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University of Groningen

Visiting address:
Nettelbosje 2
9747 AE Groningen
The Netherlands

Postal address:
P.O. Box 800
9700 AV Groningen
The Netherlands

T +31 50 363 9090/7068

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Christiaan van der Kwaak
University of Groningen, Faculty of Economics and Business, Department of Economics, Econometrics and Finance
c.g.f.van.der.kwaak@rug.nl

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Christiaan van der Kwaak†

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Preliminary version

Abstract

In this paper, we study the *long-run* impact of the central bank lending at low-interest-rates to banks in times of financial crisis. While the provision of such funding mitigates the impact of financial crises ex post, we find that it increases bank risk taking ex ante, and therefore increases the likelihood of financial crises. Despite more frequent crises, however, the long-run impact on the macroeconomy is beneficial, as the positive effect from low-interest-rate funding mitigates the contraction of credit at the height of a crisis. The long-run impact on the macroeconomy, however, is quantitatively small.

Keywords: Unconventional Monetary Policy; Financial Fragility, Risk-taking
JEL: E32, E52, E62, E63

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†Affiliation: Rijksuniversiteit Groningen. Address: Nettelbosje 2, 9747 AE Groningen. Email address: c.g.f.van.der.kwaak@rug.nl. Telephone: +31(0)50 363 3760.

1 Introduction

In December 2011, the European Central Bank (ECB) lent almost one trillion euros for three years to commercial banks under the so-called unconventional Longer-Term Refinancing Operations (LTROs), which allowed banks in the Eurozone to reduce their funding costs.[1,2] Neither was this the last time the ECB lent at below-market-rates to Eurozone banks, as it started the so-called Targeted Longer-Term Refinancing Operations (TLTROs) in 2014 when the Eurozone economy effectively landed at the Effective Lower Bound (ELB).[3] Nor was the ECB the only central bank to massively lend at below-market-rates to commercial banks, as the Federal Reserve and the Bank of England also massively lent to their respective banking sectors at the height of the Great Financial Crisis in 2008.

Given the scale at which central banks sometimes lend to commercial banks, the question arises whether and to what extent such low-interest-rate funding leads to more risk taking by banks ex ante, and thereby 'sow' the seeds for future financial crises. Does the provision of such low-interest-rate funding increase the frequency of financial crises? How does it affect credit provision in the long-run? What is the long-run impact on the macroeconomy? These are the questions that we tackle in this paper.

We do so within a New Keynesian DSGE model with financial intermediaries that are financed by deposits, net worth, and central bank funding.[4] These funds are used to acquire government bonds, central bank reserves, and corporate securities that finance the stock of physical capital used in production (Van der Kwaak and Van Wijnbergen, 2014; Bocola, 2016; Kirchner and van Wijnbergen, 2016; Sims and Wu, 2021). To obtain central bank funding, intermediaries need to pledge sufficient corporate securities and government bonds as collateral (van der Kwaak, 2023). Financial intermediaries are subject to an occasionally binding incentive compatibility constraint that prevents them from perfectly elastically arbitraging away return differences when this constraint binds (Gertler and Kiyotaki, 2010; Gertler and Karadi, 2011). Following Gete and Melkadze (2020), intermediaries also take into account how their balance sheet choices affect their funding costs. Finally, intermediaries' return on corporate securities is subject to a multiplicative idiosyncratic shock (Bernanke et al., 1999), which introduces the possibility of default when the realization of the shock causes the return on intermediaries' assets to be below the return on their liabilities (van der Kwaak et al., 2023). As intermediaries are subject to limited liability, they only care about the realization of the shock *conditional* on survival, which induces them to expand their balance sheets, everything else equal (Diamond and Rajan, 2011). Conventional

[1] The announcement of these unconventional LTROs can be found at `https://www.ecb.europa.eu/press/pr/date/2011/html/pr111208_1.en.html`.

[2] Bank of Italy (2012) reports that Italian commercial banks were able to reduce overall funding costs by 10 basis points, as the interest rate on the unconventional LTROs was substantially below the interest rate on the foreign wholesale funding that it replaced.

[3] The announcement can be found at `https://www.ecb.europa.eu/press/pr/date/2014/html/pr140605_2.en.html`. Under the TLTROs, Eurozone banks were able to borrow for four years at interest rates that were below the ECB policy rate when credit provision expanded sufficiently afterwards.

[4] We interchangeably use '(commercial) banks' and '(financial) intermediaries' to denote the same group of economic agents.

monetary policy consists of the central bank setting the nominal interest rate on reserves following a standard active Taylor rule, which is bounded below by the Zero Lower Bound (ZLB). Above the ZLB, the interest rate on central bank funding is equal to that on reserves. At the ZLB, the central bank reduces the nominal interest rate on central bank funding relative to that on reserves following an endogenous rule in inflation and the output gap. Specifically, the lower inflation and the more negative the output gap, the lower the nominal interest rate on central bank funding. We solve two model versions: one with the central bank providing low-interest-rate funding at the ZLB and one without. Afterwards, we simulate both model versions for many periods, which allows us to assess the long-run impact of this unconventional monetary policy.

Our main contribution is that we are the first to investigate the *long-run* macroeconomic and financial stability implications of the central bank providing low-interest-rate funding to commercial banks in times of crises. Specifically, we are the first to investigate whether such a policy leads to more risk taking by banks ex ante, and through that channel leads to more financial crises. The focus on the long-run impact contrasts with the current literature, which focuses on the *short-run* impact of the central bank providing low-interest-rate funding in financial crisis times (Gertler and Kiyotaki, 2010; Cahn et al., 2017; van der Kwaak, 2023). Our modeling innovation is the introduction of limited liability and bank default as in Gete and Melkadze (2020) within the framework of van der Kwaak (2023), which creates the possibility of risk taking by banks (Diamond and Rajan, 2011).

We find that the central bank providing low-interest-rate funding to commercial banks indeed leads to more risk taking by banks ex ante, which negatively affects financial stability. Specifically, the fact that banks anticipate low-interest-rate funding in times of crisis induces them to operate with higher leverage ratios, as a result of which financial crises become more frequent. Ex post, however, low-interest-rate central bank funding positively affects financial stability, as it mitigates the impact that financial crises have. The reason is that such funding increases banks' profitability, which reduces the number of bank insolvencies in a crisis. Moreover, banks operating with more net worth also allows them to expand credit provision to the real economy in times of crisis (relative to no intervention), as a result of which investment and capital accumulation increase (van der Kwaak, 2023). These positive effects are strong enough to offset the negative macroeconomic effects from more frequent financial crises, as a result of which long-run capital, output, and consumption are higher relative to the case where the central bank does not provide low-interest-rate funding. The long-run impact on the macroeconomy, however, is quantitatively small.

Literature review

Since the financial crisis of 2008, a burgeoning literature has emerged in which the impact of unconventional monetary policies is studied. Early papers that study the impact of these policies within dynamic general equilibrium models are Gertler and Kiyotaki (2010); Gertler and Karadi

(2011); Curdia and Woodford (2011); Chen et al. (2012). Most of these focus on asset purchases by the central bank. Subsequently, papers emerged that focus on the macroeconomic impact of central bank lending (Gertler and Kiyotaki, 2010; Schabert, 2015; Hörmann and Schabert, 2015; Cahn et al., 2017; van der Kwaak, 2023). Most of these papers, however, focus on the short-run impact. An exception is Bocola (2016), who studies the long-run impact of the ECB's unconventional LTROs of December 2011 and February 2012. However, in all these papers the agents that borrow from the central bank are not subject to limited liability. Therefore, the risk taking channel that is at the heart of our paper is absent.

One of the first paper to highlight moral hazard and risk taking incentives is Kareken and Wallace (1978), who show that deposit insurance induces banks to lever up their balance sheet. Related is the literature that studies moral hazard in the context of bailouts in a macroeconomic context (Bianchi, 2016), and more recently Katz and van der Kwaak (2022) who compare the impact on financial stability of bank bail-ins and bailouts.

Our paper is also related to the literature in which financial crises arise endogenously within general equilibrium models. One of the first papers in this category is Boissay et al. (2016), who explain how financial crises follow credit-intensive booms. In their paper, banks are heterogenous in their intermediation capacity, as a result of which an interbank market endogenously arises. A financial crisis occurs when this interbank market breaks down after a sustained period of credit expansion has pushed down returns, and suddenly a negative shock arises. This contrasts with our paper, where a financial crisis occurs when intermediaries' incentive compatibility constraint starts to bind. The most important difference, however, is the fact that Boissay et al. (2016) employ a real business cycle model. Therefore, monetary policy cannot affect the frequency of financial crises.

Financial crises also arise endogenously within the New Keynesian model of Boissay et al. (2022). Similarly to Boissay et al. (2016), they find that financial crises especially occur at the end of a protracted economic boom when there is excess capital and the marginal product of capital is low. Firms, however, are not subject to limited liability, and hence there is no risk taking motive in their model. In addition, the focus of their paper is on how conventional monetary policy affects the frequency of financial crises, whereas the focus of our paper is on the long-run impact from low-interest-rate central bank lending. Coimbra and Rey (2023) also focus on the impact of conventional monetary policy on financial stability. In contrast to Boissay et al. (2016) and Boissay et al. (2022), however, banks are subject to limited liability and protected by deposit insurance. As a result, banks can engage in risk taking as in Kareken and Wallace (1978). Interestingly, Coimbra and Rey (2023) find a nonlinear risk-taking channel of monetary policy: when the level of interest rates is high, cutting interest rates leads to the entry of less risk-taking intermediaries, which expands credit to the real economy. However, when interest rates are already low, the effect from less risk-taking intermediaries entering into the market is relatively small, while the effect from more risk-taking intermediaries increasing leverage ratios dominates. As a result, financial instability increases while the macroeconomic stimulus is relatively small. Another paper which features limited liability and risk-shifting incentives for financial intermediaries within a New Keynesian model is Rottner (2023), who focuses on the mechanisms behind the buildup of the financial crisis of 2008. Therefore, his model does not feature unconventional monetary policies, which were only employed *after* the 2008 financial crisis started.

In an empirical context, Drechsler et al. (2014) show that weakly capitalized banks took out more loans from the ECB and engaged in risk taking by using the LTRO funding to acquire risky assets such as distressed sovereign debt. Acharya and Steffen (2015) establish the presence of carry trade behavior in the sense of banks buying high-yielding peripheral bonds. Risk-shifting and regulatory arbitrage motives were stronger for large banks and banks with high risk-weighted assets and low capital ratios.

There is also empirical research on the impact of conventional monetary policy on financial stability. Schularick et al. (2021) investigate whether increasing interest rates can defuse financial stability risks during booms. Interestingly, they find that doing so *increases* the risk of a financial crisis rather than decreasing it. Moreover, raising rates does not mitigate the negative effect on GDP when a financial crisis materializes ex post. Grimm et al. (2023) are the first to show that loose monetary policy substantially increases the probability of financial crises. While loose monetary policy is expansionary in the short run, it leads to strong negative effects on GDP in the medium term. They also identify the underlying mechanisms, and find that the culprit is a buildup in asset prices and credit growth when interest rates remain below the natural rate for an extended period. Finally, Grimm et al. (2023) provide empirical evidence for risk taking through reaching for yield.

2 Model

2.1 Financial intermediaries

The economy features a continuum of financial intermediaries $j \in [0, 1]$, which are owned by households. Intermediaries enter period t with net worth $n_{j,t}$, and start the period by paying out an (exogenous) fraction σ in dividends to households, who are the ultimate owners of the intermediaries. In addition to ex post net worth $(1-\sigma)\, n_{j,t}$, they issue deposits $d_{j,t}$ at price q_t and obtain funding $d^{cb}_{j,t}$ from the central bank. The resulting funds finance the acquisition of corporate securities $s^k_{j,t}$ at a price q^k_t, government bonds $s^b_{j,t}$ at price q^b_t, and central bank reserves $m^R_{j,t}$:

$$q^k_t s^k_{j,t} + q^b_t s^b_{j,t} + m^R_{j,t} = (1-\sigma)\, n_{j,t} + q_t d_{j,t} + d^{cb}_{j,t}. \tag{1}$$

In order to access central bank funding, intermediaries must pledge collateral at the central bank. However, the central bank applies a haircut $1-\theta^a$ on the market value of asset $a \in \{k, b\}$ when determining how much central bank funding to provide for one euro of asset a. Therefore, financial intermediary j must abide by the following collateral constraint (van der Kwaak, 2023):

$$d^{cb}_{j,t} \leq \theta^k q^k_t s^k_{j,t} + \theta^b q^b_t s^b_{j,t}. \tag{2}$$

Corporate securities pay an aggregate gross return R^k_{t+1} in period $t+1$, while government bonds, central bank reserves and central bank funding pay a gross return R^b_{t+1}, R^R_{t+1}, and R^{cb}_{t+1}, respectively. Deposits $d_{j,t}$ issued in period t pay an amount $d_{j,t}/\pi_{t+1}$ in period $t+1$, where $\pi_t \equiv P_t/P_{t-1}$ denotes the gross inflation rate of final goods and P_t the price level. In addition to aggregate shocks, the return on corporate securities is also subject to a multiplicative idiosyncratic shock $\omega_{j,t+1}$, which all intermediaries draw from the same lognormal distribution with mean one and time-varying volatility $\sigma_{\omega,t}$ (Bernanke et al., 1999). Therefore, the pre-dividend net worth $n_{j,t+1}$ at the beginning of period $t+1$ is given by:

$$n_{j,t+1} = \omega_{j,t+1} R^k_{t+1} q^k_t s^k_{j,t} + R^b_{t+1} q^b_t s^b_{j,t} + R^R_{t+1} m^R_{j,t} - \frac{d_{j,t}}{\pi_{t+1}} - R^{cb}_{t+1} d^{cb}_{j,t}. \tag{3}$$

From the above law of motion, we can derive the cut-off value $\bar{\omega}_{j,t+1}$, below which intermediary j is insolvent:

$$\bar{\omega}_{j,t+1} = \frac{d_{j,t}/\pi_{t+1} + R^{cb}_{t+1} d^{cb}_{j,t} - R^b_{t+1} q^b_t s^b_{j,t} - R^R_{t+1} m^R_{j,t}}{R^k_{t+1} q^k_t s^k_{j,t}}. \tag{4}$$

From this expression, we see that the cut-off value is increasing in deposits and central bank funding, while it is decreasing in government bonds and central bank reserves, everything else equal. Furthermore, we see that a relative portfolio shfit from risky corporate securities to safe reserves and bonds decreases the cut-off value, everything else equal, and hence decreases the probability of insolvency and vice versa.

