Monetary Policy in a Tightening Cycle

Raising nominal rates without causing a financial crisis*

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Abstract

With inflation reaching levels not seen in more than thirty years, central banks in many advanced economies have embarked on a rapid tightening cycle over the past eighteen months. Interest rate hikes impose capital losses on bank balance sheets. As net worth declines, risks to financial stability grow. In recent months, this has reignited a debate on a potential trade-off between monetary and financial stability. In this paper, I set up a new-Keynesian model of savers and borrowers with banks subject to a principal-agent friction and the risk of a run on deposits. In the model, a contractionary rates policy depresses bank net worth and increases the risk of a run. I show that a limited expansion of the central bank balance sheet can address concerns about financial stability with little to no costs for the pursuit of monetary stability. Differences in the transmission of both monetary instruments are key for this result. A decomposition of bank net worth illustrates this and the financial sector implications of monetary policy. Further, a U.S. 'pandemic era inflation' scenario is used as a laboratory to analyse policy counterfactuals against the backdrop of heightened inflation and declining bank net worth. In this environment, a temporary balance sheet expansion successfully stabilizes bank net worth without adding significant inflationary pressure.

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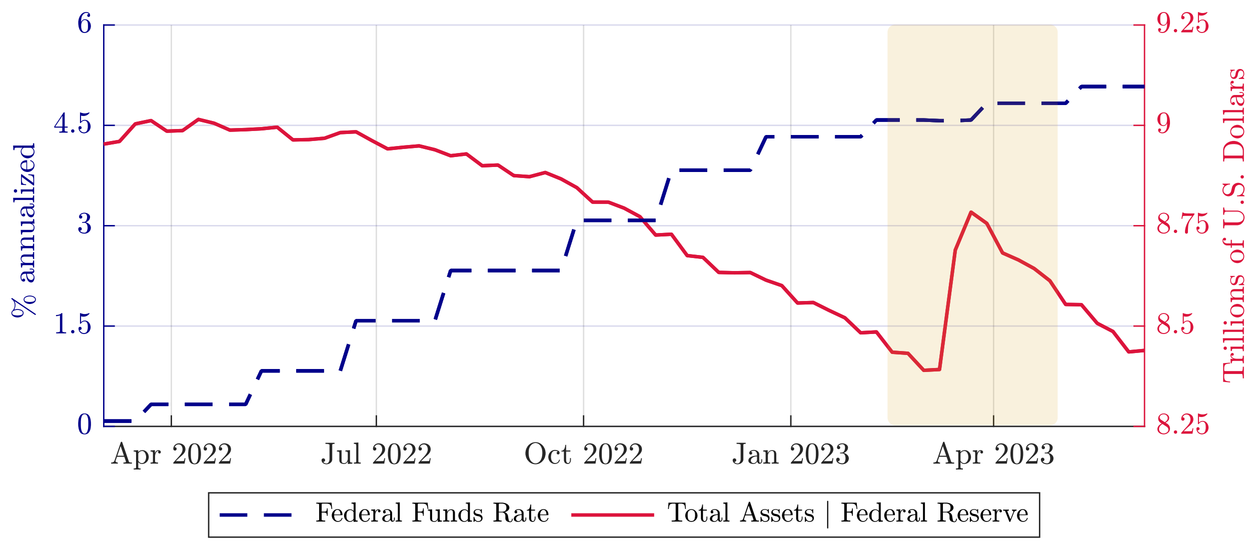
1 Introduction

Over the past eighteen months, inflation in advanced economies has reached levels not seen in more than thirty years. In response, many central banks have been rapidly tightening their monetary stance, raising nominal interest rates and phasing out asset purchase policies employed ever since the 2007/08 Great Financial Crisis. This contractionary policy has caused adverse effects on financial institutions, giving rise to instances of financial turmoil, and reigniting a debate on a potential trade-off between monetary and financial stability.[1]

Figure 1. Federal Reserve, March 2023 | SVB crisis



Note. This Figure plots the Federal Funds Target Rate (left axis, blue) and the stock of total assets on the Federal Reserve balance sheet (right axis, red) around the U.S. regional banking (SVB) crisis in March 2023. Source: Federal Reserve Bank of St Louis.

In practice, major central banks such as the U.S. Federal Reserve, the European Central Bank, and the Bank of England reacted to instances of financial instability in recent months with renewed balance sheet expansions while further raising nominal interest rates. Figure 1 illustrates this unconventional pairing of monetary instruments using the example of the Federal Reserve's monetary policy stance in the first months of 2023.

[1] Raghuram Rajan, Professor of Finance at the University of Chicago's Booth School of Business and a former Governor of the Reserve Bank of India, summarized this perspective in an interview in June 2023, arguing that central banks find themselves in a 'very, very tough situation [. . .] You're damned if you raise rates significantly more and put even more pressure on banks, but you're damned if you don't.'
Wall Street Journal: 'Jerome Powell's Big Problem Just Got Even More Complicated' | 12 June 2023

When in the U.S. in March 2023, several regional banks – including the now defunct Silicon Valley Bank (SVB) – emerged to be at the brink of collapse with consumer price inflation still at 5% far above target, the Federal Reserve opted to keep raising its main policy rate, the federal funds target rate (Figure 1, blue), while pausing the only recently initiated balance sheet reduction for a sizeable balance sheet expansion (Figure 1, red). At the time, the Federal Reserve Chair justified this mix of a contractionary interest rate and an expansionary balance sheet policy, arguing 'the balance sheet expansion is really temporary lending to banks [...] It is not intended to directly alter the stance of monetary policy.'[2]

Most conventional models of the macroeconomy characterize the central bank balance sheet as a pure extension or substitute of regular interest rate policy. This is particularly true for a broad range of new-Keynesian models that highlight the aggregate demand stimulus a balance sheet expansion – often simply termed quantitative easing or QE – provides when nominal interest rates are constrained at the effective lower bound. Thus, pairing a balance sheet expansion with a contractionary interest rate policy might seem surprising, if not counterintuitive. So, what are the implications of this unconventional policy pairing? Is there a trade-off between monetary and financial stability in a high inflation environment? And what constitutes effective monetary policy in a tightening cycle?

