$

where N is the number of simulations and $q^5(Y_n)$ is the fifth percentile in the distribution of output deviations from steady state across periods in simulation $n \in N$.[14]

We present our findings in Table 3, which displays both the GDP-at-risk and median outcomes, alongside the full distribution of output deviations from the steady state in the left panel of Fig.4. To further test the robustness of our analysis, we also examine an alternative model that incorporates a zero lower bound on the policy rate - resulting in two occasionally binding constraints - and compare these results with those from our baseline approach. This comparative analysis is shown in Table 4 and illustrated in the right panel of Fig.4[15].

[14]Simulations employ the Occbin toolkit, which uses a first-order perturbation approach by linearizing the model around its steady state. The algorithm, developed by Giovannini et al. (2021), achieves solutions by connecting regime-specific linear approximations. This design ensures computational efficiency, though it does not account for higher-order effects or precautionary behaviour.

[15]In addition to our primary analysis of monetary policy shocks, Appendix E provides a robustness check. There, we

Table 3: 5th percentile and median values of the distribution of output deviations from steady state.

	No NBFI	NBFI	diff.
Median, linear	-0.0888%	-0.0986%	-0.0098%
Median, non linear	-0.1687%	-0.1759%	-0.0072%
GaR, linear	-8.8319%	-9.6250%	-0.7931%
GaR, non linear	-9.1712%	-9.9841%	-0.8129%

Note: GDP-at-risk and median values are computed respectively as the 5th and the 50th percentiles of the distribution of output deviations from the steady state over 100 periods, where each period is averaged over 1000 simulations. The non-linear model includes an occasionally binding constraint on bank capital adjustment costs.

Table 4: 5th percentile and median values of the distribution of output deviations from steady state (two OBCs).

	No NBFI	NBFI	diff.
Median, linear	-0.0373%	-0.0419%	-0.0046%
Median, non linear	-0.3564%	-0.3898%	-0.0334%
GaR, linear	-8.6408%	-9.4130%	-0.7722%
GaR, non linear	-9.0671%	-9.8712%	-0.8041%

Note: GDP-at-risk and median values are computed respectively as the 5th and the 50th percentiles of the distribution of output deviations from the steady state over 100 periods, where each period is averaged over 1000 simulations. The non-linear model includes two occasionally binding constraints on bank capital adjustment costs and on the policy rate.

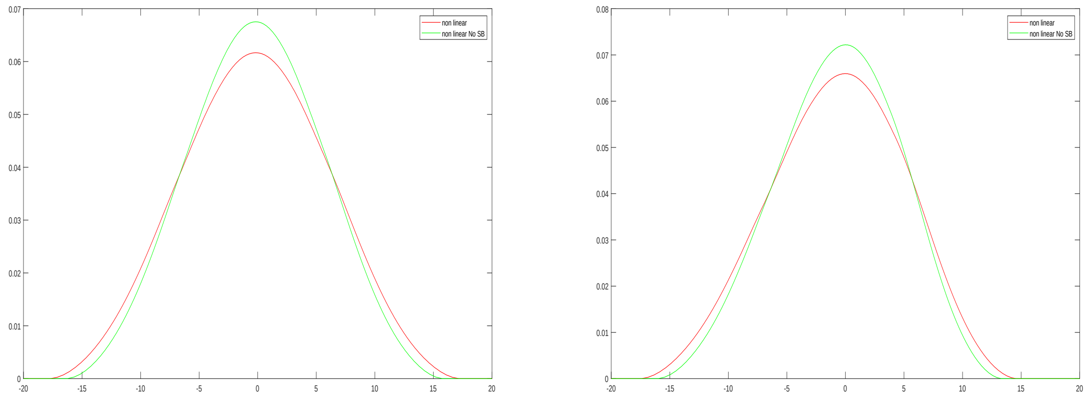
The presence of non-bank financial institutions (NBFIs) amplifies the adverse effects of monetary policy shocks. This observation aligns with our impulse response analysis, where the asset price channel influences the market value of bonds held by NBFIs, ultimately affecting their leverage and lending decision in our baseline model. Notably, due to the model's asymmetry, this impact is far more pronounced at the lower end of the distribution than at the median. For instance, while introducing NBFIs reduces the median value by just 0.01 percentage points, the effect on GDP at risk is substantial - the fifth percentile shifts left by 0.81 percentage points.

Moreover, when we introduce the zero lower bound as a second non-linearity, these findings remain robust. In this scenario, the presence of NBFIs lowers the median value by only 0.03 percentage points but decreases GDP at risk by 0.80 percentage points[16].

explore both a scenario incorporating all shocks - calibrated according to Gebauer and Mazelis (2023) - and one that specifically features a supply-side shock.

[16] In Appendix F, we illustrate the qualitative effects of the zero lower bound using a series of impulse response functions.

Figure 4: Probability Density Functions: GDP deviations from steady state



(a) One OBC (asymmetric adj. costs) (b) Two OBC (asymmetric adj. costs + ZLB)

Note: The left-hand panel displays the probability density functions of GDP deviations from steady state for two models with an occasionally binding constraint on bank capital adjustment costs. The red line represents the baseline model, while the green line corresponds to the counterfactual model in which NBFIs are turned off. The right-hand panel shows the same comparison, but for models that include both an occasionally binding constraint on bank capital adjustment costs and a constraint on the policy rate (ZLB).

Table 5: Binding likelihood across models

	Banks overcapitalized	Banks undercapitalized	
ZLB binding	8.3%	24.03%	32.33%
ZLB not binding	32.72%	34.95%	67.67%
	41.03%	58.98%	100%

Note: The occasionally binding constraint on capital requirements becomes active when banks are sufficiently overcapitalized, such that they no longer consider their leverage position when setting the spread between the wholesale loan rate and the deposit rate. The occasionally binding constraint on the policy rate is triggered when the rate reaches zero, starting from a steady-state value of 0.0066 (equivalent to an annualized rate of 2.64%).

To conclude, introducing a second non-linearity allows us to examine how asymmetric capital requirements interact with the zero lower bound (ZLB) - specifically, whether a capital-constrained banking system is more likely to encounter the lower bound. As shown in Table 5, this interplay is evident. In our model, the ZLB binds 32.33% of the times overall. However, focusing specifically on periods when banks are constrained (either undercapitalized or close enough to the macroprudential capital requirement, which occurs 58.9% of the time), the ZLB binds in 40.7% of those instances (computed as 24.03% divided by 58.98%). This is a notably higher proportion compared to the 20.2% (computed as 8.3% divided by 41.03%) observed when banks become unconstrained and the adjusment costs are switched off.

These findings are consistent with the literature on downside risk, which demonstrates that the lower quantiles of GDP growth are typically more volatile than the median. However, our results reveal and additional mechanism. In most previous studies, the gap between the median and the lower tail (often the fifth percentile) is attributed to the model's inherent non-linearity. Empirically, this is captured by methods such as quantile regression (Forni et al. (2024)), or theoretically by altering equilibrium conditions - for instance, through endogenous risk-taking, as in Adrian et al. (2020). In contrast, our model indicates that non-bank financial institutions (NBFIs) introduce a new source of risk beyond the non-linearity already present due to asymmetric macroprudential policies. Without NBFIs, the amplification of the difference between the median and the fifth percentile would still occur because of asymmetric adjustment costs, but the effect would be less pronounced.