When $\omega_{j,t+1} < \bar{\omega}_{j,t+1}$, financial intermediaries have insufficient funds to repay all creditors, and is taken over by the deposit insurance agency (DIA) of the government. The DIA guarantees repayment of a fraction γ of deposits, while the cash flows for remaining fraction $1-\gamma$ is equal to the funds that can be recouped from the assets of the insolvent intermediary net of central bank funding (Clerc et al., 2015; van der Kwaak et al., 2023).[5] However, there are deadweight costs when recouping the corporate securities from the insolvent intermediary, as a result of which only a fraction $1-\mu$ of the cash flows $\omega_{j,t+1} R^k_{t+1} q^k_t s^k_{j,t}$ from these securities can be recouped (Bernanke et al., 1999).[6]

Following Gete and Melkadze (2020), we assume that intermediaries take into account how their balance sheet decisions affect the price q_t at which they can issue deposits to households. In order for households to be willing to hold deposits, the marginal cost from acquiring an additional unit of deposits q_t must be equal to the marginal benefit, which is equal to $1/\pi_{t+1}$ in case realization of the idiosyncratic shock is above the cut-off value $\bar{\omega}_{j,t+1}$. When the realization

[5] In reality, central banks are preferred creditors who are repaid before depositors are.

[6] We assume that there are no deadweight costs from recouping government bonds and central bank reserves, as government bonds are traded in highly liquid markets and the central bank has full control over central bank reserves.

is below the cut-off value, the marginal benefit is equal to γ/π_{t+1} plus a fraction $1-\gamma$ of the gross return on recouped assets $(1-\mu)\,\omega_{j,t+1}R^k_{t+1}q^k_t s^k_{j,t} + R^b_{t+1}q^b_t s^b_{j,t} + R^R_{t+1}m^R_{j,t} - R^{cb}_{t+1}d^{cb}_{j,t}$ of intermediary j:

$$\begin{aligned} q_t &= E_t\Bigg(\mathcal{M}_{t,t+1}\Bigg\{\int_{\bar{\omega}_{j,t+1}}^{\infty}\frac{1}{\pi_{t+1}}\cdot f\left(\omega_{j,t+1}\right)d\omega_{j,t+1} \\ &+ \int_0^{\bar{\omega}_{j,t+1}}\Bigg[\gamma\cdot\frac{1}{\pi_{t+1}} \\ &+ (1-\gamma)\,\frac{(1-\mu)\,\omega_{j,t+1}R^k_{t+1}q^k_t s^k_{j,t} + R^b_{t+1}q^b_t s^b_{j,t} + R^R_{t+1}m^R_{j,t} - R^{cb}_{t+1}d^{cb}_{j,t}}{d_{j,t}}\Bigg]\cdot f\left(\omega_{j,t+1}\right)d\omega_{j,t+1}\Bigg\}\Bigg), \end{aligned} \tag{5}$$

where $\mathcal{M}_{t,t+1}$ denotes households' stochastic discount factor. Financial intermediaries are owned by households, as a result of which future cash flows in period $t+s$ are discounted using households' stochastic discount factor $\mathcal{M}_{t,t+1}$. We show in Appendix A.1 that in equilibrium all intermediaries will choose the same ratio of deposits over corporate securities, government bonds, reserves, and central bank funding, respectively. Together with the fact that the distribution of the idiosyncratic shock is common across intermediaries, this implies that the cut-off value will be the same $\bar{\omega}_{j,t+1} = \bar{\omega}_{t+1}$. Hence, households' expected cash flows are identical across intermediaries, as a result of which the deposit price q_t will be the same across intermediaries, and households will hold deposits across all intermediaries.

Intermediaries are interested in maximizing the beginning-of-period continuation value $V_{j,t}$, which consists of the dividends $\sigma n_{j,t}$ received by households in period t and the expected discounted continuation value in period $t+1$:

$$V_{j,t} = \max_{\left\{s^k_{j,t},s^b_{j,t},m^R_{j,t},d_{j,t},d^{cb}_{j,t}\right\}} \sigma n_{j,t} + E_t\left\{\mathcal{M}_{t,t+1}\max\left[V_{j,t+1},0\right]\right\}. \tag{6}$$

Next, we follow Faria-e Castro (2021) by defining the ex post dividend continuation value $\mathcal{V}_{j,t}$:

$$\mathcal{V}_{j,t} \equiv V_{j,t} - \sigma n_{j,t}.$$

This allows us to rewrite intermediary j's optimization objective (6) as:

$$\mathcal{V}_{j,t} = \max E_t\left[\mathcal{M}_{t,t+1}\int_{\bar{\omega}_{j,t+1}}^{\infty}\left(\sigma n_{j,t+1} + \mathcal{V}_{j,t+1}\right)f\left(\omega_{j,t+1}\right)d\omega_{j,t+1}\right]. \tag{7}$$

Financial intermediaries, however, cannot perfectly elastically expand their balance sheet because of a moral hazard problem that limits the size of their balance sheet by the ex post dividend continuation value $\mathcal{V}_{j,t}$. This gives rise to the following incentive compatibility constraint (Gertler and Kiyotaki, 2010; Gertler and Karadi, 2011, 2013):

$$\mathcal{V}_{j,t} \geq \lambda_t^k q_t^k s_{j,t}^k + \lambda_t^b q_t^b s_{j,t}^b, \tag{8}$$

where λ_t^a with $a \in \{k, b\}$ is time-varying as in van der Kwaak and van Wijnbergen (2017):

$$\begin{aligned} \log\left(\lambda_t^k/\bar{\lambda}_k\right) &= \rho_k \log\left(\lambda_{t-1}^k/\bar{\lambda}_k\right) + \varepsilon_{k,t}, && (9) \\ \lambda_t^b &= \left(\bar{\lambda}_b/\bar{\lambda}_k\right)\lambda_t^k. && (10) \end{aligned}$$

Intermediaries' optimization problem consists of maximizing (7) subject to the balance sheet constraint (1), the collateral constraint (2), the law of motion for net worth (3), the cut-off value (4), the debt pricing equation (5), and the incentive compatibility constraint (8). As a result, we get the following first order conditions, see Appendix A.1:

$$\begin{aligned} s_{j,t}^k \quad &: \quad E_t\left[\Omega_{t,t+1}\int_{\bar{\omega}_{j,t+1}}^{\infty}\omega_{j,t+1}R_{t+1}^k f\left(\omega_{j,t+1}\right)d\omega_{j,t+1}\right] \\ &= \frac{\chi_t}{1+\mu_t}\left(1-\frac{d_{j,t}}{q_t^k}\cdot\frac{\partial q_t}{\partial s_{j,t}^k}\right)+\lambda_t^k\left(\frac{\mu_t}{1+\mu_t}\right)-\theta^k\left(\frac{\psi_t}{1+\mu_t}\right), && (11) \\ s_{j,t}^b \quad &: \quad E_t\left[\Omega_{t,t+1}\int_{\bar{\omega}_{j,t+1}}^{\infty}R_{t+1}^b f\left(\omega_{j,t+1}\right)d\omega_{j,t+1}\right] \\ &= \frac{\chi_t}{1+\mu_t}\left(1-\frac{d_{j,t}}{q_t^b}\cdot\frac{\partial q_t}{\partial s_{j,t}^b}\right)+\lambda_t^b\left(\frac{\mu_t}{1+\mu_t}\right)-\theta^b\left(\frac{\psi_t}{1+\mu_t}\right), && (12) \\ m_{j,t}^R \quad &: \quad E_t\left[\Omega_{t,t+1}\int_{\bar{\omega}_{j,t+1}}^{\infty}R_{t+1}^R f\left(\omega_{j,t+1}\right)d\omega_{j,t+1}\right] = \frac{\chi_t}{1+\mu_t}\left(1-d_{j,t}\cdot\frac{\partial q_t}{\partial m_{j,t}^R}\right), && (13) \\ d_{j,t} \quad &: \quad E_t\left[\Omega_{t,t+1}\int_{\bar{\omega}_{j,t+1}}^{\infty}\left(\frac{1}{\pi_{t+1}q_t}\right)f\left(\omega_{j,t+1}\right)d\omega_{j,t+1}\right] = \frac{\chi_t}{1+\mu_t}\left(1+\frac{d_{j,t}}{q_t}\cdot\frac{\partial q_t}{\partial d_{j,t}}\right), && (14) \\ d_{j,t}^{cb} \quad &: \quad E_t\left[\Omega_{t,t+1}\int_{\bar{\omega}_{j,t+1}}^{\infty}R_{t+1}^{cb} f\left(\omega_{j,t+1}\right)d\omega_{j,t+1}\right] = \frac{\chi_t}{1+\mu_t}\left(1+d_{j,t}\cdot\frac{\partial q_t}{\partial d_{j,t}^{cb}}\right)-\frac{\psi_t}{1+\mu_t} && (15) \end{aligned}$$

where χ_t denotes intermediaries' shadow value of the balance sheet constraint (1), ψ_t the shadow value of the collateral constraint (2), μ_t the shadow value of intermediaries' incentive compatibility constraint (8), and $\Omega_{t,t+1} \equiv \mathcal{M}_{t,t+1}\left[\sigma + (1-\sigma)\chi_{t+1}\right]$.

Next, it turns out that intermediaries' incentive compatibility constraint (8) can be rewritten as, see Appendix A.1:

$$\chi_t (1-\sigma) n_{j,t} \geq \lambda_t^k q_t^k s_{j,t}^k + \lambda_t^b q_t^b s_{j,t}^b. \tag{16}$$

Finally, the law of motion for aggregate net worth consists of the after-dividend aggregated net worth of intermediaries (3) that are solvent plus aggregate net worth χ_b that is provided to intermediaries that start operating:

$$n_t = \int_{\bar{\omega}_t}^{\infty} \sigma \left(\omega_t R_t^k q_{t-1}^k s_{t-1}^k + R_t^b q_{t-1}^b s_{t-1}^b + R_t^R m_{t-1}^R - \frac{d_{t-1}}{\pi_t} - R_t^{cb} d_{t-1}^{cb} \right) f(\omega_t)\, d\omega_t + \chi_b. \quad (17)$$

2.2 Households

There exists a continuum of identical households of measure one. Income comes from supplying labor h_t at wage rate w_t, (partial) repayment of deposits d_{t-1} issued in period $t-1$, corporate securities $s_{t-1}^{k,h}$, government bonds $s_{t-1}^{b,h}$, and profits ω_t of financial and non-financial firms. Income is spent on consumption c_t, lump sum taxes τ_t, deposits $q_t d_t$, corporate securities $q_t^k s_t^{k,h}$, and government bonds $q_t^b s_t^{b,h}$. Finally, households incur quadratic transaction costs when adjusting their holdings of corporate securities and government bonds (Gertler and Karadi, 2013). As a result, households' budget constraint is given by:

$$\begin{aligned} c_t + \tau_t + q_t d_t + q_t^k s_t^{k,h} + q_t^b s_t^{b,h} &+ \frac{1}{2}\kappa_k \left(s_t^{k,h} - \hat{s}^{k,h} \right)^2 + \frac{1}{2}\kappa_b \left(s_t^{b,h} - \hat{s}^{b,h} \right)^2 \\ &= w_t h_t + \frac{d_{t-1}}{\pi_t} + R_t^k q_{t-1}^k s_{t-1}^{k,h} + R_t^b q_{t-1}^b s_{t-1}^{b,h} + \omega_t. \quad (18) \end{aligned}$$

Household's lifetime utility is given by Epstein-Zin (EZ) preferences (Rudebusch and Swanson, 2012):

$$V_t = u(c_t, h_t) - \beta \left\{ \mathbb{E}_t \left[-V_{t+1}^{1-\psi} \right] \right\}^{\frac{1}{1-\psi}},$$

where $u(c_t, h_t) = \frac{c_t^{1-\sigma_c} - 1}{1-\sigma} - \frac{\chi}{1+\varphi} h^{1+\varphi}$ is given by Greenwood-Hercowitz-Huffman (GHH) preferences, in which σ_c denotes the inverse elasticity of intertemporal substitution, φ the inverse Frisch elasticity, and where ψ effectively determines the degree of risk aversion. In this formulation, households' risk aversion increases with ψ when $u(c_t, h_t) < 0$ everywhere, which will be the case in our simulations. Households' optimization problem is to maximize lifetime utility subject to the budget constraint (18), which results in the following first order conditions for labor supply, corporate securities, and government bonds:

$$h_t \; : \; w_t c_t^{-\sigma_c} = \chi h_t^{\varphi}, \quad (19)$$

$$s_t^{k,h} \; : \; \mathbb{E}_t \left\{ \mathcal{M}_{t,t+1} \left[\frac{R_{t+1}^k q_t^k}{q_t^k + \kappa_k \left(s_t^{k,h} - \hat{s}^{k,h} \right)} \right] \right\} = 1, \quad (20)$$

$$s_t^{b,h} \; : \; \mathbb{E}_t \left\{ \mathcal{M}_{t,t+1} \left[\frac{R_{t+1}^b q_t^b}{q_t^b + \kappa_b \left(s_t^{b,h} - \hat{s}^{b,h} \right)} \right] \right\} = 1, \quad (21)$$

with the stochastic discount factor $\mathcal{M}_{t,t+1}$ given by:

$$\mathcal{M}_{t,t+1} = \beta \left(\frac{c_{t+1}}{c_t}\right)^{-\sigma} \left(\frac{V_{t+1}}{\left\{\mathbb{E}_t\left[V_{t+1}^{1-\psi}\right]\right\}^{\frac{1}{1-\psi}}}\right)^{-\psi}. \tag{22}$$

Finally, we remember that the first order condition for deposits is given by equation (5).