A monetary tightening comes with adverse effects on financial institutions subject to interest rate risk: as rising rates impose capital losses on balance sheets, net worth declines.[3] In a world of imperfect macroprudential regulation, these adverse effects can turn from a regular transmission mechanism of monetary policy to a concern for financial stability.

In this paper, I set up a new-Keynesian model of borrowers and savers with run-prone frictional financial intermediation that rationalizes these effects. In this environment, I argue that a central bank balance sheet expansion, or termed differently, a temporarily repurposed QE intervention, is a natural complement to a monetary tightening that can eliminate any emerging trade-off between monetary and financial stabilization. As I show, targeted balance sheet expansions can stabilize bank net worth and reduce the risk of a run on deposits, thereby smoothing out the financial stability implications of rapidly rising rates without directly affecting central bank's primary mandate of monetary stabilization.

[2] Transcript of Chair Powell's Press Conference on March 22, 2023:
https://www.federalreserve.gov/mediacenter/files/FOMCpresconf20230322.pdf

[3] On impact and in the short-run, for most financial institutions subject to interest rate risk, capital losses dominate the beneficial effects of increasing interest margins in a higher-rate environment.

In the model, financial intermediaries (banks) channel funds from savers to borrower subject to a principal-agent problem limiting leverage and giving rise to a financial accelerator. Credit spreads are determined by bank net worth. Banks also engage in maturity transformation as deposits are short-term while lending is assumed to be in the form of long-term debt. With pre-determined deposit rates and state-contingent returns to lending, this implies that banks are subject to interest rate risk. Thus, a contractionary rates policy imposes capital losses and depresses bank net worth as the value of the portfolio of existing (low-interest) debt declines when interest rates rise. In light of banks maturity mismatch, roll-over risk links this fall in net worth to financial instability. As net worth declines, the probability of a run on deposits increases. This is one dimension of the supposed trade-off between monetary and financial stabilization captured in the model.

Monetary policy is conducted by a central bank with two instruments at its disposal: an inertial interest rate policy and a balance sheet policy that exchanges reserves for long-term debt. The central bank is not subject to the same principal-agent problem as banks. Thus, a balance sheet expansion that creates additional demand for long-term debt stabilizes the value of banks' loan portfolio and compresses credit spreads, thereby reducing frictions in financial intermediation, and stimulating the economy. In this sense, and at the effective lower bound in particular, lower nominal interest rates and balance sheet expansions can be thought of as substitutes in an output-inflation space through their effect on aggregate demand. Both policies are not collinear though. They come with very different implications in a bank net worth-inflation space. This allows for the two instruments to be moved in different directions when both monetary and financial stability are a concern.

I show that an expansionary central bank balance sheet policy can be an effective complement to a contractionary rates policy when bank net worth is low and the risk of a run elevated. A well-calibrated policy mix smooths out the impact of rising rates on net worth while preserving their desired contractionary effect on above-target inflation in tightening cycle. Differences in the transmission of both instruments (and a redistributionary cost-push dimension of frictional intermediation) are relevant for this result. A novel decomposition of bank net worth illustrates this and provides further insights the financial sector implications of monetary policy. Furthermore, a simulation exercise implements a U.S. 'pandemic era inflation' scenario as a laboratory to analyze policy counterfactuals against the backdrop of heightened inflation and the accelerating risks to financial stability. In this environment, a temporary balance sheet expansion is successful in smoothing the adverse effects of a contractionary interest rate policy on bank net worth at little to no cost to inflation.

Literature This paper relates to at least three broad strands of the literature.[4] First, it builds on and connects to the vast literature on monetary policy and financial stability that has emerged since the Great Financial Crisis. A small and non exhaustive list of influential contributions include Woodford (2012) and Cúrdia and Woodford (2016) on optimal monetary policy in an environment with frictions in financial intermediation, Korinek and Simsek (2016) with a focus on macroprudential policy, and, more recently, Boissay, Collard, Galí, and Manea (2021) on the endogenous emergence of financial crises and Akinci, Benigno, Del Negro, and Queralto (2023) on the financial (in)stability real interest rate r^{**}. Brunnermeier, Eisenbach, and Sannikov (2012) and Adrian and Liang (2018) provide excellent overviews on recent developments in the field. Relative to this literature that often focuses on financial stability concerns arising from risk shifting behavior in a low interest rate environment, this paper is about financial instability in a tightening cycle. It suggests temporary central bank balance sheet expansions as an effective tool to address risks of bank runs and financial crisis endogenously arising from rapidly rising rates.

Second, this paper relates to a large literature on central bank balance sheet policies as a macroeconomic stabilization tool. The contributions in this literature break the irrelevance result in Wallace (1981), and extended in Eggertsson and Woodford (2003) to cases at the effective lower bound, typically highlighting the importance of different transmission channels along at least two dimensions. One, in an environment of segmented markets, a portfolio balance channel as theoretically described in Vayanos and Vila (2021) and investigated in Chen, Cúrdia, and Ferrero (2012), Ellison and Tischbirek (2014), and Harrison (2012, 2017), amongst others, implies that central bank asset purchases come with a strong aggregate demand dimension and can be a powerful substitute to conventional interest rate policies, in particular at the effective lower bound for nominal rates. In a similar vein, a signaling channel as introduced and empirically described, amongst others, by Krishnamurthy and Vissing-Jorgensen (2011) and Bauer and Rudebusch (2014) suggests balance sheet expansions at the effective lower bound provide an additional stimulus as they serve as a strong commitment device for a 'lower-for-longer' interest rate policy. Bhattarai, Eggertsson, and Gafarov (2023) explore this signaling channel in a new-Keynesian model and show how a balance sheet expansion that reduces the outstanding maturity of government debt creates expectations of a future monetary expansion in a time-consistent equilibrium. Two, in models with frictions in financial intermediation and liquidity, central bank balance sheet policies typically ease intermediation and funding

[4] In the interest of conciseness, this brief literature review mostly highlights theoretical (and selected empirical) contributions. Section 2 documents further references in the context of the model setup.