Thus far, our results suggest that NBFIs negatively affect financial stability, providing further justification for monetary authorities to pay close attention to how monetary policy shocks influence financial stability through NBFIs. However, our analysis until now has focused on short-run GDP deviations from the steady state and the economy's immediate response to shocks. In the long-run, the impact of NBFIs may differ. In fact, macroprudential authorities are concerned with balancing the trade-off between safeguarding financial stability during adverse scenarios and fostering potential long-term growth. Notably, our model shows that steady-state output is higher when NBFIs are present, as borrowers have additional avenues for financing outside the commercial banking sector, which leads to increased aggregate lending and investment. This raises an important question: does a trade-off between short- and long-term outcomes exist in our framework? To address this, we conduct a standard welfare analysis in the next subsection to assess the long-term impact of NBFIs.

5.4 Welfare Analysis

To assess welfare, we assume a linear model, meaning that, over the long term, any asymmetries caused by state-dependent adjustment costs on bank capital and the zero lower bound do not persist[17]. Following standard practice, we define the welfare of agent i (representing borrowers and savers in our model) as their expected, discounted lifetime utility and solve the model using a second-order approximation[18]. The utility for each agent, described recursively, is as follows:

$$W_{i,t} = U_{i,t} + \beta_i W_{i,t+1} \tag{47}$$

Following Rubio and Carrasco-Gallego (2014), social welfare is defined as a weighted sum of individual welfare of the patient household and the entrepreneur:

[17] In economic terms, this is equivalent to assuming that in the long-run banks attach the same value to the disutility of being overcapitalized and undercapitalized.

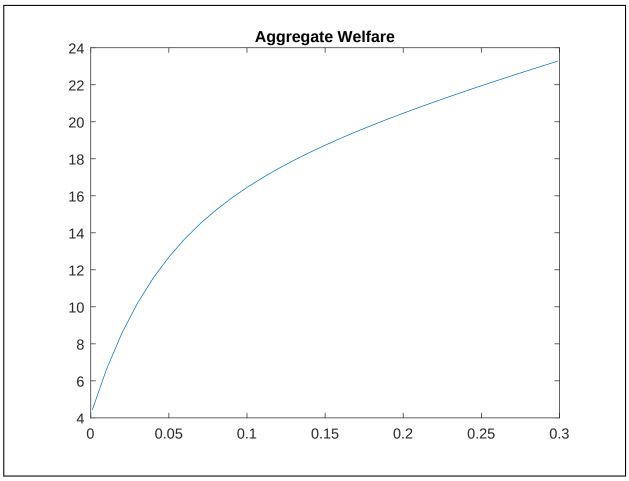
[18] This is necessary because expected utility depends nonlinearly on consumption and hours worked - a first-order approximation would overlook the impact of volatility on consumption.

$$W_t = (1 - \beta_p)W_{p,t} + (1 - \beta_e)W_{e,t} \tag{48}$$

where the patient household welfare, $W_{p,t}$, and the entrepreneur welfare, $W_{e,t}$, are weighted by the respective discount factors. Weighting individual welfares by one minus the discount factor of their group, implies that different agents receive the same level of utility from a constant consumption stream.

To ensure a fair comparison, we adjust the model so that as the lending volume of NBFIs increases (captured by a higher loan-to-value ratio, m^s), the lending volume from commercial banks decreases (lower m^c). This approach guarantees that total steady-state credit and GDP remain constant across all simulations[19]. Figure 5 illustrates how aggregate welfare changes as the proportion of NBFI credit rises - in particular, as m^s increases from 0 to 0.3 and m^c correspondingly drops from 0.3 to 0[20].

Figure 5: Welfare analysis: aggregate welfare across different combinations of m^s



We observe a clear trend: welfare tends to increase as the proportion of NBFI lending rises, with the most pronounced gains occurring when NBFIs are first introduced to an economy - specifically between a share of 0 and 0.1. This pattern suggests that even a modest presence of NBFIs can yield meaningful benefits, particularly in settings where they have not previously operated.

Looking at the long term, our findings indicate that reduced regulation - a greater share of NBFIs entails that fewer aggregate resources are spent on bank adjustment costs - enhances overall welfare.

[19] And hence it does not imply that welfare in the model with NBFIs is higher just because total lending is higher.

[20] Recent findings by Gebauer and Mazelis (2023) reveal that NBFIs accounted roughly one-third of total lending to non-financial corporations. This substantial share highlights the importance of evaluating how NBFIs influence overall welfare, especially when their lending increases as bank lending declines proportionally. If NBFI lending simply rises without a corresponding reduction in bank lending, the aggregate steady-state borrowing, investment and GDP - and thus welfare - would increase automatically, without involving any meaningful trade-off. Our analysis, therefore, maintains a constant level of total steady-state lending. This approach ensures that any changes in welfare stem from the reallocation of lending and the resulting shift effect, which is driven by differences in the variance of future shocks, as captured in a second-order approximation.

This advantage appears to outweigh the short-run risks that NBFI bring, namely the amplification of fluctuations due to their procyclical influence on asset prices.

In essence, our results highlight a fundamental trade-off. While NBFIs can improve long-run welfare (assuming non-linear effects do not intervene), they also increase short-run vulnerability, as evidenced by more frequent and more severe deviations of GDP from its steady-state level. In other words, the economy becomes more exposed to downside risks, even as its long-term prospects improve.

6 Conclusions

In closing, this study advances our understanding of the macroprudential landscape by illuminating the multifaceted dynamics of commercial bank capital requirements and the ever-evolving role of non-bank financial institutions within the financial system. By constructing a microfounded DSGE framework with state-dependent capital regulation and a dual-sector financial architecture, we have demonstrated the asymmetric effects of capital shortfalls on lending spreads and the pronounced impact of NBFIs in monetary transmission.

The findings reveal a critical trade-off: while NBFIs introduce short-run vulnerabilities by amplifying adverse shocks - especially through the asset price channel and under zero lower bound conditions - they simultaneously deliver long-run welfare gains through reduced regulatory burden and enhanced resource allocation. This dichotomy underscores the importance for policymakers of balancing financial system stability against the potential efficiency gains offered by NBFIs.

Moreover, the analysis highlights the necessity for vigilant regulatory oversight and adaptive macroprudential framework that respond not only to conventional banking sector risks but also to the systemic implications posed by the shadow banking sphere. As monetary authorities navigate periods of heightened financial stress, monitoring the feedback loops between regulatory policy, monetary interventions, and the structural composition of the financial sector will prove crucial.

Ultimately, our results invite a nuanced revaluation of financial regulation - one that accounts for the asymmetric nature of capital requirements and the complex interplay between banking and non-bank intermediaries - so that modern financial systems can better reconcile the imperatives of short-term resilience and long-term prosperity.