2.3 Production sector

2.3.1 Final goods producers

Final goods producers acquire retail goods y_t^f from a continuum of retail goods producers $f \in [0,1]$, and produce the final good y_t using the following constant elasticity of substitution production function:

$$y_t = \left[\int_0^1 \left(y_t^f\right)^{\frac{\epsilon-1}{\epsilon}} df\right]^{\frac{\epsilon}{\epsilon-1}}. \tag{23}$$

The market for final goods is perfectly competitive, as a result of which final goods producers take aggregate demand y_t, the price of final goods P_t, and the price of retail goods P_t^f as given. They subsequently choose how many retail goods y_t^f to purchase from each retail goods producer f in order to maximize profits:

$$\max_{y_t^f} \quad P_t y_t - \int_0^1 P_t^f y_t^f df,$$

subject to the production technology (23). As a result, we have the following demand equation for retail good f:

$$y_t^f = \left(\frac{P_t^f}{P_t}\right)^{-\epsilon} y_t. \tag{24}$$

2.3.2 Retail goods producers

There exists a continuum of retails goods producers $f \in [0,1]$. Each retail producer f acquires intermediate goods $y_{j,t}$ for a nominal price P_t^m and converts these one-for-one into retail goods y_t^f, after which the newly produced retail goods are sold to final goods producers at a price P_t^f. Following Calvo (1983) and Rotemberg (1982), we assume that each retail good is unique, as a result of which retail producer f is a monopolist. However, retail goods producers effectively operate under monopolistic competition, as final goods producers can substitute between different retail goods, see equation (23). Retail goods producers aik to maximize profits by setting the price P_t^f, but are subject to price adjustment costs as in Cao et al. (2023).[7] Therefore, retail

[7]Rotemberg (1982) has quadratic adjustment costs, which leads to severe deflationary episodes that increase the frequency with which the ZLB binds to unrealistic levels. See Cao et al. (2023) for more details.

goods producer f's optimization problem is given by:

$$\max_{P_t^f} \mathbb{E}_t \left\{ \sum_{s=0}^{\infty} \beta^s \frac{\lambda_{t+s}}{\lambda_t} \left[P_{t+s}^f y_{t+s}^f - P_{t+s}^m y_{t+s}^f \right.\right.$$
$$\left.\left. -\kappa_p \left[\frac{P_{t+s}^f / P_{t+s-1}^f - \pi}{\sqrt{\pi - \overline{\underline{\pi}}}} - 2\sqrt{P_{t+s}^f / P_{t+s-1}^f - \overline{\underline{\pi}}} + 2\sqrt{\pi - \overline{\underline{\pi}}} \right] y_{t+s} \right] \right\},$$

subject to final goods producers' demand (24) for retail good f. Here, π denotes the steady state gross inflation rate of the consumer price index, and $\overline{\underline{\pi}}$ governs the curvature of the cost function as inflation decreases. Next, we take the derivative with respect to P_t^f, and observe that all retail good producers will choose the same price $P_t^f = P_t$ in equilibrium, as a result of which we end up with the following nonlinear New Keynesian Philips curve:

$$\kappa_p \left(\frac{1}{\sqrt{\pi - \overline{\underline{\pi}}}} - \frac{1}{\sqrt{\pi_t - \overline{\underline{\pi}}}} \right) \pi_t = 1 - \epsilon + \epsilon m_t + \kappa_p E_t \left[\beta \Lambda_{t,t+1} \left(\frac{1}{\sqrt{\pi - \overline{\underline{\pi}}}} - \frac{1}{\sqrt{\pi_{t+1} - \overline{\underline{\pi}}}} \right) \pi_{t+1} \frac{y_{t+1}}{y_t} \right], \quad (25)$$

where $\pi_t \equiv P_t / P_{t-1}$ denotes the gross inflation rate of the consumer price index and $m_t \equiv P_t^m / P_t$ the relative price of intermediate goods.

2.3.3 Intermediate goods producers

A continuum of intermediate goods producers of measure one are operative in a perfectly competitive market for intermediate goods. Intermediate goods producer j issues corporate securities $s_{j,t-1}^k$ at price q_{t-1}^k at the end of period $t-1$ to acquire physical capital $k_{j,t-1}$ at price q_{t-1}^k from capital goods producers. Hence, $s_{j,t-1}^k = k_{j,t-1}$ in equilibrium. Following Gertler and Kiyotaki (2010), intermediate goods producers can credibly commit after-labor profits to the owners of the corporate securities. After realization of the productivity shock z_t at the beginning of period t, intermediate goods producer j hires labor $h_{j,t}$ at wage rate w_t in a perfectly competitive market. Subsequently, production of intermediate good j takes place using a production function that is constant returns to scale in capital and labor:

$$y_{j,t} = z_t k_{j,t-1}^{\alpha} h_{j,t}^{1-\alpha}. \quad (26)$$

After production, intermediate goods producer j sells the intermediate goods to retail goods producers at price m_t, and the depreciated capital stock at price q_t^k to capital goods producers. After workers are paid, the remaining funds are transferred to the owners of the corporate securities. Therefore, intermediate goods producer j's profits $\Pi_{j,t}^i$ are given by:

$$\Pi_{j,t}^i = m_t y_{j,t} + q_t^k (1 - \delta) k_{j,t-1} - w_t h_{j,t} - R_t^k q_{t-1}^k k_{j,t-1}.$$

After substitution of the production technology (26) and taking the derivative with respect to labor, we find the following first order condition for labor demand $h_{j,t}$:

$$w_t = (1-\alpha)\, m_t z_t k_{j,t-1}^{\alpha} h_{j,t}^{-\alpha}. \tag{27}$$

As intermediate goods producers pay all after-wage profits to the owners of its corporate securities, we have that $\Pi_{j,t}^{i} = 0$. After substitution of the wage rate (27), we find the following ex post return on corporate securities:

$$R_t^k = \frac{\alpha m_t z_t k_{j,t-1}^{\alpha-1} h_{j,t}^{1-\alpha} + q_t^k (1-\delta)}{q_{t-1}^k}. \tag{28}$$

2.3.4 Capital goods producers

A continuum of capital goods producers is operative in a perfectly competitive market for physical capital. At the end of period t, capital goods producers acquire the remaining capital stock $(1-\delta)\, k_{t-1}$ from intermediate goods producers at price q_t^k, which they convert one-for-one into new capital goods. In addition, they acquire i_t units of final goods, which they convert into $\Gamma(i_t)$ units of new capital goods. Therefore, the law of motion for capital is given by:

$$k_t = \Gamma(i_t) + (1-\delta)\, k_{t-1}. \tag{29}$$

Capital goods producers sell the newly produced capital goods k_t at a price q_t^k to intermediate goods producers. Therefore, period t profits Π_t^k are given by:

$$\Pi_t^k = q_t^k k_t - q_t^k (1-\delta)\, k_{t-1} - i_t = q_t^k \Gamma(i_t) - i_t,$$

where we substituted the law of motion for capital (29). Hence, we find the following first order condition for investment:

$$q_t^k \Gamma'(i_t) = 1. \tag{30}$$

2.4 Government

2.4.1 Central bank

The central bank follows a standard active Taylor rule $R_t^{n,T}$ when the economy is not at the Zero Lower Bound (ZLB):

$$R_t^{n,T} = \left[\bar{R}^{n,T} \left(\frac{\pi_t}{\bar{\pi}}\right)^{\kappa_\pi} \left(\frac{m_t}{\bar{m}}\right)^{\kappa_m}\right]^{1-\rho_r} \left(R_{t-1}^{n,T}\right)^{\rho_r}. \tag{31}$$

However, the actual policy rate R_t^n on central bank reserves is bounded by the ZLB. Therefore, it is given by:

$$R_t^n = \max\left\{R_t^{n,T}, 1\right\}. \tag{32}$$

The relation between the ex post real return on central bank reserves and the nominal interest is given by:

$$R_t^R = \frac{R_{t-1}^n}{\pi_t}. \tag{33}$$

In normal times, the nominal interest rate on central bank funding $R_t^{n,cb}$ is equal to the nominal interest rate on reserves R_t^n.[8] However, when the economy lands at the ZLB, the central bank reduces the nominal interest rate on central bank funding relative to that on reserves. Specifically, the nominal interest rate on central bank funding is given by:

$$R_t^{n,cb} = R_t^n - \Gamma_t^{cb}, \tag{34}$$

where Γ_t^{cb} is given by:

$$\Gamma_t^{cb} = \max\left[0, \left(\frac{\pi_t}{\bar{\pi}}\right)^{\Psi_\pi} \left(\frac{m_t}{\bar{m}}\right)^{\Psi_m} \mathcal{E}_t - 1\right], \tag{35}$$

where $\mathcal{E}_t$ is given by:

$$\mathcal{E}_t = \frac{\exp\left[\zeta\left(1 - \frac{R_t^{n,T}}{R_t^n}\right)\right]}{1 + \exp\left[\zeta\left(1 - \frac{R_t^{n,T}}{R_t^n}\right)\right]}. \tag{36}$$

The relation between the ex post gross real return on central bank funding and the nominal interest rate is given by:

$$R_t^{cb} = \frac{R_{t-1}^{n,cb}}{\pi_t}. \tag{37}$$

The central bank finances the loans d_t^{cb} to financial intermediaries by issuing central bank reserves m_t^R, which are held by financial intermediaries, see also van der Kwaak (2023). Moreover, we assume that the central bank operates with zero net worth.[9] Therefore, the central bank balance sheet is given by:

$$d_t^{cb} = m_t^R.$$

Central bank lending earns the gross real return R_t^{cb}, while the central bank pays the gross real return R_t^R on reserves. Therefore, central bank profits Π_t^{cb} in period t are given by:

$$\Pi_t^{cb} = R_t^{cb} d_{t-1}^{cb} - R_t^R m_{t-1}^R \tag{38}$$

As the central bank operates with zero net worth, all profits and losses are directly transferred to the fiscal authority.

[8]For example, the main refinancing rate at which commercial banks can borrow from the European Central Bank (ECB) is equal to the interest rate on excess central bank reserves.

[9]Central bank net worth is in most advanced economies a negligible fraction of the size of the central bank balance sheet, which motivates this modeling decision.

2.4.2 Fiscal authority

The fiscal authority obtains revenues from levying lump sum taxes τ_t, central bank profits Π_t^{cb}, and issuing debt b_t at price q_t^b. Following Woodford (1998, 2001), we assume that government debt is long-term and exponentially decaying: a bond issued in period $t-1$ pays a coupon x_c in period t, a coupon $\rho_b x_c$ in period $t+1$, a coupon $\rho_b^2 x_c$ in period $t+2$, etc. As a result, the cash flows from a bond issued in period $t-1$ are equal to a fraction ρ_b of the cash flows from a bond issued in period t. Therefore, we immediately infer that the price of a bond issued in period $t-1$ is equal to $\rho_b q_t^b$. Hence, the realized return R_t^b in period t of a bond issued in period $t-1$ is given by:

$$R_t^b = \frac{x_c + \rho_b q^b}{\pi_t q_{t-1}^b}, \tag{39}$$

where π_t denotes the gross inflation rate of final goods.

There exists a deposit insurance agency (DIA) that takes ownership of insolvent banks. Depositors receive a fraction γ of outstanding deposit liabailities d_{t-1}/π_t in full, while the remaining fraction $1-\gamma$ of the cash flows come from the assets that are recouped from insolvent intermediaries (Clerc et al., 2015; van der Kwaak et al., 2023). Therefore, the expenditures of the DIA are equal to:

$$\begin{aligned}
\mathcal{D}_t &= \int_0^{\bar{\omega}_t} \Bigg\{ \gamma \frac{d_{t-1}}{\pi_t} + (1-\gamma)\left[(1-\mu)\,\omega_t R_t^k q_{t-1}^k s_{t-1}^k + R_t^b q_{t-1}^b s_{t-1}^b + R_t^R m_{t-1}^R - R_t^{cb} d_{t-1}^{cb}\right] \\
&- \left[(1-\mu)\,\omega_t R_t^k q_{t-1}^k s_{t-1}^k + R_t^b q_{t-1}^b s_{t-1}^b + R_t^R m_{t-1}^R - R_t^{cb} d_{t-1}^{cb}\right] \Bigg\} f(\omega_t)\, d\omega_t \\
&= \gamma \int_0^{\bar{\omega}_t} \left\{ \frac{d_{t-1}}{\pi_t} - \left[(1-\mu)\,\omega_t R_t^k q_{t-1}^k s_{t-1}^k + R_t^b q_{t-1}^b s_{t-1}^b + R_t^R m_{t-1}^R - R_t^{cb} d_{t-1}^{cb}\right] \right\} f(\omega_t)\, d\omega_t,
\end{aligned}$$

where we subtract the gross return on central bank funding, as the central bank is a preferential creditor and is repaid in full before depositors are.[10] The government revenues are used for outstanding debt liabilities $R_t^b q_{t-1}^b b_{t-1}$ and reimbursement of the DIA. Therefore, the budget constraint of the fiscal authority can be written as:

$$q_t^b b_t + \tau_t + \Pi_t^{cb} = R_t^b q_{t-1}^b b_{t-1} + \mathcal{D}_t. \tag{40}$$

Finally, we assume that the stock of government debt is constant across time $b_t = \bar{b}$, which is achieved by lump sum taxes adjusting period by period.

[10] In reality, most central bank funding is collateralized. Hence, the central bank can sell the assets under collateral and be repaid in full when the commercial bank cannot repay the central bank. Therefore, central banks are effectively a preferential creditor with respect to depositors.

2.5 Market clearing & equilibrium

The markets for corporate securities and government bonds clear when demand by intermediaries and households is equal to the supply:

$$k_t = s_t^k + s_t^{k,h}, \quad (41)$$

$$b_t = s_t^b + s_t^{b,h} + s_t^{b,cb}, \quad (42)$$

The market for final goods clears when the following equation holds in equilibrium:

$$y_t = c_t + i_t + \text{adjustment costs}. \quad (43)$$

3 Calibration

We calibrate the model version with deposit insurance on a quarterly frequency. Specifically, we set households' subjective discount factor $\beta = 0.995$ and set the central bank's inflation target equal to 2% annual inflation, which is in line with the inflation target of the European Central Bank (ECB). These targets imply a long-run risk-free real interest rate that is approximately equal to 2% per year. We set $\sigma_c = 2$, which implies an intertemporal elasticity of substitution of 1/2. The inverse Frisch elasticity φ is set to 2, which is in line with micro estimates by Chetty et al. (2011). With Epstein-Zin preferences it is less straightforward to calibrate the degree of risk aversion in models with endogenous labor supply, as the labor margin influences households' risk appetite. However, Swanson (2012, 2018) show that the coefficient of relative risk aversion (CRRA) is approximately equal to:

$$\text{CRRA} \approx \frac{\sigma_c}{1 + \frac{\sigma_c}{\varphi}} + \psi \frac{1 - \sigma_c}{1 + \frac{\sigma_c - 1}{1 + \varphi}}.$$

We set $\psi = -115$, which implies that CRRA ≈ 87.25, which is in line with papers in the quantitative New Keynesian DSGE literature.[11] The parameters for households' transaction costs from corporate securities κ_k and bond holdings κ_b are equal to 0.05 and 0.01, respectively, while the elasticity of substitution between different retail goods producers ϵ is equal to 11, the last of which implies a (non-stochastic) steady state markup equal to 10%. Following Cao et al. (2023), we set $\overline{\pi}$ equal to 0.97, after which we adjust κ_P to ensure the average slope of the New Keynesian Phillips curve is equal to 0.04. We set the capital share α equal to 1/3 and the depreciation rate δ at 0.025, which are values that are commonly employed in the literature. The following functional form for the capital producers' investment adjustment cost function is given by:

$$\Gamma(i_t) = a_k + \left(\frac{b_k}{1 - 1/\gamma_k}\right) i_t^{1-1/\gamma_k}.$$

[11] Rudebusch and Swanson (2012) employ a value 75, Basu and Bundick (2017) 80, while Van Binsbergen et al. (2012) find estimates between 50 and 85.