pressures by increasing the supply of perfectly safe and liquid assets in the economy. This liquidity channel can be powerful, particularly in times of financial turmoil. Early contributions that study the effect of balance sheet policies in models of frictional financial intermediation include Gertler and Kiyotaki (2010, 2015), Gertler and Karadi (2011, 2013), Cúrdia and Woodford (2011) as well as Carlstrom, Fuerst, and Paustian (2017). Del Negro, Eggertsson, Ferrero, and Kiyotaki (2017) implement balance sheet policies in a medium-scale new-Keynesian model with resaleability and collateral constraints, Cui and Sterk (2021) study the policy in a heterogeneous agent framework, and Sims and Wu (2021) as well as Sims, Wu, and Zhang (2023) present a tractable model for the analysis of multiple monetary instruments. Moreover, Gertler et al. (2020b,a) introduce a notion of bank runs and financial panics in their analysis of central bank balance sheet policies, linking monetary and financial stabilization in line with the analysis in this paper. The present paper is very much part of this sequence of papers that stress the financial sector and liquidity implications of balance sheet policies. Relative to all of these contributions though, it highlights the interaction of interest rate and balance sheet policies, focusing on the substitutability and complementarity of the two monetary instruments.

Third, this paper relates to a small and much more recent strand of the literature that studies the optimal sequencing of monetary instruments at the onset of a tightening cycle. Benigno and Benigno (2022) and Cantore and Meichtry (2023) are two contributions in this field that analyze the trade-offs associated with policy rate increases and central balance sheet contractions. Contrary to both of these, in this paper I explicitly consider the adverse effects of a monetary tightening on financial intermediaries and show that there might be times in a rapid tightening cycle when a temporary balance sheet expansion (rather than a contraction) is the more natural complement to a contractionary rates policy.

The paper proceeds with Section 2 and a tractable model of savers and borrowers subject to frictional financial intermediation. Section 3 presents the main results. Section 4 concludes.

2 Model

This section sets up a model with frictional financial intermediation, nominal rigidities, and a central bank that conducts interest rate and balance sheet policies. The model builds on and extends a model introduced in de Groot and Haas (2023). It combines a setup with patient and impatient households – savers and borrowers – as in Kiyotaki and Moore (1997) and Iacoviello (2005) with credit frictions in financial intermediation and balance sheet policies as introduced in Gertler and Kiyotaki (2010) and Gertler and Karadi (2011). In the model, financial intermediaries (banks) engage in maturity transformation – funding a long-term loan portfolio issuing short-term deposit – in the spirit of Carlstrom et al. (2017). They are also prone to roll-over crises (bank runs) as their net worth position deteriorates. This link between banks' balance sheet and financial stability adapts Gertler et al. (2020b).[5]

In the model, banks engage in maturity transformation channelling funds from savers to borrowers subject to a principal-agent problem and the risk of a bank run. Given banks' exposure to interest rate risk, a contractionary interest rate policy imposes capital losses. As net worth declines, this increases the likelihood of a costly bank run in which all net worth is wiped out and savers resort to direct lending to borrowers subject to significant efficiency costs. A central bank balance sheet expansion – which exchanges reserves for long-term loans – has real effects as the central bank is less efficient than banks in intermediating but not credit constrained (and more efficient than direct lending between the two households).[6]

The model – to a first-order approximation – can be reduced to six equations that allow for tractable insights regarding the role balance sheet policies can play in a tightening cycle. All results continue to hold when additional features are introduced as shown below.

[5] In its tractability, the model also shares features with Cúrdia and Woodford (2016) and Sims et al. (2023) even if assumptions regarding the labor supply of the two households, transfers, and the functional form of the financial friction differ markedly. In addition, the concept of run risk and financial instability is absent in these papers. More details are provided below. Away from the ZLB, the model in this section nests the simple model in de Groot and Haas (2023) while introducing a maturity mismatch, run risk, central bank balance sheet policies, and accounting for endogenous effects of monetary policy on financial intermediaries.

[6] For the central bank balance sheet to matter, it must be able to address (or circumvent) existing frictions in financial markets as first argued by Wallace (1981). In this paper, which focuses on the adverse effects of a monetary tightening on financial intermediaries, this is through a liquidity or credit channel of central bank balance sheet policies in the spirit of Gertler and Kiyotaki (2010), Cúrdia and Woodford (2011), and Del Negro et al. (2017). A notion that is already present in contributions before the Great Financial Crisis though such as Sargent and Wallace (1982) and Holmström and Tirole (1998). Further frictions such as market segmentation as in Vayanos and Vila (2021) and limited commitment on the part of monetary policymakers as in Bhattarai et al. (2023) give rise to additional portfolio balance and signaling channels of central bank balance sheet policies. These additional channels are omitted for the purposes of this paper.

2.1 Set up

Four types of agents populate the model: households, banks, firms, and a central bank. Households are either savers or borrowers. Both types supply labor and transact through banks. Banks are subject to frictional financial intermediation and prone to roll-over risk due to a maturity mismatch between short-term deposits and a long-term loan portfolio. Monopolistic firms employ labor to produce and set prices subject to nominal rigidities. The central bank conducts monetary policy using two instruments: the nominal interest rate on reserves and the size of its balance sheet (QE/QT).[7]

Households A continuum of households consists of savers and borrowers. The two types are ex-ante heterogeneous and distinguished by their relative patience pinned down by the discount factors β_s and β_b, respectively. The discount factors satisfy $0 < \beta_b < \beta_s < 1$.

Saver households are composed of two sets of members with perfect consumption insurance: workers and bankers. At any time t, a fraction b of household members are bankers and a fraction $1 - b$ are workers. To restrain bankers' accumulation of net worth and keep their principal-agent problem binding (outlined below), it is assumed that a ratio $1 - \theta$ of bankers switches their role with workers every period, keeping the overall proportions constant. This makes bankers' horizon finite with an average survival rate of $1/(1 - \theta)$. When bankers exit, they transfer their retained earnings to the their respective household.

Saver households consume, $C_{s,t}$, supply labor, $L_{s,t}$, and have access to two means of saving: short-term bank deposits, D_t, and direct lending to borrower households though holdings of long-term debt, $Q_t B_{s,t}$. Deposits earn a pre-determined gross nominal return $R_{d,t-1}$ while holdings of long-term debt are priced at Q_t and subject to an efficiency cost $f\left(B_{s,t}\right)$.