References

Adrian, T., F. Duarte, N. Liang, and P. Zabczyk (2020): "NKV: A New Keynesian Model with Vulnerability," *AEA Papers and Proceedings*, 110, 470–76.

Aikman, D., K. Bluwstein, and S. Karmakar (2021): "A tail of three occasionally-binding constraints: a modelling approach to GDP-at-Risk," .

Bandera, N. and J. Stevens (2024): "Monetary policy consequences of financial stability interventions: assessing the UK LDI crisis and the central bank policy response," Tech. rep., Bank of England.

Bichsel, R., L. Lambertini, A. Mukherjee, and D. Wunderli (2022): "The pass-through of bank capital requirements to corporate lending spreads," *Journal of Financial Stability*, 58, 100910.

Buchak, G., G. Matvos, T. Piskorski, and A. Seru (2018): "Fintech, regulatory arbitrage, and the rise of shadow banks," *Journal of Financial Economics*, 130 (3), 453–483.

Corbae, D. and P. D'Erasmo (2021): "Capital buffers in a quantitative model of banking industry dynamics," *Econometrica*, 89, 2975–3023.

Elenev, V., T. Landvoigt, and S. Van Nieuwerburgh (2021): "A macroeconomic model with financially constrained producers and intermediaries," *Econometrica*, 89, 1361–1418.

Forni, M., L. Gambetti, N. Maffei-Faccioli, and L. Sala (2024): "The effects of monetary policy on macroeconomic risk," *European Economic Review*, 167.

Fève, P., A. Moura, and O. Pierrard (2019): "Shadow banking and financial regulation: A small-scale DSGE perspective," *Journal of Economic Dynamics and Control*, 101, 130–144.

Gebauer, S. and F. Mazelis (2023): "Macroprudential regulation and leakage to the shadow banking sector," *European Economic Review*, 154, 104404.

Gennaioli, N., A. Shleifer, and R. W. Vishny (2013): "A Model of Shadow Banking," *The Journal of Finance*, 68(4), 1331–1363.

Gerali, A., S. Neri, L. Sessa, and F. M. Signoretti (2010): "Credit and Banking in a DSGE Model of the Euro Area," *Journal of money, Credit and Banking*, 42, 107–141.

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

Giovannini, M., P. Pfeiffer, and M. Ratto (2021): "Efficient and robust inference of models with occasionally binding constraints," *JRC Working Papers in Economics and Finance*.

Gorton, G. and A. Metrick (2010): "Regulating the Shadow Banking System," *Brookings Papers on Economic Activity*, 41(2), 261–312.

He, Z. and A. Krishnamurthy (2019): "A Macroeconomic Framework for Quantifying Systemic Risk," *American Economic Journal: Macroeconomics*, 11(4), 1–37.

Holden, T. D., P. Levine, and J. M. Swarbrick (2020): "Credit Crunches from Occasionally Binding Bank Borrowing Constraints," *Journal of Money, Credit and Banking*, 52(2-3), 549–582.

Iacoviello, M. (2005): "House Prices, Borrowing Constraints, and Monetary Policy in the Business Cycle," *American Economic Review*, 95(3), 739–764.

——— (2015): "Financial business cycles," *Review of Economic Dynamics*, 18, 140–163.

Karmakar, S. (2016): "Macroprudential Regulation and Macroeconomic Activity," *Journal of Financial Stability*, 25, 166–178.

Lang, J. H. and D. Menno (2025): "The state-dependent impact of changes in bank capital requirements," *Journal of Banking & Finance*, 176.

Meeks, R., B. Nelson, and A. Piergiorgio (2017): "Shadow Banks and Macroeconomic Instability," *Journal of Money, Credit and Banking*, 49(7), 1483–1516.

Ordoñez, G. (2018): "Sustainable Shadow Banking," *American Economic Journal: Macroeconomics*, 10(1), 33–56.

Plantin, G. (2014): "Shadow Banking and Bank Capital Regulation," *The Review of Financial Studies*, 28(1), 146–175.

Ross, S. (1976): "Options and efficiency," *Quarterly Journal of Economics*, 90, 75–89.

Rubio, M. and J. A. Carrasco-Gallego (2014): "Macroprudential and monetary policies: Implications for financial stability and welfare," *Journal of Banking and Finance*, 49.

Schroth, J. (2021): "Macroprudential policy with capital buffers," *Journal of Monetary Economics*, 118, 296–311.

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

Van den Heuvel, S. J. (2008): "The Welfare Cost of Bank Capital Requirements," *Journal of Monetary Economics*, 55(2), 298–320.

Van der Ghote, A. (2021): "Interactions and coordination between monetary and macroprudential policies," *American Economic Journal: Macroeconomics*, 13, 1–34.

Verona, F., M. M. F. Martins, and I. Drumond (2013): "Un(anticipated) Monetary Policy in a DSGE Model with a Shadow Banking System," *International Journal of Central Banking*, 9 (3), 78–124.

A Private Bonds in the Entrepreneur Budget Constraint

As explained in section 3.3, bonds are modelled as perpetuities with decreasing coupon payments, with κ denoting the decay parameter ($0 \leq \kappa \leq 1$). This means that a one unit bond issued in period t for Q_t dollars obligates the issuer to a coupon payment of one dollar in $t+1$, κ dollars in $t+2$, κ^2 dollars in $t+3$, and so on. If, as in Sims and Wu (2021), we define as cf_t new nominal bond issuance, the budget constraint of the entrepreneur would be:

$$c_t^E + w_t h_{d,t} + (1+r_{t-1}^{CE}) l_{t-1}^{CE} \Pi_t^{-1} + cf_{t-1}\Pi_t^{-1} + \kappa cf_{t-2}\Pi_{t-1}^{-1}\Pi_t^{-1} + \kappa^2 cf_{t-3}\Pi_{t-2}^{-1}\Pi_{t-1}^{-1}\Pi_t^{-1} ... + q_t^K k_t =$$
$$p_t^E y_t^E + l_t^{CE} + q_t^S cf_t + q_t^K (1-\delta^k) k_{t-1}$$