The parameter b_k is chosen such that $\bar{q}^k = 1$ in the non-stochastic steady state, while the value for a_k ensures that $\bar{i} = \delta\bar{k}$.

We assume that 8% of intermediaries' net worth is paid out in dividends each period. This implies $\sigma = 0.08$, which is close to the value employed in Gertler et al. (2019). In line with Gertler and Karadi (2011, 2013), we target an unweighted leverage ratio of 5, while an annual credit spread that is equal to 150 annual basis points (Akinci and Queralto, 2022). We follow Mendicino et al. (2020) in targeting an annual probability of bank default equal to 0.665%, while setting the diversion rate of government bonds being equal to half the diversion rate of corporate securities (van der Kwaak and van Wijnbergen, 2017). These targets are matched by adjusting the transfer χ_b to newly starting bankers, the diversion rate $\bar{\lambda}_k$ of corporate securities, and the standard deviation σ_ω of the idiosyncratic shock. We follow Bernanke et al. (1999) in setting the deadweight losses from bank default μ equal to 0.12. Finally, we adjust the parameters $\hat{s}^{k,h}$ and $\hat{s}^{b,h}$ in households' quadratic transactions costs to ensure that financial intermediaries hold 80% of the total supply of corporate securities on average, while intermediaries' government bonds are on average equal to 7.6% of total assets.

We set the stock of government bonds $\bar{b}$ such that the ratio of government debt over annual output is equal to 60%. We set ρ_b equal to 0.95, which implies an average duration of government debt of 20 quarters (5 years). Finally, we target a long-run bond price q^b that is approximately equal to 1 by adjusting the coupon payment x_c.

The Taylor rule's inflation feedback coefficient κ_π is set at 2.5, the output gap coefficient κ_m at 0.25, while we set the interest rate smoothing parameter equal to zero (Gertler et al., 2019). We set the coefficients determining the central bank's unconventional central bank lending policy equal to $\Psi_\pi = \kappa_\pi \Psi$ and $\Psi_m = \kappa_m \Psi$, with values for Ψ equal to 0.05, 0.1, and 0.15.

We set the productivity AR(1) coefficient ρ_z and standard deviation σ_z to values commonly found in the literature. Finally, we discretize the process for λ_t^k as a five point Markov chain with autocorrelation 0.85 and a standard deviation of 10.5%. In doing so, we follow the usual Rouwenhorst (1995) procedure. These choices ensure that the frequency with which the economy is at the ZLB is 6.6%.

4 Numerical results

4.1 The role of deposit insurance

We start this section by discussing the role of deposit insurance, as it is well known from the finance literature that deposit insurance can induce financial intermediaries to take more risk (Kareken and Wallace, 1978). The reason why we start with this exercise is to check that risk taking by banks is a feature of our model. In other words, if we do not find more risk taking by banks as a result of deposit insurance, our model is unlikely to capture other forms of risk taking by banks.

Specifically, deposit insurance leads to risk taking by banks because depositors no longer price

Parameter	Value	Definition
Households		
β	0.995	Households' subjective discount factor
$1/\sigma_c$	1/2	Coefficient of intertemporal elasticity of substitution
φ	2	Inverse Frisch elasticity
ψ	-115	Coefficient of relative risk-aversion
κ_k	0.05	Coefficient HHs transaction costs corporate securities
κ_b	0.01	Coefficient HHs transaction costs bond holdings
Financial intermediaries		
σ	0.08	Dividend payout rate
$E\left[\bar{r}^k - \bar{r}^d\right]$	0.00375	Spread between corporate securities and deposits
$F\left(\bar{\omega}\right)$	0.16625	Probability of bank default
σ_ω	0.0867	Probability of bank default
λ_k	0.265	Diversion rate corp. securities
λ_b	0.1325	Diversion rate gov't bonds
$\bar{\phi}$	5	Average leverage ratio
χ_b	0.2784	Starting net worth new bankers
μ	0.12	Deadweight losses from bank default
Goods producers		
α	1/3	Capital share
δ	0.025	Depreciation rate
ϵ	11	Elasticity of substitution
κ_P	9.8	Elasticity of substitution
$\underline{\pi}$	0.97	Rotemberg parameter
γ_k	4	Investment adjustment costs
a_k	-0.2184	Constant in investment adjustment costs
b_k	0.8997	Constant in investment adjustment costs
Fiscal policy		
$\bar{b}/\bar{y}$	2.4	60% of annual GDP
x_c	0.0621	Coupon payment bonds
ρ_b	0.95	parameter determining effective duration bonds
Monetary policy		
$\bar{\pi}$	1.005	Steady state gross inflation rate
κ_π	2.500	Inflation feedback on nominal interest rate
κ_m	0.25	Output feedback on nominal interest rate
ρ_r	0	Interest rate smoothing parameter
Autoregressive processes		
ρ_z	0.95	AR(1) parameter productivity shock
ρ_λ	0.85	AR(1) parameter diversion shock
σ_z	0.005	Standard deviation productivity shock
σ_ϕ	0.105	Standard deviation risk-premium shock

Table 1: Calibration targets.

in the probability of bank default, which reduces intermediaries' funding costs, everything else equal. Lower funding costs, in turn, increase intermediaries' profitability, everything else equal. As a result, intermediaries borrow more in order to expand the balance sheet, which leads to intermediaries operating with higher leverage ratios, everything else equal. To study the extent to which our model features this 'deposit insurance risk taking channel', we compare the ergodic means in Table 2 of the model version with deposit insurance ('DI', with $\gamma = 1$ in equation (5)) with the model version without deposit insurance ('no DI', with $\gamma = 0$ in equation (5)). For both model versions, we set $\Gamma_t^{cb} = 0$ in equation (35) to study the role of deposit insurance in isolation. Finally, we also report the so-called 'weighted leverage ratio', which we define as $l_t^w = \left[q_t^k s_t^k + \left(\lambda_t^b / \lambda_t^k\right) q_t^b s_t^b\right] / n_t$.

Variable	No DI	DI
Output: y	2.9037	2.9126
Consumption: c	2.2697	2.2723
Physical capital: k	25.3160	25.5434
Net worth: n	4.9052	4.8783
Capital price: q^k	0.9913	0.9934
Bank securities: k^b	20.0530	20.2856
Bank bonds: b^b	3.4309	3.3902
Leverage: l	4.7811	4.8640
Weighted leverage: l^w	4.4260	4.5127
Frac. of insolv. banks: $F(\bar{\omega})$	0.0834%	0.1346%
Max. frac. of insolv. banks: $F(\bar{\omega})$	25.4054%	41.5197%
Gross bank funding cost: R^d	1.0094	1.0091
Prob. of fin. crisis:	4.2780%	4.7590%
Prob. of fin. crisis and ZLB:	2.0970%	3.6020%
Prob. of binding leverage constr.:	29.3397%	30.2817%
Prob. of ZLB:	4.2010%	6.6089%

Table 2: Ergodic means of selected variables. 'DI' stands for the model version with deposit insurance ($\gamma = 1$), while 'no DI' stands for the model version without deposit insurance ($\gamma = 0$). For both model versions we set $\Gamma_t^{cb} = 0$ in equation (34).

We start by looking at the impact that deposit insurance has on the financial sector. Interestingly, we see that net worth decreases on average (with respect to the model version without deposit insurance), while both the weighted and unweighted leverage ratios increase. Despite the fact that average funding costs R^d decrease, we see that there is substantially more financial instability in the model version with deposit insurance: the probability of financial crises increases by almost 0.5 percentage points (4.7590% vs. 4.2780%), as well as the probability of a financial crisis that coincides with hitting the ZLB, which increases by 1.5 percentage points. Moreover, the average fraction of intermediaries that default per quarter increases by more than 50% relative to the model version without deposit insurance (0.1346% vs. 0.0834%), as well as the maximum number of intermediaries that default in a single quarter (41.5197% vs. 25.4054%). The higher frequency of financial crises and the fact that more intermediaries default in a given quarter also explain why intermediaries operate with less net worth on average, as financial crises and intermediaries defaulting usually leads to large drops in aggregate net worth.

The reason why there is more financial fragility in the model version with deposit insurance is two-fold. First, intermediaries operate with higher leverage ratios, thereby making their balance sheets more vulnerable to negative shocks in general. Second, financial intermediaries also make their balance sheet more risky through a relative portfolio shift from safe government bonds ('Bank bonds' in Table 2) to corporate securities ('Bank securities'), thereby exposing a larger fraction of the balance sheet to the idiosyncratic shock. Hence, these results highlight that the moral hazard from deposit insurance described in Kareken and Wallace (1978) plays an important role in our model.

However, despite more risk taking and higher financial fragility, we see that deposit insurance has a positive effect on the macroeconomy. Output, consumption, and the stock of physical capital are larger than in the model version without deposit insurance. As mentioned above, deposit insurance induces intermediaries to provide more credit to the real economy, as a result of which the economy operates with a higher capital stock on average. A higher stock of capital, in turn, increases output and consumption. Observe, however, that the quantitative differences are relatively small, as they are less than 1% for the macroeconomic variables.

4.2 The impact of low-interest-rate central bank funding

Now that we have discussed the role of deposit insurance, we move on to study the impact that low-interest-rate central bank funding has on the financial sector and the macroeconomy. Therefore, Γ_t^{cb} is no longer zero period by period (as in the previous section), but is again given by equation (35). We first study the impact of low-interest-rate central bank funding in financial crisis times in Section 4.2.1, after which we study the long-run impact of this policy in Section 4.2.2.

4.2.1 The impact of low-interest-rate central bank funding in financial crisis times

In this section, we study the impact of low-interest-rate central bank funding in times of financial crises. To do so, we first solve model versions with and without low-interest-rate central bank funding, and simulate both model versions for 500,000 periods. Afterwards, we identify times of financial crises, which we define as periods in which bank deposits fall by more than two times the unconditional standard deviation across the entire simulation (Bianchi, 2016). We subsequently create event windows by averaging across financial crises starting from the 15 quarters before a crisis hits until 15 quarters afterwards. The results can be found in Figures 1 - 3 for the model version without deposit insurance, and in Figures 4 - 6 for the model version with deposit insurance.

It turns out that the dynamics around financial crises and the impact of low-interest-rate central bank funding is similar for the model versions with and without deposit insurance. Therefore,

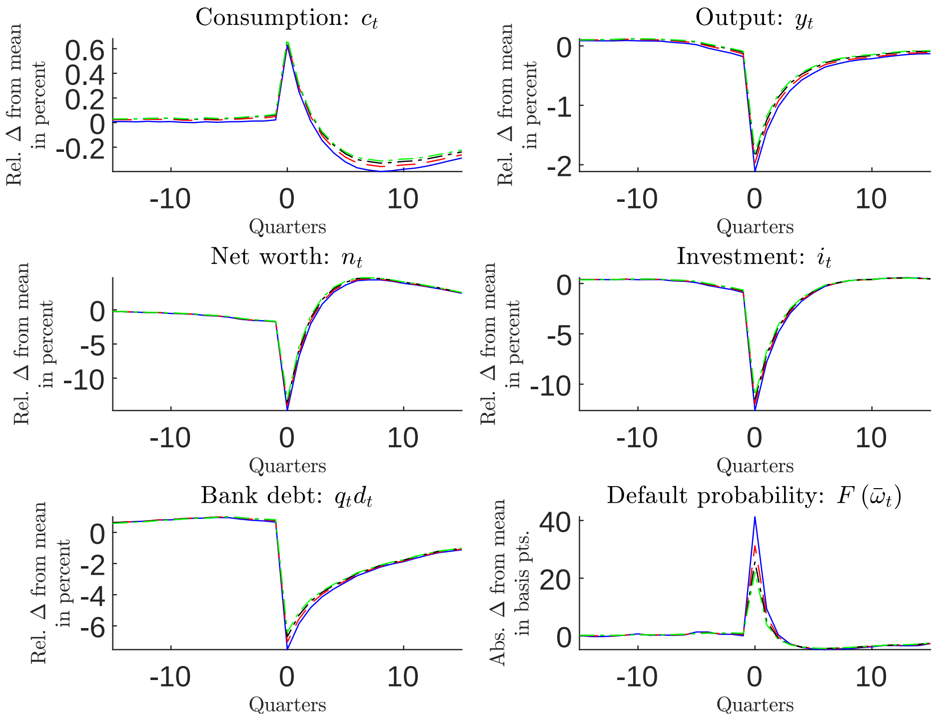

Figure 1: Dynamics around financial crisis events in economy without deposit insurance ($\gamma = 0$). The blue solid line denotes the model version without low-interest-rate central bank funding. In the other simulations, the central bank provides low-interest-rate funding at the ZLB. Specifically, the red, dashed line represents the case with $\Psi = 0.05$, the black, dot-dashed line $\Psi = 0.1$, and the green, dot-dashed line with $\Psi = 0.15$. Ψ denotes the parameter that determines Ψ_π and Ψ_m in equation (35) via the relation $\Psi_\pi = \kappa_\pi \Psi$ and $\Psi_m = \kappa_m \Psi$, where κ_π and κ_m are the coefficients from the Taylor rule (31).