Using the perpetual bond concept in Woodford (2001), long-term debt is assumed to be issued by borrowers in the form of perpetuities with cash flows of $1,\ \kappa,\ \kappa^2$ ... where $\kappa \in [0, 1]$ is the decay parameter of coupon payments. At time t, denoting with CI_t the new nominal issuance of long-term debt and with B_{t-1} the total outstanding liability on

[7] For the remainder of this paper, and where not explicitly specified differently, the terms central bank balance sheet expansion and quantitative easing (QE) as well as central bank balance sheet contraction and quantitative tightening (QT) are used interchangeably in the interest of conciseness. In doing so, I follow the academic literature which employs a slightly broader definition of what constitutes QE/QT compared to several central banks that use these terms primarily for balance sheet policies targeting the yield curve. Crucially, this broader definition fits the results in this paper that show balance sheet expansions of different forms, including a repurposed QE, can be a very effective complement to a monetary tightening.

all past issuances given by $B_{t-1} = CI_{t-1} + \kappa\, CI_{t-2} + \kappa^2\, CI_{t-3} + \ldots$, the new issuance can be written recursively as $CI_t = (B_t - \kappa B_{t-1})$. This attractive feature of perpetual bonds implies that period t and $t-1$ total outstanding liabilities, B_t and B_{t-1}, and the price for the latest period t issuance, Q_t, are sufficient to pin down to the complete portfolio of perpetuities.

Thus, the representative saver household's problem is given by

$$V_{s,t} = \max_{\{C_{s,t}, L_{s,t}, D_t, B_{s,t}\}} \left(\frac{{C_{s,t}}^{1-\sigma}}{1-\sigma} - \chi \frac{{L_{s,t}}^{1+\varphi}}{1+\varphi} \right) + \beta_s\, \mathbb{E}_t V_{s,t+1}, \tag{1}$$

subject to

$$P_t C_{s,t} + D_t + Q_t B_{s,t} + f\left(B_{s,t}\right) = P_t W_{s,t} L_{s,t} + R_{d,t-1} D_{t-1} + B_{s,t-1} \left(1 + \kappa Q_t\right) + \Omega_t - T_t, \tag{2}$$

where P_t is the aggregate price level, $W_{s,t}$ is the real wage, and Ω_t denotes profits from firm ownership as well as retained earnings from exiting bankers. Further, T denotes a redistributionary lump-sum tax the government collects from savers and pay to borrowers.[8]

Saver households' four first-order conditions can be summarized by two intertemporal Euler equations and an intratemporal labor-leisure trade-off given by

$$1 = \mathbb{E}_t \Lambda_{t,t+1}\, R_{d,t} / \Pi_{t+1}, \tag{3}$$

$$1 = \mathbb{E}_t \Lambda_{t,t+1}\, \frac{1 + \kappa Q_{t+1}}{Q_t + f'\left(B_{s,t}\right)} / \Pi_{t+1}, \tag{4}$$

$$\chi L_{s,t}^{\varphi} = C_{s,t}^{-\sigma} W_{s,t}, \tag{5}$$

where $\Lambda_{t-1,t} \equiv \beta_s \exp\left(s_t\right) \left(C_{s,t+1}/C_{s,t}\right)^{-\sigma}$ is defined as savers' real stochastic discount factor and $\Pi_t \equiv P_t / P_{t-1}$ denotes the gross inflation rate in the economy. The two intertemporal Euler equations pin down the return on deposits and the expected return on direct lending. The efficiency cost of direct lending, $f\left(B_{s,t}\right)$, will be calibrated such that, in normal times, the large majority of funds is channeled to borrowers via banks. It is only in times of turmoil as savers consider a run on their deposits that direct lending becomes relevant as the remaining outside option. As in Gertler et al. (2020b), Equation (4) will be key to determine the (much lower) price of long-term debt in this run scenario and can be used to compute the probability of a run at any time t, as outlined in detail below.

[8] This transfer (and its functional form) is not crucial for any of the results presented in this paper but facilitates the tractability of the model with a clean set of equilibrium conditions as shown in Section 2.2.

Borrower households only consist of workers. They consume, $C_{b,t}$, supply labor, $L_{b,t}$, and borrow, both rolling over the stock of outstanding liabilities, B_{t-1}, and issuing new debt, CI_t. As outlined above, this borrowing specification in the form of perpetuities implies that – in the absence of capital – banks engage in maturity transformation, holding a state-contingent portfolio of debt obligations funded with non-state contingent deposits in addition to their own net worth. The representative borrower household's problem is given by

$$V_{b,t} = \max_{\{C_{b,t}, L_{b,t}, B_t\}} \left(\frac{C_{b,t}{}^{1-\sigma}}{1-\sigma} - \chi \frac{L_{b,t}{}^{1+\varphi}}{1+\varphi} \right) + \beta_b \, \mathbb{E}_t V_{b,t+1}, \tag{6}$$

subject to

$$P_t C_{b,t} + B_{t-1} (1 + \kappa Q_t) = P_t W_{b,t} L_{b,t} + Q_t B_t + T_t. \tag{7}$$

Borrowers households' three first-order conditions can be summarized by an intertemporal Euler equation and an intratemporal labor-leisure trade-off given by

$$1 = \mathbb{E}_t \, \beta_b \left(C_{b,t+1}^{-\sigma} / C_{b,t}^{-\sigma} \right) R_{b,t+1} / \Pi_{t+1}, \tag{8}$$

$$\chi L_{b,t}^{\varphi} = C_{b,t}^{-\sigma} W_{b,t}, \tag{9}$$

where $R_{b,t} = (1 + \kappa Q_t) / Q_{t-1}$ is the gross nominal interest rate on outstanding debt.