However, the main feature of these bonds is that we do not need to keep track of all past issuances. If we define as b_{t-1}^{SE} total coupon liability at the beginning of time t ($b_{t-1}^{SE} = cf_{t-1}\Pi_t^{-1} + \kappa cf_{t-2}\Pi_{t-1}^{-1}\Pi_t^{-1} + +\kappa^2 cf_{t-3}\Pi_{t-2}^{-1}\Pi_{t-1}^{-1}\Pi_t^{-1} ...$), and we iterate it forward we can show that:

$$cf_t = b_t^{SE} - \kappa b_{t-1}^{SE}$$

This results in the following budget constraint:

$$c_t^E + w_t h_{d,t} + (1+r_{t-1}^{CE}) l_{t-1}^{CE} \Pi_t^{-1} + b_{t-1}^{SE} + q_t^K k_t = p_t^E y_t^E + l_t^{CE} + q_t^S cf_t + q_t^K (1-\delta^k) k_{t-1}$$
$$c_t^E + w_t h_{d,t} + (1+r_{t-1}^{CE}) l_{t-1}^{CE} \Pi_t^{-1} + b_{t-1}^{SE} + q_t^K k_t = p_t^E y_t^E + l_t^{CE} + q_t^S b_t^{SE} - \kappa q_t b_{t-1}^{SE} + q_t^K (1-\delta^k) k_{t-1}$$
$$c_t^E + w_t h_{d,t} + (1+r_{t-1}^{CE}) l_{t-1}^{CE} \Pi_t^{-1} + (1+\kappa q_t^S) b_{t-1}^{SE} + q_t^K k_t = p_t^E y_t^E + l_t^{CE} + q_t^S b_t^{SE} + q_t^K (1-\delta^k) k_{t-1}$$
$$c_t^E + w_t h_{d,t} + (1+r_{t-1}^{CE}) l_{t-1}^{CE} \Pi_t^{-1} + (1+r_t^{SE}) q_{t-1}^{SE} b_{t-1}^{SE} + q_t^K k_t = p_t^E y_t^E + l_t^{CE} + q_t^S b_t^{SE} + q_t^K (1-\delta^k) k_{t-1}$$

where in the last line we used equation 11.

B Steady State

We assume a zero-inflation steady state. The households discount factor and the commercial banks' deposit rates are pinned down by β^P; the policy rate, the loan and the deposit rates are calibrated according to the mark-ups described in section 4. By assuming identical loan rates we can derive τ^S:

$$\Lambda^P = \beta^P$$

$$r^{C,D} = \frac{1}{\beta^P} - 1$$

$$r = r^{C,D} + 0.0035/4$$

$$r^{C,E} = r + 0.0240/4$$

$$r^{S,D} = r^{C,D} + 0.0200/4$$

$$r^{S,E} = r^{C,E}$$

$$\tau^S = 1 - \frac{1 + r^{C,D}}{1 + r^{S,D}}$$

Hours worked h, productivity A and the price of capital q^K are normalized to one, while the price of private and government bonds can be pinned down from the interest rates, and the wholesale good price from equation 21, 22 and 23:

$$q^S = \frac{1}{1 + r^{S,E} - \kappa}$$

$$p^E = \frac{\epsilon^P - 1}{\epsilon^P}$$

From equations 18, 19 and 20 we can derive the capital to GDP ratio as:

$$\frac{k}{Y} = \left(\frac{\frac{1-(1-\delta^k)(\frac{m^C(1-\beta^E(1+r^{C,E}))}{(1+r^{C,E})} + \frac{m^S(1-\beta^E(1+r^{S,E}))}{(1+r^{S,E})})}{\beta^E} - (1-\delta^k)}{\alpha^E p^E} \right)^{-1}$$

This allows us to derive the following variables:

$$Y = (\frac{k}{Y})^{\frac{\alpha^E}{1-\alpha^E}}$$

$$k = Y * \frac{k}{Y}$$

$$I = \delta^k k$$

$$w = (1-\alpha^E)p^E Y$$

$$mrs^P = w\frac{\epsilon^w - 1}{\epsilon^w}$$

$$f_1 = \frac{mrs^P w^{\epsilon^w}}{1-\phi^w \Lambda^p}$$

$$f_2 = \frac{w^{\epsilon^w}}{1-\phi^w \Lambda^p}$$

$$x_1 = \frac{p^E Y}{1-\phi^p \Lambda^p}$$

$$x_2 = \frac{Y}{1-\phi^p \Lambda^p}$$

$$l^{C,E} = \frac{m^C(1-\delta^k)k}{(1+r^{C,E})}$$

$$b^{S,E} = \frac{m^S(1-\delta^k)k}{(1+r^{S,E})q^S}$$

From the entrepreneurs budget constraint we can pin-down their consumption, and their three Lagrange multipliers as a result:

$$c^E = p^E Y - \delta^k k - w - r^{C,E} l^{C,E} - q^S r^{S,E} b^{S,E}$$

$$\lambda^E = \frac{(1-\beta^E a^E)}{(1-a^E)}(c^E)^{-1}$$

$$\delta^{C,E} = \frac{(1-\beta^E(1+r^{C,E})}{(1+r^{C,E}))}\lambda^E$$

$$\delta^{S,E} = \frac{(1-\beta^E(1+r^{S,E})}{(1+r^{S,E}))}\lambda^E$$

By assuming that SS commercial banks capital is equal to target we can derive:

$$k^C = \nu^C l^{C,E}$$

$$d^{C,P} = l^{C,E} - k^C$$

$$j^C = r^{C,E} l^{C,E} - r^{C,D} d^{C,P}$$

$$\sigma^C = \frac{j^C}{k^C}$$

Given NBFI leverage and private bonds holding, we can also derive NBFI net worth, deposits, λ^S, Ω^S, θ^S and X:

$$k^S = \frac{q^S b^{S,E}}{\phi^S}$$

$$d^{S,P} = q^S b^{S,E} - k^S$$

$$\lambda^S = \frac{\phi^S (r^{S,E} - r^{S,D})}{(1 + r^{S,D})}$$

$$\Omega^S = \frac{1 - \sigma^S}{(1 - \sigma^S (1 + \lambda^S) \beta^P (1 + r^{S,D}))}$$

$$\theta^S = \frac{\Omega^S - (1 - \sigma^S)}{\phi^S \sigma^S}$$

$$X = k^S - \sigma^S ((r^{S,E} - r^{S,D}) q^S b^{S,E} + (1 + r^{S,D}) k^S)$$

Finally, we can use the labour supply scaling parameter to recover the remaining households variables.