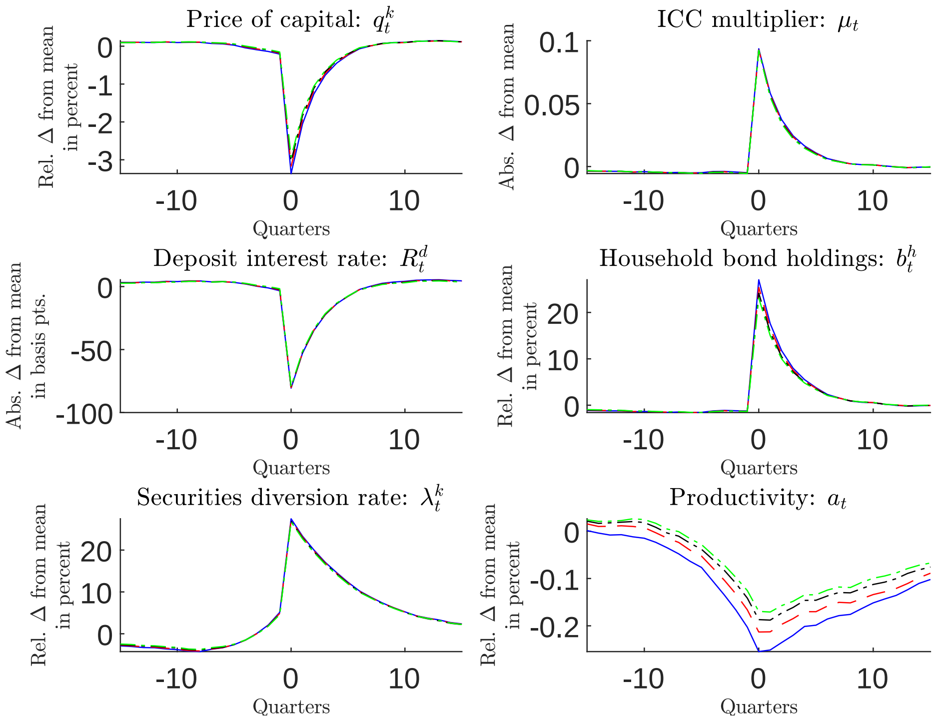

Figure 2: Dynamics around financial crisis events in economy without deposit insurance ($\gamma = 0$). The blue solid line denotes the model version without low-interest-rate central bank funding. In the other simulations, the central bank provides low-interest-rate funding at the ZLB. Specifically, the red, dashed line represents the case with $\Psi = 0.05$, the black, dot-dashed line $\Psi = 0.1$, and the green, dot-dashed line with $\Psi = 0.15$. Ψ denotes the parameter that determines Ψ_π and Ψ_m in equation (35) via the relation $\Psi_\pi = \kappa_\pi \Psi$ and $\Psi_m = \kappa_m \Psi$, where κ_π and κ_m are the coefficients from the Taylor rule (31).

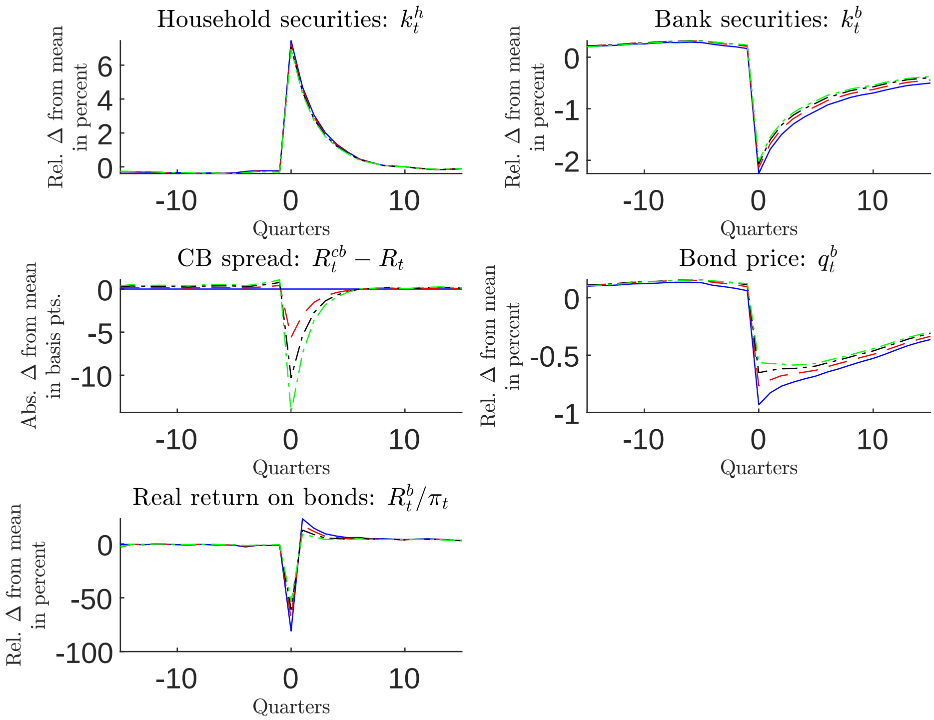

Figure 3: Dynamics around financial crisis events in economy without deposit insurance ($\gamma = 0$). The blue solid line denotes the model version without low-interest-rate central bank funding. In the other simulations, the central bank provides low-interest-rate funding at the ZLB. Specifically, the red, dashed line represents the case with $\Psi = 0.05$, the black, dot-dashed line $\Psi = 0.1$, and the green, dot-dashed line with $\Psi = 0.15$. Ψ denotes the parameter that determines Ψ_π and Ψ_m in equation (35) via the relation $\Psi_\pi = \kappa_\pi \Psi$ and $\Psi_m = \kappa_m \Psi$, where κ_π and κ_m are the coefficients from the Taylor rule (31).

we discuss both model versions (with and without deposit insurance) simultaneously.

We start by explaining the impact of financial crises without the central bank offering low-interest-rate funding. Therefore, we have that $\Gamma_t^{cb} = 0$ in equation (35) period by period. We first observe that financial crises are periods in which intermediaries' diversion rate λ_t^k sharply increases. Productivity simultaneously decreases, but its trough is only 0.1% below the ergodic mean and is therefore limited. The increase in the diversion rate, however, is substantial as it increases by more than 20% with respect to its ergodic mean, as a result of which intermediaries' incentive compatibility constraint (16) tightens substantially. As a result, bank creditors become much more wary to provide intermediaries with funds (Panel 'Bank debt: $q_t d_t$'), which forces intermediaries to shrink the size of their balance sheets by selling corporate securities and government bonds to households, see the Panels 'Bank securities: k_t^b', 'Household securities: k_t^h' and 'Household bond holdings: b_t^h'. Intermediaries' fire sales of corporate securities and government bonds lead to a drop in the price of capital and bonds, as households cannot perfectly elastically buy the additional bonds and securities due to transaction costs. These price drops, in turn, lead to lower realized returns on intermediaries' existing holdings of corporate securities and government bonds. As a result, intermediaries' net worth falls, which tightens incentive compatibility constraint (16) further. In response, intermediaries further shrink the size of their balance sheets (Gertler and Kiyotaki, 2010; Gertler and Karadi, 2011). In equilibrium, intermediaries' net worth drops by almost 20% of its long-run average, while bank debt falls by close to 10%. Lower net worth simultaneously leads to a sharp increase in bank defaults.

The resulting credit contraction by intermediaries leads to a large drop in investment by more than 10% of its long-run average, with a subsequent drop in output of more than 2%. Observe, however, that consumption initially increases when the financial crisis hits, which is a feature of the 'comovement' problem (Barro and King, 1984): in order for output to drop in impact, labor supply needs to fall, which requires consumption to increase as the marginal utility from consumption has to fall, see Bocola (2016) for a discussion of the 'comovement' problem.

Next, consider the impact of the central bank providing low-interest-rate funding in times of financial crises. To capture this, Γ_t^{cb} is now given by equation (35). As the financial crisis pushes the economy to the ZLB, the central bank reduces the interest rate on central bank funding relative to that on central bank reserves. As a result, intermediaries' net worth increases, which allows them to expand their balance sheet as intermediaries' incentive compatibility constraint (16) is relaxed. Therefore, intermediaries' demand for corporate securities and government bonds increases (relative to no provision of low-interest-rate funding), which leads to capital gains on intermediaries' existing corporate securities and bond holdings (van der Kwaak, 2023). This, in turn, further relaxes intermediaries' incentive compatibility constraints (16), which leads to a second round of capital gains. Also observe that the capital gains on intermediaries' existing holdings of bonds and securities substantially decreases the fraction of intermediaries that default at the moment a financial crisis hits the economy.

However, we also see that the increase in intermediaries' net worth is relatively limited (rel-

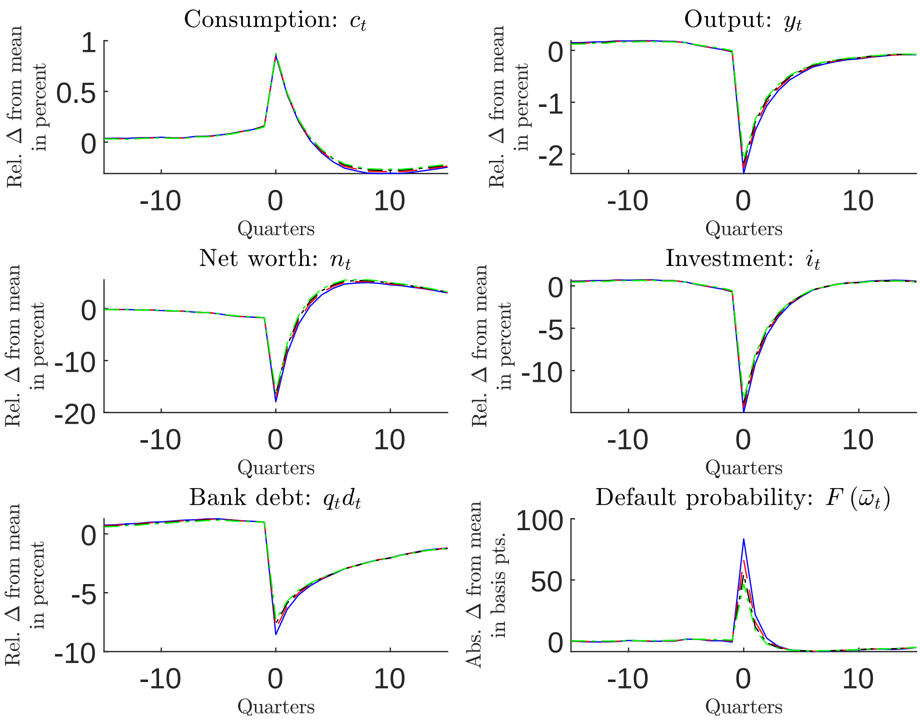

Figure 4: Dynamics around financial crisis events in economy with deposit insurance ($\gamma = 1$). The blue solid line denotes the model version without low-interest-rate central bank funding. In the other simulations, the central bank provides low-interest-rate funding at the ZLB. Specifically, the red, dashed line represents the case with $\Psi = 0.05$, the black, dot-dashed line $\Psi = 0.1$, and the green, dot-dashed line with $\Psi = 0.15$. Ψ denotes the parameter that determines Ψ_π and Ψ_m in equation (35) via the relation $\Psi_\pi = \kappa_\pi \Psi$ and $\Psi_m = \kappa_m \Psi$, where κ_π and κ_m are the coefficients from the Taylor rule (31).

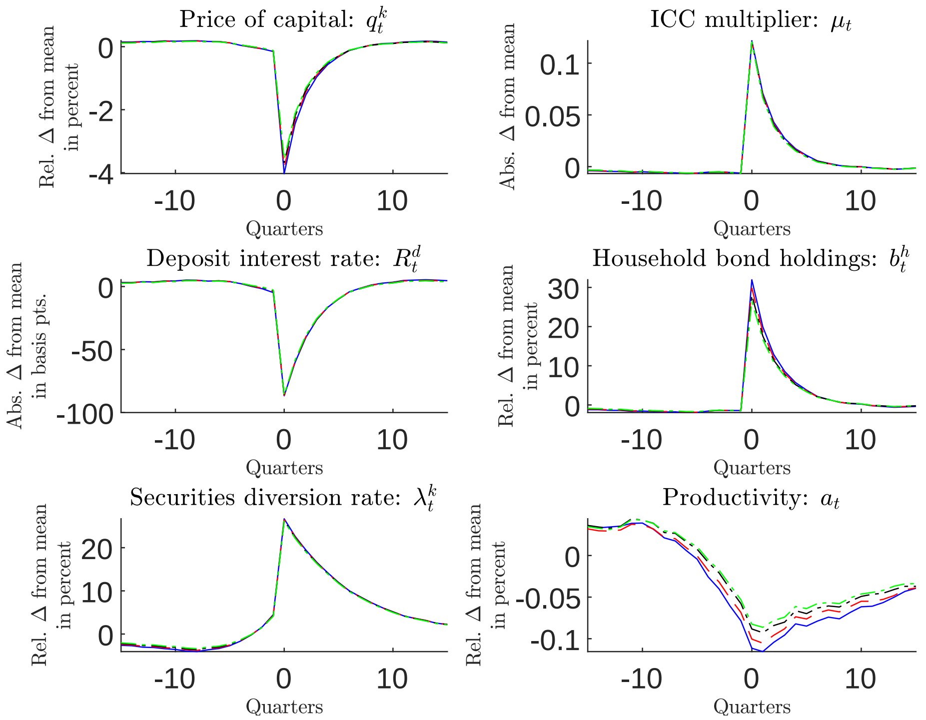

Figure 5: Dynamics around financial crisis events in economy with deposit insurance ($\gamma = 1$). The blue solid line denotes the model version without low-interest-rate central bank funding. In the other simulations, the central bank provides low-interest-rate funding at the ZLB. Specifically, the red, dashed line represents the case with $\Psi = 0.05$, the black, dot-dashed line $\Psi = 0.1$, and the green, dot-dashed line with $\Psi = 0.15$. Ψ denotes the parameter that determines Ψ_π and Ψ_m in equation (35) via the relation $\Psi_\pi = \kappa_\pi \Psi$ and $\Psi_m = \kappa_m \Psi$, where κ_π and κ_m are the coefficients from the Taylor rule (31).