Banks Financial intermediaries (banks) channel funds from savers to borrowers and engage in maturity transformation.[9] Each bank is run by a banker. At time t, banker j issues short-term deposits, $D_t(j)$, to supplement accumulated net worth, $N_t(j)$, in order to fund a portfolio of long-term debt holdings, $Q_t B_{f,t}(j)$, and short-term central bank reserves, $A_t(j)$. Reserves are supplied inelastically by the central bank and earn a gross nominal return R_t. The balance sheet of banker j can therefore be written as

$$Q_t B_{f,t}(j) + A_t(j) = D_t(j) + N_t(j). \tag{10}$$

In normal times, when depositors roll over their deposits and do not coordinate on a run, the timing is as follows: i) Bankers receive a return on their loan portfolio and repay depositors. ii) Bankers exit with probability $1 - \theta$. An exiting banker is replaced by a

[9] In this model, the term 'bank' is used as a short-form for a diverse set of financial intermediaries (retail and commercial banks as well as investment funds) subject to interest rate risk and prone to roll-over crises.

worker with a fixed start up endowment of net worth, $\bar{N}$. iii) Bankers accept new deposits and demand reserves. iv) A banker can divert a fraction λ of its assets (net of reserves) to its household, in which case, the depositors force bankruptcy and recover the remaining assets.

This agency problem creates a financial friction and makes bankers' net worth a relevant determinant of equilibrium outcomes. The banker problem is given by

$$V_{f,t}(j) = \max_{\{B_{f,t}(j),\, A_t(j),\, D_t(j),\, N_t(j)\}} \mathbb{E}_t \Lambda_{t,t+1} \left[(1-\theta) N_{t+1}(j) + \theta V_{f,t+1}(j) \right], \tag{11}$$

subject to the banker's balance sheet, (10), the incentive compatibility constraint, (12), and the accumulation of net worth equation, (13), the latter two of which given by

$$V_{f,t}(j) \geq \lambda\, Q_t B_{f,t}(j), \tag{12}$$

$$N_t(j) = \left(R_{b,t}/\Pi_t\right) B_{f,t-1}(j) - \left(R_{d,t-1}/\Pi_t\right) \left[D_{t-1}(j) - A_{t-1}(j)\right]. \tag{13}$$

Since banks are competitive and holdings of central bank reserves are not subject to the incentive compatibility constraint, arbitrage ensures that deposits and reserves command the same nominal interest rate, $R_{d,t} = R_t$. In a symmetric equilibrium, bankers also have a common leverage ratio, denoted $\Phi_t \equiv Q_t B_{f,t}/N_t = Q_t B_{f,t}(j)/N_t(j)$.

Thus, building on de Groot and Haas (2023) (and as derived in Appendix A.1), the banking sector problem can be summarized in just two equations. Aggregate net worth is given by

$$N_t = \theta \left[\left(R_{b,t}/\Pi_t\right) \Phi_{t-1} - \left(R_{t-1}/\Pi_t\right)\left(\Phi_{t-1} - 1\right) \right] N_{t-1} + (1-\theta)\bar{N}, \tag{14}$$

which is the sum of accumulated net worth of non-exiting bankers and the fixed start up fund $\bar{N}$ newly entering banks receive. The aggregate incentive compatibility constraint is

$$\lambda \Phi_t = \mathbb{E}_t \Lambda_{t,t+1} \frac{1-\theta+\theta\lambda\Phi_{t+1}}{\Pi_{t+1}} \left[R_{b,t+1}\Phi_t - R_{d,t}\left(\Phi_t - 1\right) \right]. \tag{15}$$

A financial panic is defined as depositors coordinating to not roll over their deposits. This notion of a run on the entire banking system and the probability of such a run occurring captures financial (in)stability in the model. In the spirit of Gertler et al. (2020b), the probability of a runs is endogenously linked to the bank's net worth position. As a monetary tightening imposes capital losses on bank balance sheet's due to their exposure to interest rate risk, net worth falls, and the probability of a financial panic increases.

Production Intermediate firm i produces output $X_t(i) = L_{s,t}(i)^{\omega} L_{b,t}(i)^{1-\omega}$, hiring workers in a competitive labor market. Retail firms repackage intermediate output one-for-one, $Y_t(i) = X_t(i)$. Final output, $Y_t = \left(\int_0^1 Y_t(i)^{(\epsilon-1)/\epsilon} di\right)^{\epsilon/(\epsilon-1)}$, is a CES aggregate of retail firm output, where $\epsilon > 0$. Cost minimization results in demand for good i given by $Y_t(i) = (P_t(i)/P_t)^{-\epsilon} Y_t$, where $P_t = \left(\int_0^1 P_t(i)^{1-\epsilon} di\right)^{1/(1-\epsilon)}$. Subject to a Calvo nominal price rigidity, each period, retail firms adjust their prices with probability $1-\iota$. In doing so, they solve $\max_{P_t(i)} \mathbb{E}_t \sum_{\tau=0}^{\infty} \iota^{\tau} \Lambda_{t,t+\tau} \left(\frac{P_t(i)}{P_{t+\tau}} - \mathcal{M}_{t+\tau}\right) Y_{t+\tau}(i)$ subject to the demand for good i, where $\mathcal{M}_t = W_{s,t}^{\omega} W_{b,t}^{1-\omega} / \left(\omega^{\omega}(1-\omega)^{1-\omega}\right)$ denotes marginal cost.

The first-order condition is given by

$$\mathbb{E}_t \sum_{\tau=0}^{\infty} \iota^{\tau} \Lambda_{t,t+\tau} \left(\frac{P_{*,t}}{P_{t+\tau}} - \frac{\epsilon}{\epsilon-1}\mathcal{M}_{t+\tau}\right) Y_t(i) = 0, \tag{16}$$

where $P_{*,t}$ is the optimal reset price and the evolution of the aggregate price index is

$$P_t = \left((1-\iota) P_{*,t}^{1-\epsilon} + \iota P_{t-1}^{1-\epsilon}\right)^{1/(1-\epsilon)}. \tag{17}$$

Monetary Policy Monetary policy is conducted by a central bank with two instruments at its disposal: an inertial interest rate policy and a balance sheet policy that exchanges reserves for long-term debt. The central bank is not subject to the same principal-agent problem as banks. Thus, a balance sheet expansion that creates additional demand for long-term debt stabilizes the value of banks' loan portfolio and compresses credit spreads, thereby reducing frictions in financial intermediation, and stimulating the economy.