$$C = Y - I - j^C$$

$$c^P = C - c^E$$

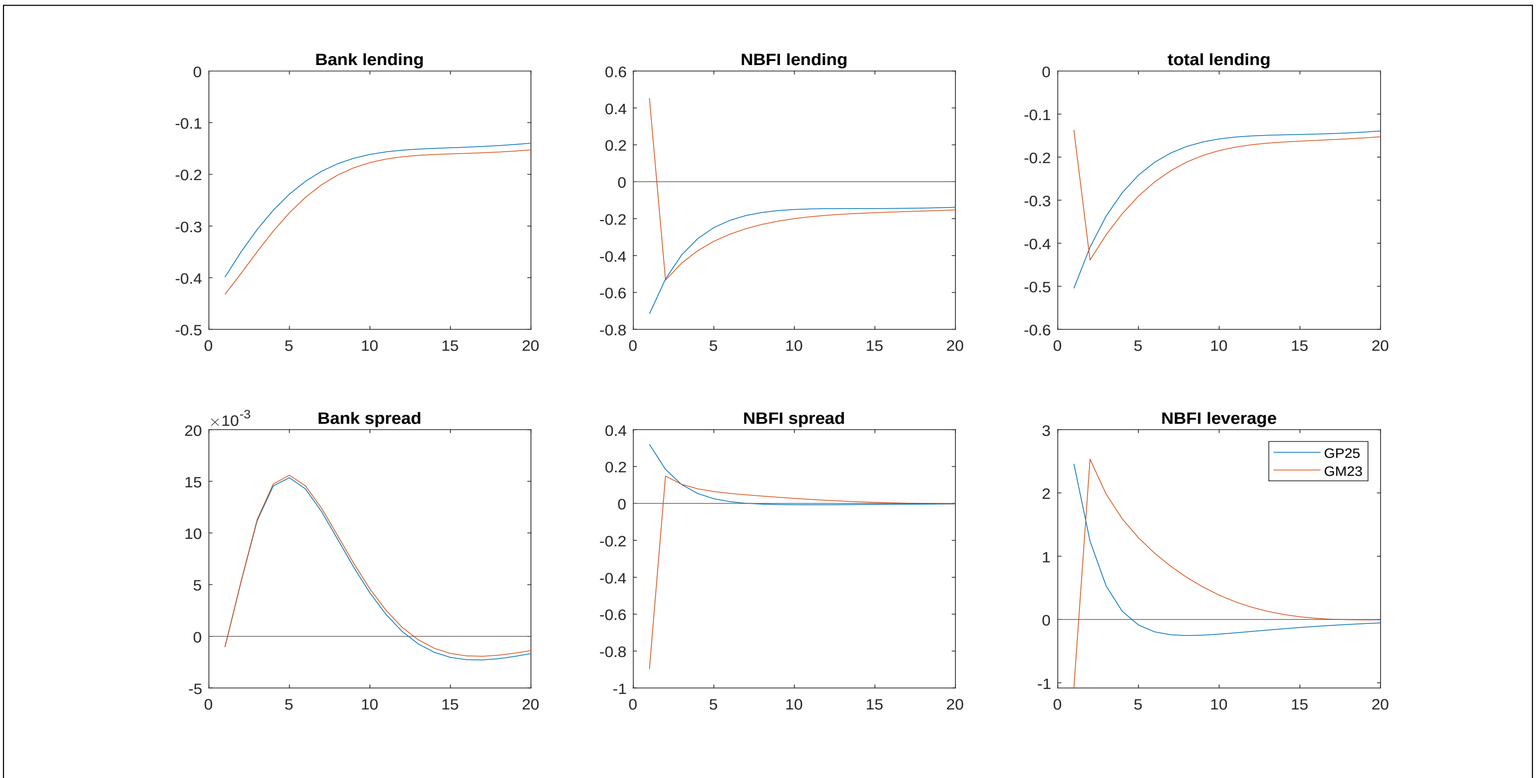
$$\lambda^P = \frac{(1 - \beta^P a^P)}{(1 - a^P)} (c^P)^{-1}$$

$$\chi = \lambda^P mrs^P$$

C Comparison with Gebauer and Mazelis (2023)

Figure 6 presents a comparison between the impulse responses generated by our model (GP25) and those from Gebauer and Mazelis (2023) (GM23). The key distinction arises from our divergence from the assumption - employed in Gertler and Karadi (2011) and adopted by Gebauer and Mazelis (2023) - that the price of capital matches the price of financial assets on institutional balance sheets. In our framework, NBFI leverage is tied to bond prices (q^s), not capital prices (q^k) as in Gebauer and Mazelis (2023). This leads to a notable difference: in Gebauer and Mazelis (2023), NBFI leverage first declines but turns positive after several quarters, while in our model, it rises immediately. This is a direct mechanical consequence of higher interest rate, which depress the value of long-term bonds. Consequently, NBFI spreads evolve differently: in Gebauer and Mazelis (2023), spreads decrease, whereas in our model, where spreads are defined as the expected ex-post bonds returns minus the deposit rate, spreads increase on impact because falling bond prices boost expected returns. The combination of rising spreads and tighter leverage constraints causes a prompt decline in NBFI lending in our model. In contrast, although total lending also falls in Gebauer and Mazelis (2023), the decrease is less sharp, owing to the partial substitution between bank and NBFI lending.

Figure 6: Interest Rate Shock: comparison with Gebauer and Mazelis (2023)



Note: Bank and NBFI spreads are reported as annualized absolute deviations from their steady-state values. All other variables are expressed as percentage deviations. Specifically, since in our model the annualized policy rate is defined as $R_t^{ann} = R_t * 400$, a 0.01 standard deviation monetatry policy shock corresponds to a 4% deviation in the annualized policy rate.

D The Role of NBFI - Constant Aggregate SS Lending

We consider NBFIs as an additional avenue for firms to obtain funding. As a result, our baseline model - which includes NBFIs - features a higher level of aggregate steady-state lending compared to the scenario that excludes them. To test the robustness of our findings, we compare the two models from the original paper with an alternative version: here, NBFIs are excluded, but steady-state bank lending is increased so that aggregate lending, capital, investment, and GDP match those of the baseline model with NBFIs (see Figure 7).

The Figure illustrates that when steady-state bank lending is higher, a negative shock leads to a sharper reduction in bank loans (yellow compared to orange line). By contrast, comparing the baseline model to this alternative scenario (yellow versus blue line) reveals that even though aggregate lending falls more in the baseline model (relative to its steady state), the declines in capital demand and GDP are less severe. This suggests that, in this configuration, NBFIs do not amplify the effects of shocks on GDP.

Our interpretation is as follows: based on the linearized capital demand equation, if we ensure that steady-state lending, investment, capital and GDP are equal across both models, then the role of the collateral constraint's shadow value, δ_C, in the alternative model effectively becomes a weighted average of the impacts of δ_C and δ_S in the baseline (see a comparison between equations A.1 and A.2 below). This means that, because NBFI interest rates do not rise - at least initially - δ_S increases more (as indicated by the lending demand equations A.3 and A.4). This higher value of δ_S act to moderate the reduction in capital demand when both types of financial institutions are present, assuming all else remains constant.

Baseline model - capital demand

$$\begin{aligned}\frac{\beta^E\lambda^E\alpha^E p^E y^E(1-\alpha^E)}{k}\hat{k}_t &= \beta^E\lambda^E\left(\frac{\alpha^E p^E y^E}{k}+(1-\delta^k)\right)\lambda\hat{^E_{t+1}} - \lambda^E\left(q\hat{^k_t}+\lambda\hat{^E_t}\right) \\ &+ \frac{\beta^E\lambda^E\alpha^E p^E y^E(1-\alpha^E)}{k}\left(p\hat{^E_{t+1}} + A\hat{_{t+1}} + (1-\alpha^E)n\hat{_{t+1}}\right) \\ &+ (\beta^E\lambda^E + m^C\delta^C + m^S\delta^S)(1-\delta^k)q\hat{^k_{t+1}} \\ &+ (1-\delta^k)m^C\delta^C\hat{\delta^C} + (1-\delta^k)m^S\delta^S\hat{\delta^S}\end{aligned} \tag{A.1}$$