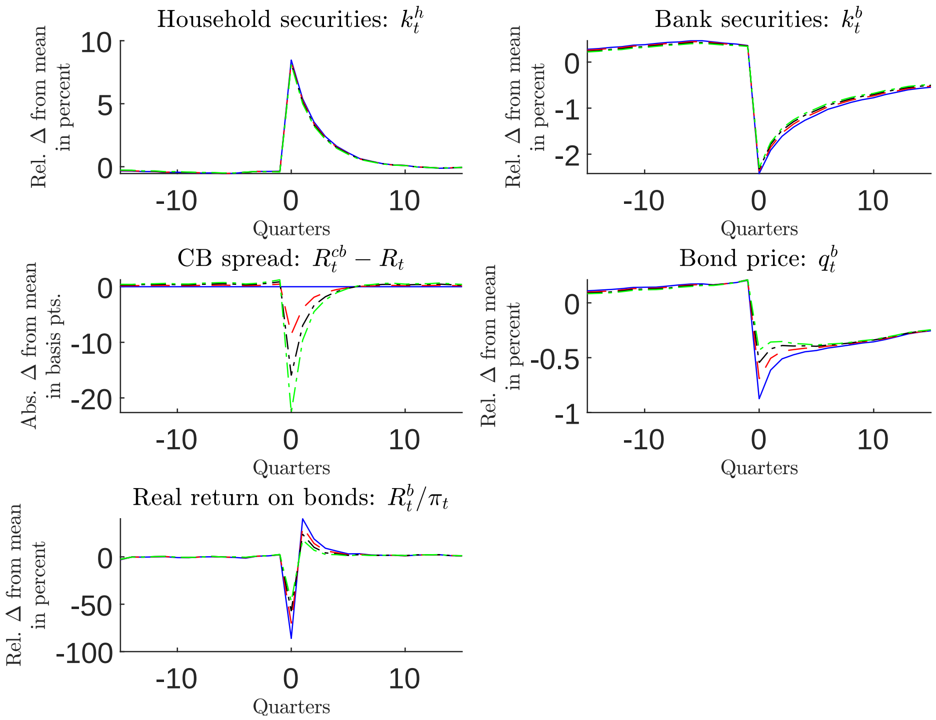

Figure 6: Dynamics around financial crisis events in economy with deposit insurance ($\gamma = 1$). The blue solid line denotes the model version without low-interest-rate central bank funding. In the other simulations, the central bank provides low-interest-rate funding at the ZLB. Specifically, the red, dashed line represents the case with $\Psi = 0.05$, the black, dot-dashed line $\Psi = 0.1$, and the green, dot-dashed line with $\Psi = 0.15$. Ψ denotes the parameter that determines Ψ_π and Ψ_m in equation (35) via the relation $\Psi_\pi = \kappa_\pi \Psi$ and $\Psi_m = \kappa_m \Psi$, where κ_π and κ_m are the coefficients from the Taylor rule (31).

ative to no provision of low-interest-rate funding), and therefore intermediaries' credit provision to the real economy is relatively limited, see the panel 'Bank securities: k_t^b'. Even though investment increases as a result of more credit provision, we see that the quantitative impact of the central bank providing low-interest-rate funding is small. Therefore, capital accumulation is relatively small (not shown), as a result of which consumption and output barely increase relative to the central bank not providing low-interest-rate funding.

4.2.2 The long-run impact of low-interest-rate central bank funding

Next, we study the long-run impact that the provision of low-interest-rate central bank funding has on the macroeconomy and on financial sector stability. We do so in Table 3 for the model version with no deposit insurance ($\gamma = 0$), and in Table 4 for the model version with insurance ($\gamma = 1$). In both tables, we also investigate the strength Ψ with which the central bank decreases the interest rate on central bank funding for a given amount of deflation $\pi_t/\bar{\pi}$ and output gap $m_t/\bar{m}$. Just as for the event windows in the previous section, we find that the impact of low-interest-rate central bank funding is similar for the model versions with and without deposit insurance.

Variable	No LTROs	$\Psi = 0.05$	$\Psi = 0.1$	$\Psi = 0.15$
Output: y	2.9037	2.9048	2.9057	2.9065
Consumption: c	2.2697	2.2702	2.2705	2.2709
Physical capital: k	25.3160	25.3459	25.3693	25.3885
Net worth: n	4.9052	4.9059	4.9068	4.9079
Capital price: q^k	0.9913	0.9916	0.9918	0.9920
Bank securities: k^b	20.0530	20.0836	20.1076	20.1271
Bank bonds: b^b	3.4309	3.4363	3.4408	3.4446
Leverage: l	4.7811	4.7891	4.7953	4.8002
Weighted leverage: l^w	4.4260	4.4332	4.4387	4.4430
Frac. of insolv. banks: $F(\bar{\omega})$	0.0834%	0.0809%	0.0799%	0.0795%
Max. frac. of insolv. banks: $F(\bar{\omega})$	25.4054%	15.8487%	10.7055%	8.0689%
Gross bank funding cost: R^d	1.0094	1.0094	1.0094	1.0095
Prob. of fin. crisis:	4.2780%	4.4730%	4.6120%	4.7300%
Prob. of fin. crisis and ZLB:	2.0970%	2.0760%	2.0340%	1.9950%
Prob. of binding leverage constr.:	29.3397%	29.2267%	29.1227%	29.0327%
Prob. of ZLB:	4.2010%	4.0350%	3.8810%	3.7240%

Table 3: Ergodic means of selected variables for the model version without deposit insurance. Ψ is the parameter that determines Ψ_π and Ψ_m in equation (35) via the relation $\Psi_\pi = \kappa_\pi \Psi$ and $\Psi_m = \kappa_m \Psi$, where κ_π and κ_m are the coefficients from the Taylor rule (31).

We saw in the previous section that the central bank providing low-interest-funding ameliorates the negative impact that financial crises have on net worth. As a result, we see in Table 3 and 4 that the ergodic mean of net worth increases when the central bank provides low-interest-rate funding at the ZLB. Moreover, the ergodic mean increases with the strength Ψ with which the central bank cuts the nominal interest rate on central bank funding. This leads to more

Variable	No LTROs	$\Psi = 0.05$	$\Psi = 0.1$	$\Psi = 0.15$
Output: y	2.9126	2.9143	2.9158	2.9170
Consumption: c	2.2723	2.2731	2.2737	2.2742
Physical capital: k	25.5434	25.5896	25.6283	25.6614
Net worth: n	4.8783	4.8789	4.8800	4.8814
Capital price: q^k	0.9934	0.9938	0.9942	0.9946
Bank securities: k^b	20.2856	20.3329	20.3723	20.4062
Bank bonds: b^b	3.3902	3.3990	3.4064	3.4127
Leverage: l	4.8640	4.8772	4.8879	4.8969
Weighted leverage: l^w	4.5127	4.5244	4.5340	4.5420
Frac. of insolv. banks: $F(\bar{\omega})$	0.1346%	0.1302%	0.1280%	0.1272%
Max. frac. of insolv. banks: $F(\bar{\omega})$	41.5197%	33.8822%	27.0871%	21.4959%
Gross bank funding cost: R^d	1.0091	1.0091	1.0092	1.0092
Prob. of fin. crisis:	4.7590%	4.8980%	5.0309%	5.1259%
Prob. of fin. crisis and ZLB:	3.6020%	3.5880%	3.5770%	3.5660%
Prob. of binding leverage constr.:	30.2817%	30.2937%	30.3517%	30.3927%
Prob. of ZLB:	6.6089%	6.4059%	6.2389%	6.0819%

Table 4: Ergodic means of selected variables for the model version with deposit insurance. Ψ is the parameter that determines Ψ_π and Ψ_m in equation (35) via the relation $\Psi_\pi = \kappa_\pi \Psi$ and $\Psi_m = \kappa_m \Psi$, where κ_π and κ_m are the coefficients from the Taylor rule (31).

credit provision to the real economy (see 'Bank securities: k^b' in Table 3 and 4), which in turn increases investment. The resulting higher average stock of capital, in turn, leads to higher output and consumption. Observe, however, that the quantitative impact is limited, as the resulting increases are always less than 1% of the ergodic mean with respect to the model version without low-interest-rate central bank funding.

Next, we look at the long-run impact on financial (in)stability. We find that low-interest-rate central bank funding allows intermediaries to increase both the weighted and the unweighted leverage ratio. This is driven by the fact that low-interest-rate central bank funding increases intermediaries' profitability, everything else equal, as a result of which intermediaries' incentive compatibility constraint (16) relaxes. Therefore, depositors are willing to let intermediaries operate with higher leverage ratios, as a result of which the probability of a financial crisis increases. In addition, we see that the probability of a binding incentive compatibility constraint (16) also increases in the model version with deposit insurance, see Table 4. However, the reduction of the interest rate on central bank funding improves financial stability ex post: the average fraction of intermediaries that default decreases because low-interest-rate central bank funding increases intermediaries' net worth, the more so the larger Ψ. We also see that the maximum number of intermediary defaults across the simulation is at least halved, while the probability of simultaneously hitting the ZLB and having a financial crisis decreases.

5 Conclusion

In this paper, we study the long-run impact of the central bank providing low-interest-rate funding to financial intermediaries when the economy lands at the Zero Lower Bound (ZLB). While the literature has thus far predominantly focused on the short-run impact that such policies have on the macroeconomy (Gertler and Kiyotaki, 2010; Cahn et al., 2017; Bocola, 2016; van der Kwaak, 2023), our focus is on the long-run impact of such policies. Moreover, we do not only investigate the impact on the macroeconomy, but also on financial stability, as academics and policymakers have become more concerned in recent years that unconventional monetary policies, such as providing low-interest-rate central bank funding, might lead to more risk taking by banks and thereby increase the probability of new financial crises.

We do so within a New Keynesian DSGE model with financial intermediaries that are funded through net worth, deposits, and central bank funding. These funding sources finance government bonds, central bank reserves, and corporate securities that finance the stock of physical capital used for production. Intermediaries are subject to a collateral constraint that requires them to pledge sufficient corporate securities and government bonds as collateral (van der Kwaak, 2023). Moreover, they are subject to an occasionally binding incentive compatibility constraint a la Gertler and Kiyotaki (2010); Gertler and Karadi (2011). Furthermore, we follow van der Kwaak et al. (2023) by introducing an idiosyncratic shock that is multiplicative with intermediaries' return on corporate securities, which introduces the possibility of intermediary default when the realization of this shock causes the intermediary's return on assets to be below the return on its liabilities. Finally, intermediaries take into account how their balance sheet decisions affect their funding costs in the absence of deposit insurance (Gete and Melkadze, 2020). The central bank sets the nominal interest rate on reserves following a standard active Taylor rule, but is limited on the downside by the ZLB. Above the ZLB, the interest rate on central bank funding is equal to that on reserves. However, when the nominal rate on reserves is at the ZLB, the central bank decreases the nominal interest rate on central bank funding by following a rule that responds to inflation and the output gap. Specifically, the lower the inflation rate and the more negative the output gap, the larger the decrease in the nominal interest rate on central bank funding.

The presence of limited liability creates an incentive for financial intermediaries to take risk with their balance sheets, as the materialization of downside risks is not borne by intermediaries themselves: intermediaries only care about their expected profitability *conditional* on survival (Diamond and Rajan, 2011). In that case, providing low-interest-rate central bank funding makes intermediaries more profitable, as a result of which depositors allow intermediaries to operate with higher leverage ratios, in a similar way as deposit insurance leads to higher leverage ratios at banks Kareken and Wallace (1978).

To quantitatively investigate to what extent financial intermediaries increase risk taking when the central bank provides low-interest-rate funding at the ZLB, we solve the model using global solution methods to properly capture nonlinearities arising from risk taking and the two occasionally binding constraints (ZLB and intermediaries' incentive compatibility constraint). Afterwards, we simulate the model for many periods and calculate long-run statistics, as well as create event windows around financial crises. We find that the provision of low-interest-rate central bank funding at the ZLB mitigates the negative impact from financial crises through a similar mechanism as in van der Kwaak (2023): low-interest-rate funding increases intermediaries' profitability and net worth, which relaxes intermediaries' (binding) incentive compatibility constraint. This allows intermediaries to expand their balance sheet, which results in higher demand for corporate securities and government bonds. Higher demand for bonds and securities leads to capital gains on intermediaries' existing assets (relative to the central bank not providing low-interest-rate funding), which further increases net worth and substantially reduces the number of intermediaries that default ex post in a financial crisis.

However, in contrast to most of the literature, our model is capable of studying the long-run impact of this unconventional monetary policy. And this long-run impact is not necessarily good from a financial stability perspective: intermediaries' anticipation of getting low-interest-rate central bank funding when the economy enters a financial crisis induces intermediaries to increase their leverage ratios ex ante, which results in more frequent financial crises than when the central bank does not provide low-interest-rate funding. Furthermore, we find that the frequency of crises increases with the degree to which the central bank cuts the interest rate on central bank funding. Hence, the provision of low-interest-rate central bank funding in times of financial crises leads to more risk taking by banks ex ante.

However, we find that low-interest-rate central bank funding has a beneficial long-run impact on the macroeconomy. The fact that the impact of financial crises is (substantially) mitigated by providing low-interest-rate central bank funding leads to more credit provision to the real economy. As a result, investment and capital accumulation increase with respect to the case where the central bank does not provide low-interest-rate funding, which leads to higher long-run capital, output, and consumption. The quantitative difference, however, is small.