It is assumed the central bank employs both of its primary instrument, the nominal interest rate on reserves, according to an inertial feedback-type rule, given by

$$R_t = R_{t-1}^{\rho_r} \left[R\, \Pi_t^{\kappa_{\pi}} \left(y_t/y\right)^{\kappa_y}\right]^{(1-\rho_r)} \exp\left(\varepsilon_{r,t}\right), \tag{18}$$

where $\rho_r \in (0,1)$ is the interest rate smoothing parameter, $\kappa_{\pi} > 1$ is the feedback coefficient on inflation in deviation from its target, and $\kappa_y > 0$ is the feedback coefficient on output. Letters without a lowercase time index denote steady state values. The orthogonal monetary policy shock follows $\varepsilon_r \sim i.i.d.\ \mathcal{N}(0\, \sigma_r^2)$. Central bank balance sheet operations are assumed to come as an exogenous surprise to agents, for now, given by

$$\mathrm{qe}_t = \rho_{\mathrm{qe}}\, \mathrm{qe}_{t-1} + \varepsilon_{\mathrm{qe},t}, \tag{19}$$

where $\rho_{\mathrm{qe}} \in (0,1)$ denotes the persistence of the policy and the orthogonal balance sheet shock follows $\varepsilon_{\mathrm{qe}} \sim i.i.d.\, \mathcal{N}(0\, \sigma^2_{\mathrm{qe}})$. Below, the exogeneity assumption is relaxed.

2.2 Equilibrium

To a first-order approximation around the deterministic steady state, the private-sector equilibrium in this simple model can be summarized by five (intuitive) log-linear equations: an augmented IS equation, the new-Keynesian Phillips Curve (NKPC), and the financial sector equilibrium in the form of binding incentive compatibility constraint, evolution of net worth, and the nominal borrowing rate.[10] The respective equations are given by

$$y_t = \mathbb{E}_t y_{t+1} - \left[(1-\mathrm{c})/\sigma\right]\left(r_{d,t} - \mathbb{E}_t \pi_{t+1} - s_t\right) - \mathrm{c}\left(r_{b,t} - \mathbb{E}_t \pi_{t+1} - s_t\right) \tag{20}$$

$$\pi_t = \beta \mathbb{E}_t \pi_{t+1} + \kappa y_t, \tag{21}$$

$$\phi_t = \theta \mathbb{E}_t \phi_{t+1} + \Phi\left(r_{b,t} - r_{d,t}\right), \tag{22}$$

$$n_t = \theta R\left[n_{t-1} + \left(r_{d,t-1} - \pi_t\right) + \Phi\left(r_{b,t-1} - r_{d,t-1}\right)\right], \tag{23}$$

$$r_{b,t} = \mathbb{E}_t \pi_{t+1} + s_t + \sigma\left(\mathbb{E}_t \phi_{t+1} - \phi_t + \mathbb{E}_t n_{t+1} - n_t\right), \tag{24}$$

where lower-case letters are log-levels of their upper-case counterparts, c is the steady state consumption share of borrowers, and $\kappa = \left[(1-\iota\beta)(1-\iota)(\varphi+\sigma)\right]/\iota$ is the NKPC slope. With time-preference shocks only, output and output gap coincide. Equation (20) is the IS curve. When $\mathrm{c} = 0$ or in the absence of frictions in financial intermediation, the model reduces to the canonical 3-equation new-Keynesian model.

[10] Appendix A.2 documents the the derivation of the log-linear model. Note the system of equations could be further reduced and brought even closer to the canonical 3-equation new-Keynesian model substituting for $r_{b,t}$. I refrain from doing so in the interest of tractability for the purposes of this paper.

2.3 Calibration

The model is calibrated at quarterly frequency based on a combination of established results in the literature and a range of carefully selected calibration targets. All calibration targets are selected to match empirical moments in the U.S. from 1985 to 2019. Table 1 documents the baseline parameterization. Further information can be found in Appendix A.3.

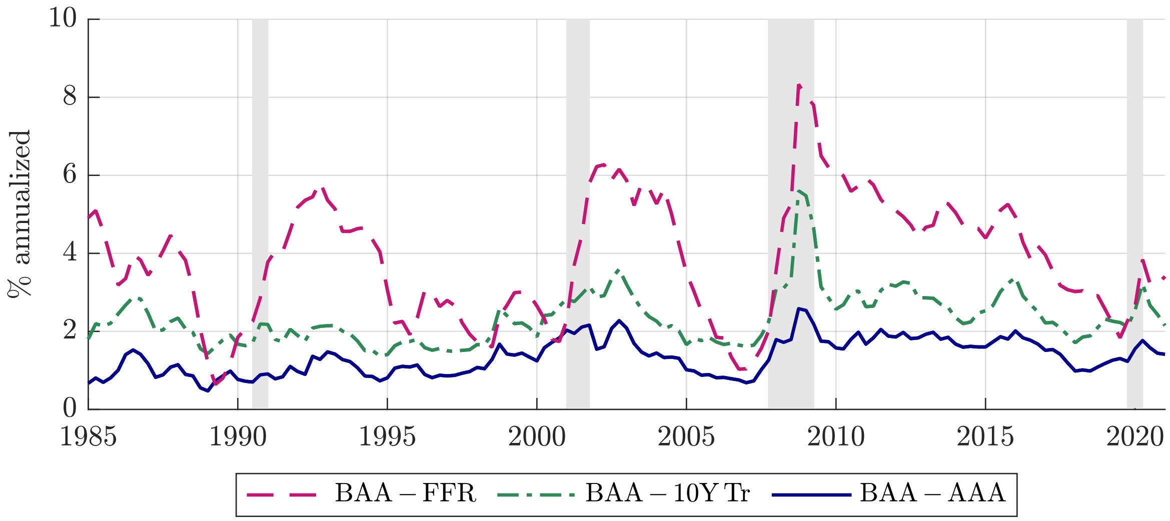
Table 1. Parameterization

Parameter		Value	Parameter		Value
Households					
σ	Risk aversion	1.0000	β	Discount factor, savers	0.9950
c	Consumption share, borrowers	0.5000	β_b	Discount factor, borrowers	0.9925
χ	Utility weight on labor	0.8045	φ	Curvature of labor disutility	1.0000
Financial intermediaries					
λ	Fraction of divertible assets	0.4126	ω	Transfer to new bankers	0.0026
θ	Survival probability of bankers	0.9750			
Producers					
ϵ	Elasticity of substitution	10.000	ι	Probability of fixed prices	0.9265
Monetary Policy					
κ_π	Policy rule inflation response	2.0000	κ_y	Policy rule output response	0.1250
ρ_r	Policy rule inertia	0.8000	ρ_{qe}	Balance sheet (QE/QT) inertia	0.8000