No NBFI model - capital demand

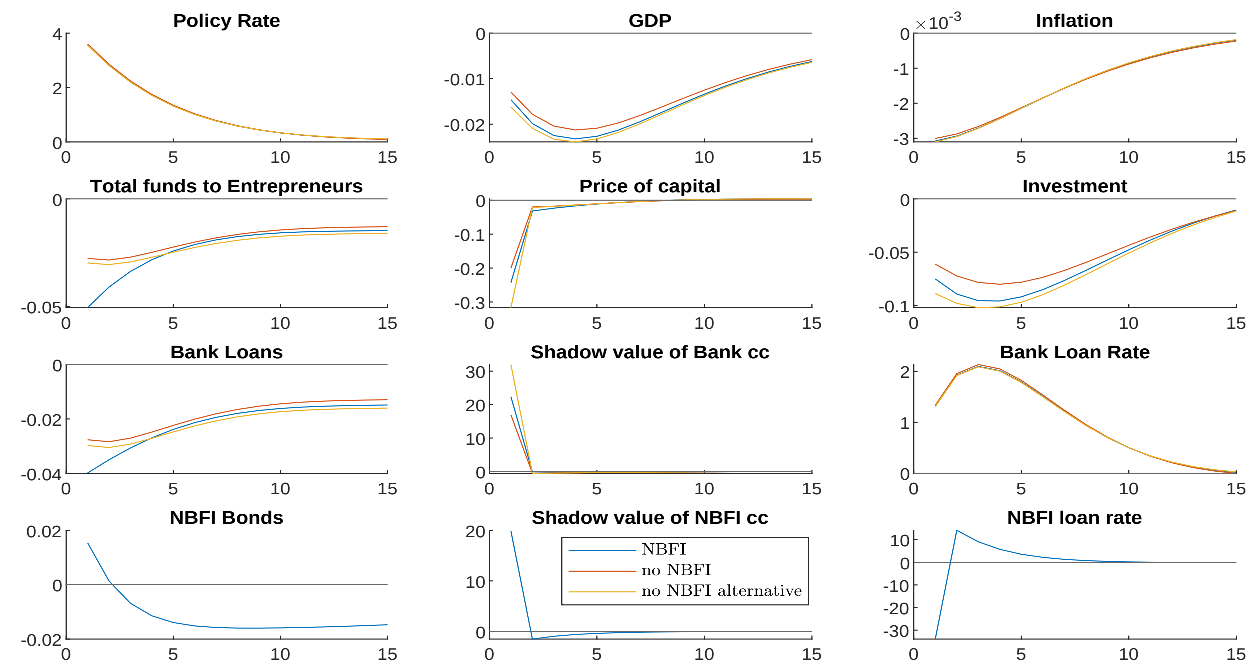
$$\frac{\beta^E\lambda^E\alpha^E p^E y^E(1-\alpha^E)}{k}\hat{k}_t = \beta^E\lambda^E\left(\frac{\alpha^E p^E y^E}{k} + (1-\delta^k)\right)\hat{\lambda^E_{t+1}} - \lambda^E\left(\hat{q^k_t}+\hat{\lambda^E_t}\right) \tag{A.2}$$
$$+ \frac{\beta^E\lambda^E\alpha^E p^E y^E(1-\alpha^E)}{k}\left(\hat{p^E_{t+1}} + \hat{A_{t+1}} + (1-\alpha^E)\hat{n_{t+1}}\right)$$
$$+ (\beta^E\lambda^E + m^C\delta^C)(1-\delta^k)\hat{q^k_{t+1}}$$
$$+ (1-\delta^k)m^C\delta^C\hat{\delta^C}$$

Lending demand equations

$$\hat{\delta^C_t} = \frac{\lambda^E}{(1+r^{CE})\delta^C}\hat{\lambda^E_t} - \frac{(\beta^E\lambda^E+\delta^C)r^{CE}}{(1+r^{CE})\delta^C}\hat{r^{CE}_t} + \frac{\beta^E\lambda^E+\delta^C}{\delta^C}\hat{\pi_{t+1}} - \frac{\beta^E\lambda^E}{\delta^C}\hat{\lambda^E_{t+1}} \tag{A.3}$$

$$\hat{\delta^S_t} = \frac{\lambda^E}{(1+r^{SE})\delta^S}\hat{\lambda^E_t} - \frac{(\beta^E\lambda^E+\delta^S)r^{SE}}{(1+r^{SE})\delta^S}\hat{r^{SE}_{t+1}} + \frac{\beta^E\lambda^E+\delta^S}{\delta^S}\hat{\pi_{t+1}} - \frac{\beta^E\lambda^E}{\delta^S}\hat{\lambda^E_{t+1}} \tag{A.4}$$

Figure 7: Interest Rate Shock: comparison with higher steady state bank lending



Note: interest rates are reported as annualized absolute deviations from their steady-state values. All other variables are expressed as percentage deviations. Specifically, since in our model the annualized policy rate is defined as $R_t^{ann} = R_t * 400$, a 0.01 standard deviation monetatry policy shock corresponds to a 4% deviation in the annualized policy rate. The blue and orange lines correspond to the two models analyzed in Section 5.2: our baseline model and a counterfactual model in which NBFIs are turned off. The yellow line represents an alternative version of the counterfactual model, where NBFIs are also turned off, but steady-state bank lending is increased to match the total lending, investment, and GDP levels of the baseline model.

E GDP-at-Risk robustness checks

In this section, we conduct two robustness checks for our GDP-at-risk analysis. First, we assess the impact of an isolated supply-side shock. Next, we explore a scenario where all shocks are included, with calibrations based on Gebauer and Mazelis (2023).

E.1 Supply Side Shock

In the first exercise, we examine how an external reduction in the elasticity of substitution, ϵ_t^p, impacts the economy. This decline drives up the reset price $\Pi_t^{\#}$ chosen by retailers, leading to higher inflation through its effect on the Phillips curve. As anticipated, this surge in inflation prompts monetary policymakers to raise interest rates, which consequently lowers bond prices and triggers the same NBFI amplification mechanism described in the main text.

Tables 6 and 7, along with Figure 9, reproduce the analysis presented earlier in Section 5.3. The results reinforce our central conclusion: the presence of NBFIs intensifies the effects of adverse supply shocks. Owing to the asymmetric design of our model, this amplification is particularly pronounced in the left tail of the GDP distribution, rather than at its center. While NBFIs exert minimal influence over the median outcome, their impact on the extremes of the distribution is substantial. These results hold true even when a zero lower bound is introduced as a secondary source of nonlinearity, as discussed in Section 5.3.

Table 6: 5th percentile and median values of the distribution of output deviations from steady state.