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Appendix "NWO Bank Risk Taking"

A Additional mathematical derivations

A.1 Financial intermediaries

The Lagrangian accompanying financial intermediaries' optimization problem is given by:

$$
\begin{aligned}
\mathcal{L} \quad = \quad & (1+\mu_t)\, E_t \Bigg\{ \beta \Lambda_{t,t+1} \int_{\bar{\omega}_{j,t+1}}^{\infty} \Bigg[\sigma \left(\omega_{j,t+1} R^k_{t+1} q^k_t s^k_{j,t} + R^b_{t+1} q^b_t s^b_{j,t} + R^R_{t+1} m^R_{j,t} - \frac{d_{j,t}}{\pi_{t+1}} - R^R_{t+1} d^{cb}_{j,t} \right) \\
+ \quad & \mathcal{V}_{j,t+1} \left(s^k_{j,t}, s^b_{j,t}, m^R_{j,t}, d_{j,t}, d^{cb}_{j,t} \right) \Bigg] f\left(\omega_{j,t+1}\right) d\omega_{j,t+1} \Bigg\} \\
- \quad & \mu_t \left(\lambda_k q^k_t s^k_{j,t} + \lambda_b q^b_t s^b_{j,t} \right) \\
+ \quad & \chi_t \Bigg[(1-\sigma) \left(\omega_{j,t} R^k_t q^k_{t-1} s^k_{j,t-1} + R^b_t q^b_{t-1} s^b_{j,t-1} + R^R_t m^R_{j,t-1} - \frac{d_{j,t-1}}{\pi_t} - R^R_t d^{cb}_{j,t-1} \right) \\
+ \quad & q_t d_{j,t} + d^{cb}_{j,t} - q^k_t s^k_{j,t} - q^b_t s^b_{j,t} - m^R_{j,t} \Bigg].
\end{aligned}
$$

The resulting first order conditions are given by:

$$
\begin{aligned}
s_{j,t}^{k} \quad &: \quad (1+\mu_t)\, E_t\left[\beta\Lambda_{t,t+1}\int_{\bar{\omega}_{j,t+1}}^{\infty}\left(\sigma\omega_{j,t+1}R_{t+1}^{k}q_t^{k}+\frac{\partial\mathcal{V}_{j,t+1}}{\partial s_{j,t}^{k}}\right)f\left(\omega_{j,t+1}\right)d\omega_{j,t+1}\right] \\
&- \quad \mu_t\lambda_k q_t^{k}-\chi_t\left(q_t^{k}-d_{j,t}\cdot\frac{\partial q_t}{\partial s_{j,t}^{k}}\right)+\psi_t\theta^{k}q_t^{k}=0, \qquad (44)\\
s_{j,t}^{b} \quad &: \quad (1+\mu_t)\, E_t\left[\beta\Lambda_{t,t+1}\int_{\bar{\omega}_{j,t+1}}^{\infty}\left(\sigma R_{t+1}^{b}q_t^{b}+\frac{\partial\mathcal{V}_{j,t+1}}{\partial s_{j,t}^{b}}\right)f\left(\omega_{j,t+1}\right)d\omega_{j,t+1}\right] \\
&- \quad \mu_t\lambda_b q_t^{b}-\chi_t\left(q_t^{b}-d_{j,t}\cdot\frac{\partial q_t}{\partial s_{j,t}^{b}}\right)+\psi_t\theta^{b}q_t^{b}=0, \qquad (45)\\
m_{j,t}^{R} \quad &: \quad (1+\mu_t)\, E_t\left[\beta\Lambda_{t,t+1}\int_{\bar{\omega}_{j,t+1}}^{\infty}\left(\sigma R_{t+1}^{R}+\frac{\partial\mathcal{V}_{j,t+1}}{\partial m_{j,t}^{R}}\right)f\left(\omega_{j,t+1}\right)d\omega_{j,t+1}\right] \\
&- \quad \chi_t\left(1-d_{j,t}\cdot\frac{\partial q_t}{\partial m_{j,t}^{R}}\right)=0, \qquad (46)\\
d_{j,t} \quad &: \quad (1+\mu_t)\, E_t\left[\beta\Lambda_{t,t+1}\int_{\bar{\omega}_{j,t+1}}^{\infty}\left(-\sigma\cdot\frac{1}{\pi_{t+1}}+\frac{\partial\mathcal{V}_{j,t+1}}{\partial d_{j,t}}\right)f\left(\omega_{j,t+1}\right)d\omega_{j,t+1}\right] \\
&+ \quad \chi_t\left(q_t+d_{j,t}\cdot\frac{\partial q_t}{\partial d_{j,t}}\right)=0, \qquad (47)\\
d_{j,t}^{cb} \quad &: \quad (1+\mu_t)\, E_t\left[\beta\Lambda_{t,t+1}\int_{\bar{\omega}_{j,t+1}}^{\infty}\left(-\sigma R_{t+1}^{cb}+\frac{\partial\mathcal{V}_{j,t+1}}{\partial d_{j,t}^{cb}}\right)f\left(\omega_{j,t+1}\right)d\omega_{j,t+1}\right] \\
&+ \quad \chi_t\left(1+d_{j,t}\cdot\frac{\partial q_t}{\partial d_{j,t}^{cb}}\right)-\psi_t=0, \qquad (48)
\end{aligned}
$$

Next, we apply the envelope theorem to further work out the above first order conditions:

$$
\begin{aligned}
\frac{\partial\mathcal{V}_{j,t}}{\partial s_{j,t-1}^{k}} &= \chi_t\left(1-\sigma\right)\omega_{j,t}R_t^{k}q_{t-1}^{k}, \qquad (49)\\
\frac{\partial\mathcal{V}_{j,t}}{\partial s_{j,t-1}^{b}} &= \chi_t\left(1-\sigma\right)R_t^{b}q_{t-1}^{b}, \qquad (50)\\
\frac{\partial\mathcal{V}_{j,t}}{\partial m_{j,t-1}^{R}} &= \chi_t\left(1-\sigma\right)R_t^{R}, \qquad (51)\\
\frac{\partial\mathcal{V}_{j,t}}{\partial d_{j,t-1}} &= -\chi_t\left(1-\sigma\right)\left(\frac{1}{\pi_t}\right), \qquad (52)\\
\frac{\partial\mathcal{V}_{j,t}}{\partial d_{j,t-1}^{cb}} &= -\chi_t\left(1-\sigma\right)R_t^{cb}, \qquad (53)
\end{aligned}
$$

Iterating one period forward, and substitution into the respective first order conditions gives us the first order conditions (11) - (15).

Next, I calculate the partial derivatives of the deposit price q_t in equation (5). To do so, we employ the Leibniz-rule:

$$\frac{d}{dx}\left(\int_{a(x)}^{b(x)} f\left(x,t\right)dt\right) = f\left(x,b(x)\right)\cdot\frac{d}{dx}b(x) - f\left(x,a(x)\right)\cdot\frac{d}{dx}a(x) + \int_{a(x)}^{b(x)}\frac{\partial}{\partial x}f\left(x,t\right)dt$$

We start with the partial derivative with respect to $s_{j,t}^k$:

$$\begin{aligned}
\frac{\partial q_t}{\partial s_{j,t}^k} &= E_t\Bigg(\beta\Lambda_{t,t+1}\Bigg\{-\frac{1}{\pi_{t+1}}\cdot f\left(\bar{\omega}_{j,t+1}\right)\cdot\frac{\partial\bar{\omega}_{j,t+1}}{\partial s_{j,t}^k} \\
&+ \left[\gamma\cdot\frac{1}{\pi_{t+1}}\right. \\
&+ \left.(1-\gamma)\frac{(1-\mu)\,\bar{\omega}_{j,t+1}R_{t+1}^k q_t^k s_{j,t}^k + R_{t+1}^b q_t^b s_{j,t}^b + R_{t+1}^R m_{j,t}^R - R_{t+1}^{cb} d_{j,t}^{cb}}{d_{j,t}}\right] f\left(\bar{\omega}_{j,t+1}\right)\cdot\frac{\partial\bar{\omega}_{j,t+1}}{\partial s_{j,t}^k} \\
&+ \int_0^{\bar{\omega}_{j,t+1}}(1-\gamma)\frac{(1-\mu)\,\omega_{j,t+1}R_{t+1}^k q_t^k}{d_{j,t}}\cdot f\left(\omega_{j,t+1}\right)d\omega_{j,t+1}\Bigg\}\Bigg) \\
&= E_t\Bigg(\beta\Lambda_{t,t+1}\Bigg\{-\frac{1}{\pi_{t+1}}\cdot f\left(\bar{\omega}_{j,t+1}\right)\cdot\frac{\partial\bar{\omega}_{j,t+1}}{\partial s_{j,t}^k} \\
&+ \left[\gamma\cdot\frac{1}{\pi_{t+1}} + (1-\gamma)\frac{1}{\pi_{t+1}} - (1-\gamma)\frac{\mu\bar{\omega}_{j,t+1}R_{t+1}^k q_t^k s_{j,t}^k}{d_{j,t}}\right]\cdot f\left(\bar{\omega}_{j,t+1}\right)\cdot\frac{\partial\bar{\omega}_{j,t+1}}{\partial s_{j,t}^k} \\
&+ (1-\gamma)\int_0^{\bar{\omega}_{j,t+1}}\frac{(1-\mu)\,\omega_{j,t+1}R_{t+1}^k q_t^k}{d_{j,t}}\cdot f\left(\omega_{j,t+1}\right)d\omega_{j,t+1}\Bigg\}\Bigg) \\
&= E_t\Bigg\{\beta\Lambda_{t,t+1}\Bigg[-(1-\gamma)\frac{\mu\bar{\omega}_{j,t+1}R_{t+1}^k q_t^k s_{j,t}^k}{d_{j,t}}\cdot f\left(\bar{\omega}_{j,t+1}\right)\cdot\frac{\partial\bar{\omega}_{j,t+1}}{\partial s_{j,t}^k} \\
&+ (1-\gamma)\int_0^{\bar{\omega}_{j,t+1}}\frac{(1-\mu)\,\omega_{j,t+1}R_{t+1}^k q_t^k}{d_{j,t}}\cdot f\left(\omega_{j,t+1}\right)d\omega_{j,t+1}\Bigg]\Bigg\}, \qquad (54)
\end{aligned}$$

where we used the cut-off value (4) in the third line.

Similarly, we find that the partial derivative with respect to $s_{j,t}^b$ is given by:

$$\begin{aligned}
\frac{\partial q_t}{\partial s_{j,t}^b} &= E_t\Bigg\{\beta\Lambda_{t,t+1}\Bigg[-(1-\gamma)\frac{\mu\bar{\omega}_{j,t+1}R_{t+1}^k q_t^k s_{j,t}^k}{d_{j,t}}\cdot f\left(\bar{\omega}_{j,t+1}\right)\cdot\frac{\partial\bar{\omega}_{j,t+1}}{\partial s_{j,t}^b} \\
&+ (1-\gamma)\int_0^{\bar{\omega}_{j,t+1}}\frac{R_{t+1}^b q_t^b}{d_{j,t}}\cdot f\left(\omega_{j,t+1}\right)d\omega_{j,t+1}\Bigg]\Bigg\}. \qquad (55)
\end{aligned}$$

Similarly, we find that the partial derivative with respect to $m^R_{j,t}$ is given by:

$$\begin{aligned}\frac{\partial q_t}{\partial m^R_{j,t}} &= E_t\left\{\beta\Lambda_{t,t+1}\left[-(1-\gamma)\frac{\mu\bar{\omega}_{j,t+1}R^k_{t+1}q^k_t s^k_{j,t}}{d_{j,t}}\cdot f\left(\bar{\omega}_{j,t+1}\right)\cdot\frac{\partial\bar{\omega}_{j,t+1}}{\partial m^R_{j,t}}\right.\right.\\ &+ \left.\left.(1-\gamma)\int_0^{\bar{\omega}_{j,t+1}}\frac{R^R_{t+1}}{d_{j,t}}\cdot f\left(\omega_{j,t+1}\right)d\omega_{j,t+1}\right]\right\}. \qquad (56)\end{aligned}$$

Similarly, we find that the partial derivative with respect to $d_{j,t}$ is given by:

$$\begin{aligned}\frac{\partial q_t}{\partial d_{j,t}} &= E_t\left\{\beta\Lambda_{t,t+1}\left[-(1-\gamma)\frac{\mu\bar{\omega}_{j,t+1}R^k_{t+1}q^k_t s^k_{j,t}}{d_{j,t}}\cdot f\left(\bar{\omega}_{j,t+1}\right)\cdot\frac{\partial\bar{\omega}_{j,t+1}}{\partial d_{j,t}}\right.\right.\\ &- \left.\left.(1-\gamma)\int_0^{\bar{\omega}_{j,t+1}}\frac{(1-\mu)\,\omega_{j,t+1}R^k_{t+1}q^k_t s^k_{j,t}+R^b_{t+1}q^b_t s^b_{j,t}+R^R_{t+1}m^R_{j,t}-R^{cb}_{t+1}d^{cb}_{j,t}}{\left(d_{j,t}\right)^2}\cdot f\left(\omega_{j,t+1}\right)d\omega_{j,t+1}\right]\right\}. \qquad (57)\end{aligned}$$

Similarly, we find that the partial derivative with respect to $d^{cb}_{j,t}$ is given by:

$$\begin{aligned}\frac{\partial q_t}{\partial d^{cb}_{j,t}} &= E_t\left\{\beta\Lambda_{t,t+1}\left[-(1-\gamma)\frac{\mu\bar{\omega}_{j,t+1}R^k_{t+1}q^k_t s^k_{j,t}}{d_{j,t}}\cdot f\left(\bar{\omega}_{j,t+1}\right)\cdot\frac{\partial\bar{\omega}_{j,t+1}}{\partial d^{cb}_{j,t}}\right.\right.\\ &- \left.\left.(1-\gamma)\int_0^{\bar{\omega}_{j,t+1}}\frac{R^{cb}_{t+1}}{d_{j,t}}\cdot f\left(\omega_{j,t+1}\right)d\omega_{j,t+1}\right]\right\}. \qquad (58)\end{aligned}$$

Taking the partial derivative of equation (4) with respect to $s^k_{j,t}$, $s^b_{j,t}$, $m^R_{j,t}$, $d_{j,t}$, and $d^{cb}_{j,t}$ and substituting in equations (54), (55), (56), (57), and (58), respectively, we find the following expressions:

$$
\begin{aligned}
\frac{\partial q_t}{\partial s^k_{j,t}} &= E_t\Bigg\{\beta\Lambda_{t,t+1}\Bigg[(1-\gamma)\,\frac{\mu\bar{\omega}^2_{j,t+1}R^k_{t+1}q^k_t}{d_{j,t}}\cdot f\left(\bar{\omega}_{j,t+1}\right) \\
&+ (1-\gamma)\int_0^{\bar{\omega}_{j,t+1}}\frac{(1-\mu)\,\omega_{j,t+1}R^k_{t+1}q^k_t}{d_{j,t}}\cdot f\left(\omega_{j,t+1}\right)d\omega_{j,t+1}\Bigg]\Bigg\},
\end{aligned} \tag{59}
$$

$$
\begin{aligned}
\frac{\partial q_t}{\partial s^b_{j,t}} &= E_t\Bigg\{\beta\Lambda_{t,t+1}\Bigg[(1-\gamma)\,\frac{\mu\bar{\omega}_{j,t+1}R^b_{t+1}q^b_t}{d_{j,t}}\cdot f\left(\bar{\omega}_{j,t+1}\right) \\
&+ (1-\gamma)\int_0^{\bar{\omega}_{j,t+1}}\frac{R^b_{t+1}q^b_t}{d_{j,t}}\cdot f\left(\omega_{j,t+1}\right)d\omega_{j,t+1}\Bigg]\Bigg\},
\end{aligned} \tag{60}
$$

$$
\begin{aligned}
\frac{\partial q_t}{\partial m^R_{j,t}} &= E_t\Bigg\{\beta\Lambda_{t,t+1}\Bigg[(1-\gamma)\,\frac{\mu\bar{\omega}_{j,t+1}R^R_{t+1}}{d_{j,t}}\cdot f\left(\bar{\omega}_{j,t+1}\right) \\
&+ (1-\gamma)\int_0^{\bar{\omega}_{j,t+1}}\frac{R^R_{t+1}}{d_{j,t}}\cdot f\left(\omega_{j,t+1}\right)d\omega_{j,t+1}\Bigg]\Bigg\},
\end{aligned} \tag{61}
$$

$$
\begin{aligned}
\frac{\partial q_t}{\partial d_{j,t}} &= E_t\Bigg\{\beta\Lambda_{t,t+1}\Bigg[-(1-\gamma)\,\frac{\mu\bar{\omega}_{j,t+1}}{\pi_{t+1}d_{j,t}}\cdot f\left(\bar{\omega}_{j,t+1}\right) \\
&- (1-\gamma)\int_0^{\bar{\omega}_{j,t+1}}\frac{(1-\mu)\,\omega_{j,t+1}R^k_{t+1}q^k_t s^k_{j,t}+R^b_{t+1}q^b_t s^b_{j,t}+R^R_{t+1}m^R_{j,t}-R^{cb}_{t+1}d^{cb}_{j,t}}{\left(d_{j,t}\right)^2}\cdot f\left(\omega_{j,t+1}\right)d\omega_{j,t+1}\Bigg]\Bigg\}.
\end{aligned} \tag{62}
$$

$$
\begin{aligned}
\frac{\partial q_t}{\partial d^{cb}_{j,t}} &= E_t\Bigg\{\beta\Lambda_{t,t+1}\Bigg[-(1-\gamma)\,\frac{\mu\bar{\omega}_{j,t+1}R^{cb}_{t+1}}{d_{j,t}}\cdot f\left(\bar{\omega}_{j,t+1}\right) \\
&- (1-\gamma)\int_0^{\bar{\omega}_{j,t+1}}\frac{R^{cb}_{t+1}}{d_{j,t}}\cdot f\left(\omega_{j,t+1}\right)d\omega_{j,t+1}\Bigg]\Bigg\},
\end{aligned} \tag{63}
$$