Households' risk aversion σ and the curvature of labor disutility ξ are normalized to 1. In line with the literature, the disutility weight on labor χ is set to 0.8045 to normalize steady state labor supply to 1. The discount factor of savers β_s is set to 0.9950, which pins down the annualized steady state policy rate R_d at 2%. This value is motivated by the mean value of the real effective U.S. federal funds rate of slightly above 1.5% over the sample period. The discount factor of borrowers β_b is set to 0.9925, in order to generate an annualized steady state credit spread, $400\,[(R_b/R_d)-1]$, of 1%. This value corresponds to the sample mean of the "BAA-AAA" corporate bond spread series depicted in Figure 2 (dark blue). The series is widely regarded as an empirically sound measure of the safety or quality premium captured by the financial friction in the model (Krishnamurthy and Vissing-Jorgensen, 2012). Appendix A.3 provides more details on this spread series and alternative measures. Finally, the consumption share of borrowers and savers is normalized to 0.5, respectively. The sensitivity and robustness of the main results with respect to this and other parameter choices is documented further below.

The survival probability of financial intermediaries θ is set to 0.975, yielding a average horizon of 10 years. Given that the steady state credit spread is pinned down by the divergence of borrowers' and savers' discount factors in this model, the remaining two financial sector parameters, $\lambda = 0.4126$ and $\omega = 0.0026$, are jointly calibrated to match a steady state leverage ratio of 4. As Appendix A.3 describes in detail, this value as taken as a approximate estimate of average aggregate leverage across the financial sector in the U.S.

Figure 2. Calibration | Empirical credit spreads in the U.S.



Note. AAA and BAA are Moody's Seasoned AAA and BAA Corporate Bond Yields, respectively; FFR is the Effective Federal Funds Rate; 10Y Tr is the market yield on Treasury Securities at 10-Year Constant Maturity. Source: Federal Reserve Bank of St Louis.

The elasticity of goods substitution is set to $\varepsilon = 10$, yielding a steady state mark up of 10%. The parameter governing the nominal price rigidity in the model is set to $\iota = 0.9265$, implying prices are adjusted on average every 13 to 14 quarters. In the absence of indexation, this relative high degree of price stickiness is the result of targeting an empirically realistic unemployment-inflation slope of 0.0062 as estimated by Hazell et al. (2022). The monetary policy rule coefficients on inflation and output are set to $\kappa_\pi = 2$ and $\kappa_y = 0.125$, standard values in the literature. For comparability, the inertia in interest rate setting and balance sheet adjustments is set to $\rho_r = \rho_{\text{qe}} = 0.8$. This value is at the lower end of empirical estimates of policy inertia but not crucial for the exercises conducted in this paper.[11]

[11] A detailed overview on empirical estimates of policy inertia for different countries using a range of different methodologies is provided in de Groot and Haas (2023), where this parameter is critically determining the signaling effect of negative rate policies. It is much less relevant for the analysis of complementarities between interest rate and balance sheet policies as conducted in this paper.

3 Results

This section presents the main results. First, it shows how a monetary tightening restrains inflation at a cost to financial intermediaries and highlights differences in the transmission of the two monetary instruments considered in this paper: regular interest rate and balance sheet policies. Second, it derives a novel decomposition of bank net worth to provide detailed insights on the financial sector implications of these divergences. Third, it shows how - in light of these divergences - a balance sheet expansion (a form of 'repurposed QE') can be an effective complement to a contractionary rate policy when bank net worth is a concern. In this case, the decomposition of bank net worth can be employed to calibrate the effective use of the central bank balance sheet. Four, it presents results for a U.S. 'pandemic-era inflation scenario' with both anticipated and non-anticipated expansionary bank balance policies addressing financial turmoil in the spirit of interventions seen in March 2023.

3.1 Transmission

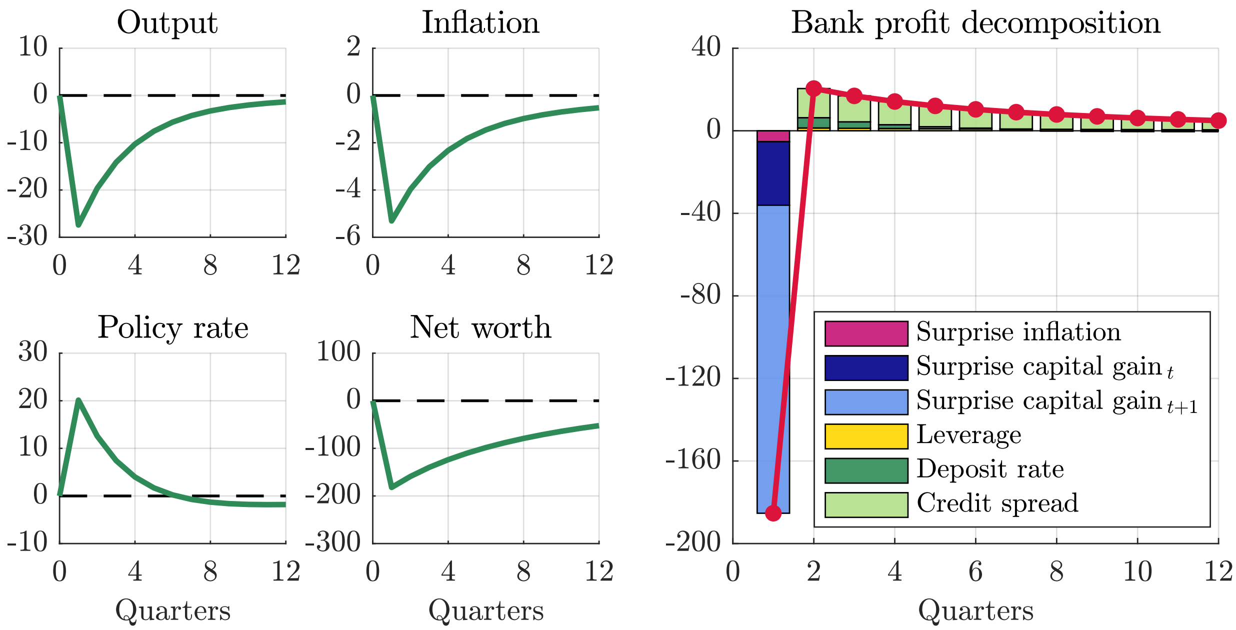
To illustrate the transmission of the two monetary instruments discussed in this paper, this section shows a comparison of impulse responses to two normalized exogenous monetary policy contractions. All impulse responses are depicted in basis point deviation from steady state, annualized for inflation and interest rates. Figure 3 highlights the main results, a more formal (analytical) derivation is to follow in the most recent version of this paper.