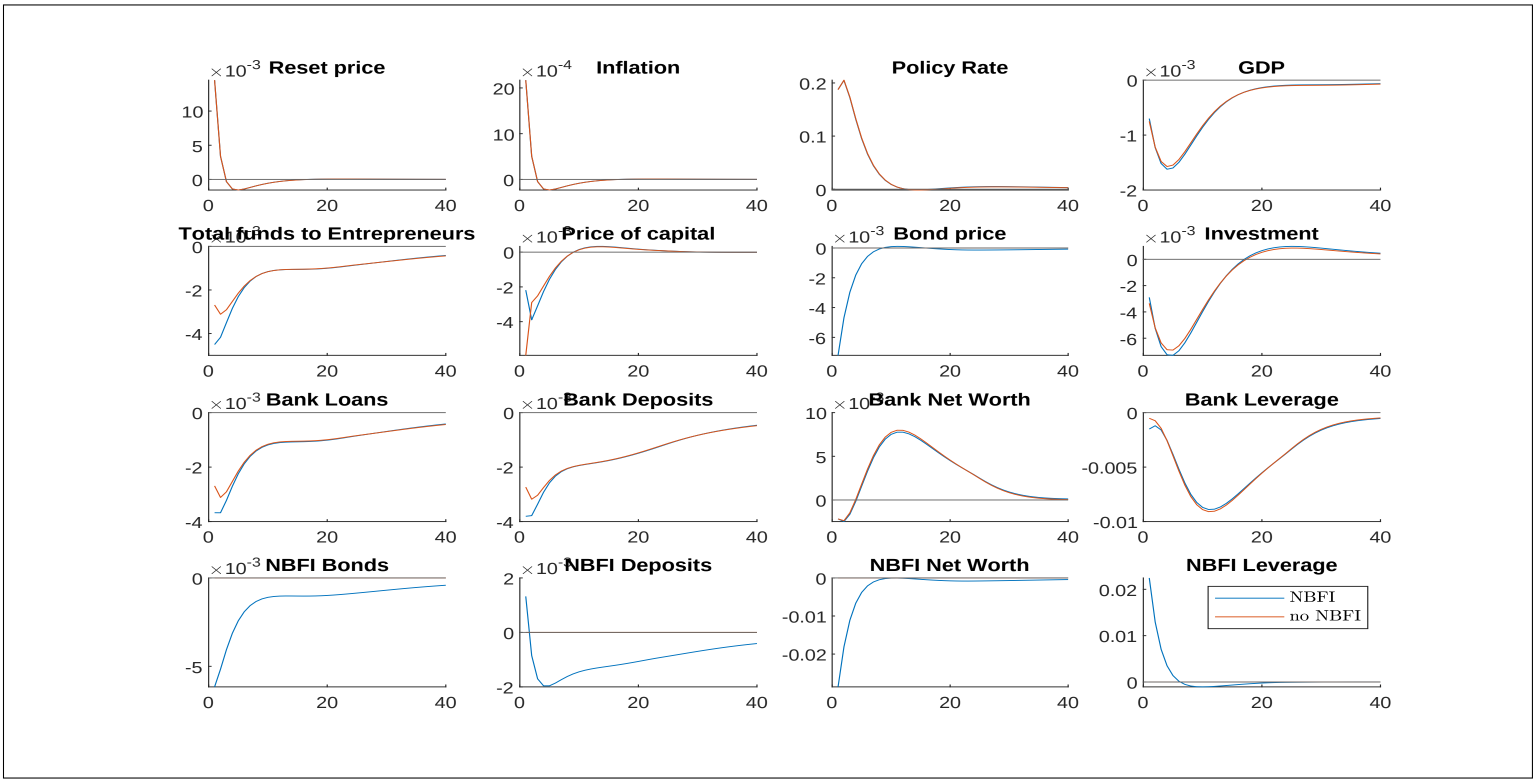
	No NBFI	NBFI	diff.
Median, linear	0.0059%	0.0058%	-0.0001%
Median, non linear	-0.0013%	-0.0011%	0.0002%
GaR, linear	-0.8845%	-0.9095%	-0.0250%
GaR, non linear	-0.9109%	-0.9372%	-0.0263%

Note: GDP-at-risk and median values are computed respectively as the 5th and the 50th percentiles of the distribution of output deviations from the steady state over 100 periods, where each period is averaged over 1000 simulations. The non-linear model includes an occasionally binding constraint on bank capital adjustment costs.

E.2 All shocks

In the second exercise, we examine the combined impact of all shocks, with each period featuring shocks drawn from a normal distribution - each calibrated following Gebauer and Mazelis (2023). Tables 8

Figure 8: The Role of NBFIs - Price Markup Shock



Note: interest rates are reported as annualized absolute deviations from their steady-state values. All other variables are expressed as percentage deviations.

Table 7: 5th percentile and median values of the distribution of output deviations from steady state (two OBCs).

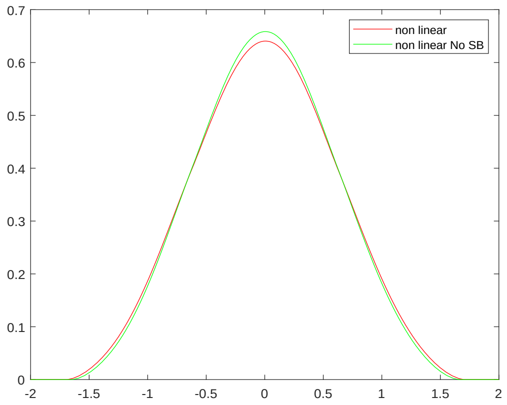
	No NBFI	NBFI	diff.
Median, linear	0.0009%	0.0011%	0.0002%
Median, non linear	-0.0064%	-0.0061%	0.0003%
GaR, linear	-0.9018%	-0.9273%	-0.0255%
GaR, non linear	-0.9289%	-0.9558%	-0.0269%

Note: GDP-at-risk and median values are computed respectively as the 5th and the 50th percentiles of the distribution of output deviations from the steady state over 100 periods, where each period is averaged over 1000 simulations. The non-linear model includes two occasionally binding constraints on bank capital adjustment costs and on the policy rate.

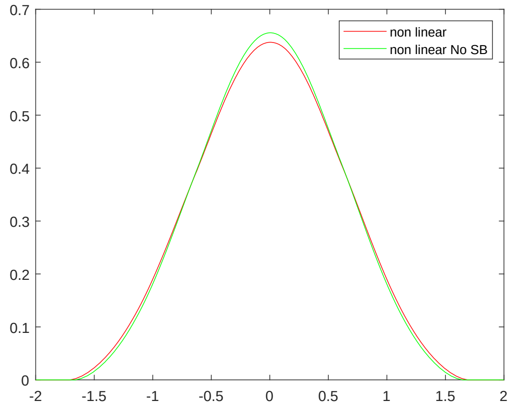
and 9, as well as Figure 10, reproduce the analyses from Section 5.3.

Our findings reinforce the earlier results: the presence of NBFIs intensifies the consequences of negative shocks. Notably, because our model is asymmetric, this amplification is particularly evident in the left tail of the GDP distribution, rather than at its center. While NBFIs have minimal effect on the median projection, their influence on the extremes of the distribution is substantial. These

Figure 9: Probability Density Functions: GDP deviations from steady state



(a) One OBC (asymmetric adj. costs)



(b) Two OBC (asymmetric adj. costs + ZLB)

Note: The left-hand panel displays the probability density functions of GDP deviations from steady state for two models with an occasionally binding constraint on bank capital adjustment costs. The red line represents the baseline model, while the green line corresponds to the counterfactual model in which NBFIs are turned off. The right-hand panel shows the same comparison, but for models that include both an occasionally binding constraint on bank capital adjustment costs and a constraint on the policy rate (ZLB).

results hold even when the zero lower bound is introduced as a second non-linearity, consistent with the approach in Section 5.3.