Next, we solve for the continuation value $\mathcal{V}_{j,t}$. To do so, we follow Gertler and Kiyotaki (2010); Gertler and Karadi (2011) and guess the following value function, which we later check:

$$\mathcal{V}_{j,t} \equiv \eta^k_t q^k_t s^k_{j,t} + \eta^b_t q^b_t s^b_{j,t} + \eta^R_t m^R_{j,t} - \eta^d_t q_t d_{j,t} - \eta^{cb}_t d^{cb}_{j,t}, \tag{64}$$

where η_t^k, η_t^b, η_t^R, η_t^d, and η_t^{cb} are given by:

$$\eta_t^k \equiv E_t\left[\Omega_{t,t+1}\int_{\bar{\omega}_{j,t+1}}^{\infty}\omega_{j,t+1}R_{t+1}^k f\left(\omega_{j,t+1}\right)d\omega_{j,t+1}\right], \tag{65}$$

$$\eta_t^b \equiv E_t\left[\Omega_{t,t+1}\int_{\bar{\omega}_{j,t+1}}^{\infty}R_{t+1}^b f\left(\omega_{j,t+1}\right)d\omega_{j,t+1}\right], \tag{66}$$

$$\eta_t^R \equiv E_t\left[\Omega_{t,t+1}\int_{\bar{\omega}_{j,t+1}}^{\infty}R_{t+1}^R f\left(\omega_{j,t+1}\right)d\omega_{j,t+1}\right], \tag{67}$$

$$\eta_t^d \equiv E_t\left[\Omega_{t,t+1}\int_{\bar{\omega}_{j,t+1}}^{\infty}\left(\frac{1}{\pi_{t+1}q_t}\right)f\left(\omega_{j,t+1}\right)d\omega_{j,t+1}\right]. \tag{68}$$

$$\eta_t^{cb} \equiv E_t\left[\Omega_{t,t+1}\int_{\bar{\omega}_{j,t+1}}^{\infty}R_{t+1}^{cb} f\left(\omega_{j,t+1}\right)d\omega_{j,t+1}\right], \tag{69}$$

Substitution of the first order conditions (11) - (15) into the guess for the value function (64) gives:

$$\begin{aligned}
\mathcal{V}_{j,t} &= \frac{\chi_t}{1+\mu_t}\left(q_t^k s_{j,t}^k + q_t^b s_{j,t}^b + m_{j,t}^R - q_t d_{j,t} - d_{j,t}^{cb}\right)\\
&- \left(\frac{\chi_t}{1+\mu_t}\right)\left(\frac{d_{j,t}}{q_t^k}\cdot\frac{\partial q_t}{\partial s_{j,t}^k}\cdot q_t^k s_{j,t}^k + \frac{d_{j,t}}{q_t^b}\cdot\frac{\partial q_t}{\partial s_{j,t}^b}\cdot q_t^b s_{j,t}^b\right.\\
&+ \left. d_{j,t}\cdot\frac{\partial q_t}{\partial m_{j,t}^R}\cdot m_{j,t}^R + \frac{d_{j,t}}{q_t}\cdot\frac{\partial q_t}{\partial d_{j,t}}\cdot q_t d_{j,t} + d_{j,t}\cdot\frac{\partial q_t}{\partial d_{j,t}^{cb}}\cdot d_{j,t}^{cb}\right)\\
&+ \left(\frac{\mu_t}{1+\mu_t}\right)\left(\lambda_k q_t^k s_{j,t}^k + \lambda_b q_t^b s_{j,t}^b\right) - \left(\frac{\psi_t}{1+\mu_t}\right)\left(\theta^k q_t^k s_{j,t}^k + \theta^b q_t^b s_{j,t}^b - d_{j,t}^{cb}\right)\\
&= \frac{\chi_t}{1+\mu_t}\left(q_t^k s_{j,t}^k + q_t^b s_{j,t}^b - q_t d_{j,t}\right) - \left(\frac{\chi_t}{1+\mu_t}\right)d_{j,t}\Xi_t + \left(\frac{\mu_t}{1+\mu_t}\right)\left(\lambda_k q_t^k s_{j,t}^k + \lambda_b q_t^b s_{j,t}^b\right),
\end{aligned} \tag{70}$$

where the second term in the fourth line is equal to zero because of the Kuhn-Tucker condition for the collateral constraint (2), and where Ξ_t is defined as:

$$\Xi_t \equiv \frac{\partial q_t}{\partial s_{j,t}^k}\cdot s_{j,t}^k + \frac{\partial q_t}{\partial s_{j,t}^b}\cdot s_{j,t}^b + \frac{\partial q_t}{\partial m_{j,t}^R}\cdot m_{j,t}^R + \frac{\partial q_t}{\partial d_{j,t}}\cdot d_{j,t} + \cdot\frac{\partial q_t}{\partial d_{j,t}^{cb}}\cdot d_{j,t}^{cb}. \tag{71}$$

Substitution of equations (59) - (63) allow us to rewrite Ξ_t:

$$
\begin{aligned}
\Xi_t &= (1-\gamma) E_t \Bigg\{ \beta \Lambda_{t,t+1} \Bigg[\frac{\mu \bar{\omega}_{j,t+1}^2 R_{t+1}^k q_t^k s_{j,t}^k}{d_{j,t}} \cdot f(\bar{\omega}_{j,t+1}) \\
&+ \int_0^{\bar{\omega}_{j,t+1}} \frac{(1-\mu)\, \omega_{j,t+1} R_{t+1}^k q_t^k s_{j,t}^k}{d_{j,t}} \cdot f(\omega_{j,t+1})\, d\omega_{j,t+1} \Bigg] \Bigg\} \\
&+ (1-\gamma) E_t \Bigg\{ \beta \Lambda_{t,t+1} \Bigg[\frac{\mu \bar{\omega}_{j,t+1} R_{t+1}^b q_t^b s_{j,t}^b}{d_{j,t}} \cdot f(\bar{\omega}_{j,t+1}) \\
&+ \int_0^{\bar{\omega}_{j,t+1}} \frac{R_{t+1}^b q_t^b s_{j,t}^b}{d_{j,t}} \cdot f(\omega_{j,t+1})\, d\omega_{j,t+1} \Bigg] \Bigg\} \\
&+ (1-\gamma) E_t \Bigg\{ \beta \Lambda_{t,t+1} \Bigg[\frac{\mu \bar{\omega}_{j,t+1} R_{t+1}^R m_{j,t}^R}{d_{j,t}} \cdot f(\bar{\omega}_{j,t+1}) \\
&+ \int_0^{\bar{\omega}_{j,t+1}} \frac{R_{t+1}^R m_{j,t}^R}{d_{j,t}} \cdot f(\omega_{j,t+1})\, d\omega_{j,t+1} \Bigg] \Bigg\} \\
&+ (1-\gamma) E_t \Bigg\{ \beta \Lambda_{t,t+1} \Bigg[-\frac{\mu \bar{\omega}_{j,t+1}}{\pi_{t+1}} \cdot f(\bar{\omega}_{j,t+1}) \\
&- \int_0^{\bar{\omega}_{j,t+1}} \frac{(1-\mu)\, \omega_{j,t+1} R_{t+1}^k q_t^k s_{j,t}^k + R_{t+1}^b q_t^b s_{j,t}^b + R_{t+1}^R m_{j,t}^R - R_{t+1}^{cb} d_{j,t}^{cb}}{d_{j,t}} \cdot f(\omega_{j,t+1})\, d\omega_{j,t+1} \Bigg] \Bigg\} \\
&+ (1-\gamma) E_t \Bigg\{ \beta \Lambda_{t,t+1} \Bigg[-\frac{\mu \bar{\omega}_{j,t+1} R_{t+1}^{cb} d_{j,t}^{cb}}{d_{j,t}} \cdot f(\bar{\omega}_{j,t+1}) \\
&- \int_0^{\bar{\omega}_{j,t+1}} \frac{R_{t+1}^{cb} d_{j,t}^{cb}}{d_{j,t}} \cdot f(\omega_{j,t+1})\, d\omega_{j,t+1} \Bigg] \Bigg\} \\
&= (1-\gamma) E_t \Bigg[\beta \Lambda_{t,t+1} \cdot \frac{\mu \bar{\omega}_{j,t+1}}{d_{j,t}} \cdot f(\bar{\omega}_{j,t+1}) \Bigg(\bar{\omega}_{j,t+1} R_{t+1}^k q_t^k s_{j,t}^k + R_{t+1}^b q_t^b s_{j,t}^b + R_{t+1}^R m_{j,t}^R \\
&- \frac{d_{j,t}}{\pi_{t+1}} - R_{t+1}^{cb} d_{j,t}^{cb} \Bigg) \Bigg] = 0,
\end{aligned}
$$

where we used equation (4) in the final lines.

Therefore, we can write expression (70) as:

$$
\mathcal{V}_{j,t} = \frac{\chi_t}{1+\mu_t}(1-\sigma)\, n_{j,t} + \left(\frac{\mu_t}{1+\mu_t}\right)\left(\lambda_k q_t^k s_{j,t}^k + \lambda_b q_t^b s_{j,t}^b\right), \tag{72}
$$

where we used intermediaries' balance sheet constraint (1). When intermediaries' incentive compatibility constraint (8) is not binding, we find that $\mathcal{V}_{j,t} = \chi_t (1-\sigma)\, n_{j,t}$. When the constraint binds, we get that:

$$
\frac{\chi_t}{1+\mu_t}(1-\sigma)\, n_{j,t} + \left(\frac{\mu_t}{1+\mu_t}\right)\left(\lambda_k q_t^k s_{j,t}^k + \lambda_b q_t^b s_{j,t}^b\right) = \lambda_k q_t^k s_{j,t}^k + \lambda_b q_t^b s_{j,t}^b,
$$

which we can rewrite as:

$$\chi_t (1-\sigma) n_{j,t} = \lambda_k q_t^k s_{j,t}^k + \lambda_b q_t^b s_{j,t}^b. \tag{73}$$

After substitution of the above expression into equation (72), we find that $\mathcal{V}_{j,t} = \chi_t (1-\sigma) n_{j,t}$. Therefore, irrespective of whether intermediaries' incentive compatibility constraint (8) is binding or not, we have that intermediaries' value function $\mathcal{V}_{j,t}$ is given by:

$$\mathcal{V}_{j,t} = \chi_t (1-\sigma) n_{j,t}. \tag{74}$$

Finally, we check whether our guess for the value function (64) is consistent with (7). To do so, we substitute expression (72) into the right hand side of (7):

$$\begin{aligned}
\mathcal{V}_{j,t} &= E_t \left\{ \beta \Lambda_{t,t+1} \int_{\bar{\omega}_{j,t+1}}^{\infty} \left[\sigma + (1-\sigma)\chi_{t+1}\right] n_{j,t+1} f(\omega_{j,t+1})\, d\omega_{j,t+1} \right\} \\
&= E_t \left\{ \beta \Lambda_{t,t+1} \int_{\bar{\omega}_{j,t+1}}^{\infty} \left[\sigma + (1-\sigma)\chi_{t+1}\right] \omega_{j,t+1} R_{t+1}^k f(\omega_{j,t+1})\, d\omega_{j,t+1} \right\} q_t^k s_{j,t}^k \\
&+ E_t \left\{ \beta \Lambda_{t,t+1} \int_{\bar{\omega}_{j,t+1}}^{\infty} \left[\sigma + (1-\sigma)\chi_{t+1}\right] R_{t+1}^b f(\omega_{j,t+1})\, d\omega_{j,t+1} \right\} q_t^b s_{j,t}^b, \\
&+ E_t \left\{ \beta \Lambda_{t,t+1} \int_{\bar{\omega}_{j,t+1}}^{\infty} \left[\sigma + (1-\sigma)\chi_{t+1}\right] R_{t+1}^R f(\omega_{j,t+1})\, d\omega_{j,t+1} \right\} m_{j,t}^R, \\
&- E_t \left\{ \beta \Lambda_{t,t+1} \int_{\bar{\omega}_{j,t+1}}^{\infty} \left[\sigma + (1-\sigma)\chi_{t+1}\right] \left(\frac{1}{\pi_{t+1} q_t}\right) f(\omega_{j,t+1})\, d\omega_{j,t+1} \right\} q_t d_{j,t}, \\
&- E_t \left\{ \beta \Lambda_{t,t+1} \int_{\bar{\omega}_{j,t+1}}^{\infty} \left[\sigma + (1-\sigma)\chi_{t+1}\right] R_{t+1}^{cb} f(\omega_{j,t+1})\, d\omega_{j,t+1} \right\} d_{j,t}^{cb},
\end{aligned} \tag{75}$$

which coincides exactly with the guess (64).

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