Table 8: 5th percentile and median values of the distribution of output deviations from steady state.

	No NBFI	NBFI	diff.
Median, linear	0.0133%	0.0209%	0.0076%
Median, non linear	-0.0085%	-0.0014%	0.0071%
GaR, linear	-2.7427%	-2.8006%	0.0579%
GaR, non linear	-2.7520%	-2.8140%	0.0620%

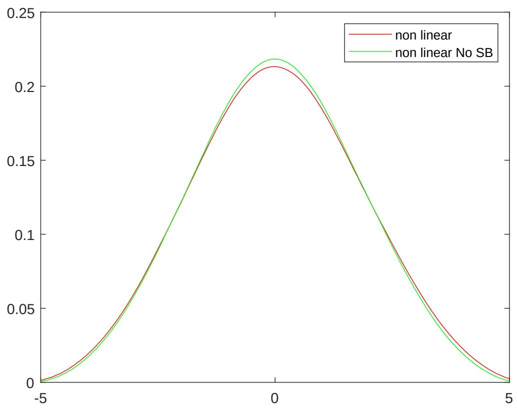
Note: GDP-at-risk and median values are computed respectively as the 5th and the 50th percentiles of the distribution of output deviations from the steady state over 100 periods, where each period is averaged over 1000 simulations. The non-linear model includes an occasionally binding constraint on bank capital adjustment costs.

Table 9: 5th percentile and median values of the distribution of output deviations from steady state (two OBCs).

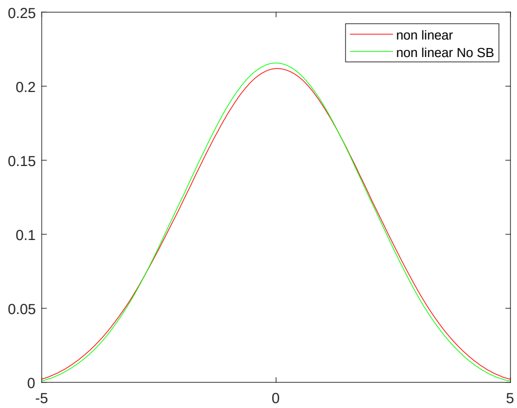
	No NBFI	NBFI	diff.
Median, linear	0.0049%	0.0327%	0.0278%
Median, non linear	-0.0194%	-0.0000%	0.0194%
GaR, linear	-2.7686%	-2.8487%	0.0801%
GaR, non linear	-2.7993%	-2.8697%	0.0704%

Note: GDP-at-risk and median values are computed respectively as the 5th and the 50th percentiles of the distribution of output deviations from the steady state over 100 periods, where each period is averaged over 1000 simulations. The non-linear model includes two occasionally binding constraints on bank capital adjustment costs and on the policy rate.

Figure 10: Probability Density Functions: GDP deviations from steady state



(a) One OBC (asymmetric adj. costs)



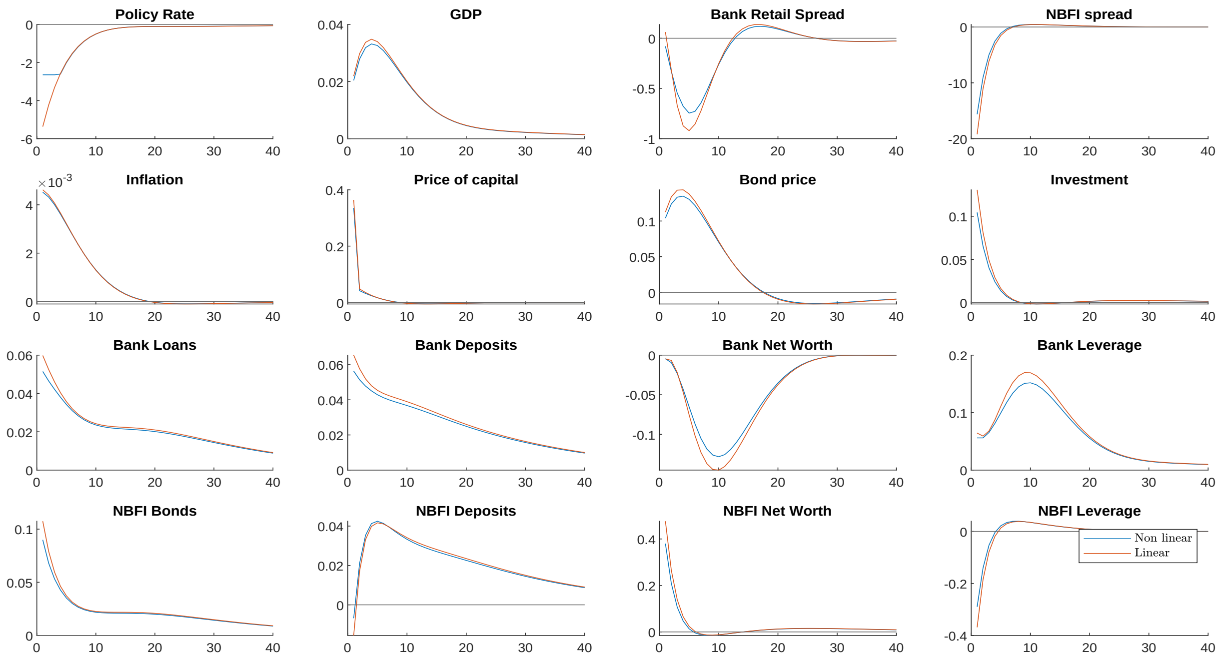
(b) Two OBC (asymmetric adj. costs + ZLB)

Note: The left-hand panel displays the probability density functions of GDP deviations from steady state for two models with an occasionally binding constraint on bank capital adjustment costs. The red line represents the baseline model, while the green line corresponds to the counterfactual model in which NBFIs are turned off. The right-hand panel shows the same comparison, but for models that include both an occasionally binding constraint on bank capital adjustment costs and a constraint on the policy rate (ZLB).

F Impulse Response Functions of a Monetary Policy Shock - the Role of the ZLB

When analysing model dynamics at the zero lower bound, clear distinctions emerge. Fig.11 illustrates the effects of an expansionary monetary policy shock, revealing that in the non-linear scenario (depicted by the blue line), the annualised policy rate can decrease by only by 2.64 percentage points (with the steady-state quarterly rate at 0.0066). This limited decline results in a smaller reduction in the bank retail spread, which in turn tempers the growth of bank loans and leverage. Because interest rates cannot fall further, the rise in bond prices is also restricted. While higher asset prices do benefit the NBFI balance sheet, the positive impact is less pronounced than in environments where rates are unconstrained. Consequently, entrepreneurs gain less access to funding from loans and bonds in the zero lower bound scenario, resulting in smaller increases in investment and GDP.

Figure 11: Interest Rate Shock: the role of the zero lower bound



Note: interest rates are reported as annualized absolute deviations from their steady-state values. All other variables are expressed as percentage deviations.