In response to a contractionary to +25 basis point iid policy rate contraction (panel a.), output in the model falls slightly more than one-for-one by 28 basis point, annualized inflation drops by 5 basis points. As the nominal policy rate tightens, the real interest rate increases, incentivizing both savers and borrowers to postpone consumption and increase (decrease) their savings (borrowing). In line with empirically observed inflation-output trade-offs, the inflation response is significantly smaller than the output response following this aggregate demand contraction. Due to policy inertia and frictional financial intermediation, the adjustment to the policy shock in the model is gradual and persistent, even in the absence of investment and capital accumulation.

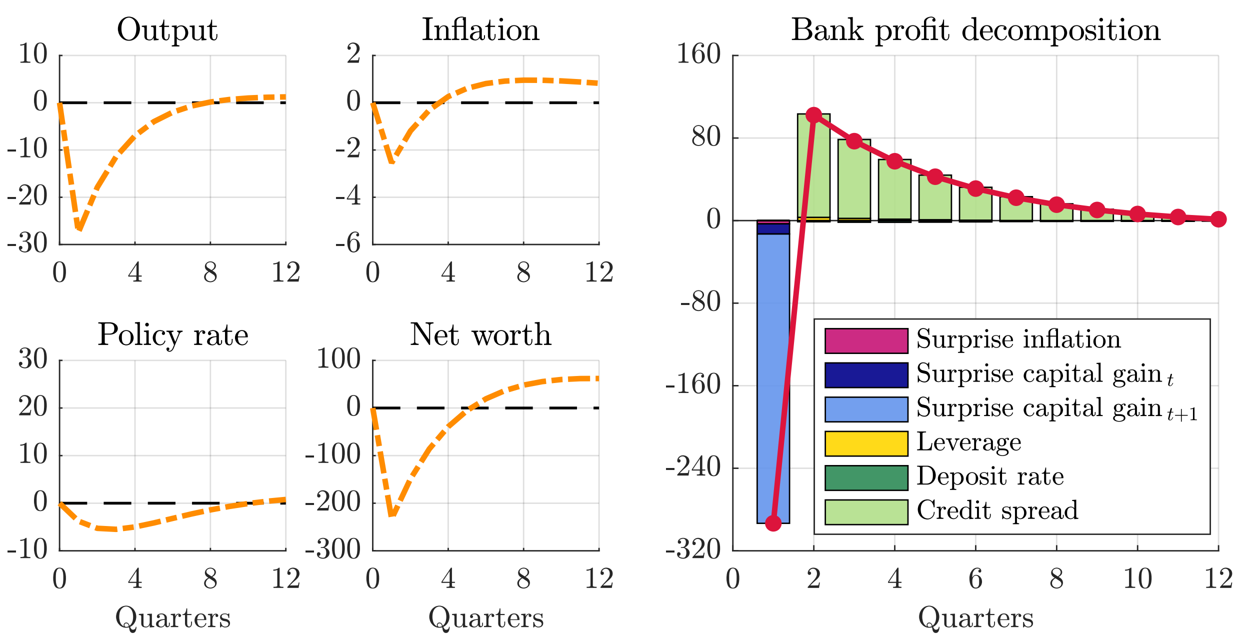
Bank net worth contracts by around 2% in response to the contractionary monetary policy, leading to a tightening of frictional financial intermediation as banks' agency problem becomes more as the ratio of own equity to lending volume declines. This causes an increase

Figure 3. Transmission | Monetary Policy & Financial Sector

a. Policy rate contraction



b. Balance sheet contraction



Note. Impulse responses to a) a +25bp policy rate shock, and b) a −80bp balance sheet shock. Bank profits are decomposed as described in Section 3.2. All variables are in basis point deviation from steady state. Inflation and the policy rate are annualized.

in credit spreads, exacerbating the aggregate demand contraction due to the monetary tightening. The financial friction comes with a financial accelerator property in the model and, importantly, a policy rate contraction results in a deterioration of bank net worth.

A −80 basis point balance sheet contraction calibrated to yield the same normalized output loss of 28 basis points on impact (panel b.), yields comparable qualitative but very different quantitative results.[12] While the balance sheet contraction comes with the expected aggregate demand contraction, moving both output and inflation in the same direction, the drop in annualized inflation is significantly smaller at 2 basis point than for the contractionary interest rate policy. At the same time, the drop in bank net worth is slightly larger at 2.25%. This hints at non-trivial differences in the monetary transmission. A thorough investigation of the financial sector transmission provides insights on this.

3.2 Bank net worth

Bank net worth is adversely affected in a monetary tightening. Both policy rate and balance sheet contractions depress net worth, thereby compounding frictions in financial intermediation. This is explored with a novel decomposition of bank profits as first derived and explored in a different environment in de Groot and Haas (2023).

In the model, the evolution of net worth – conditional on not exiting – is given by

$$N_t = \left[\left(R_{b,t}/\Pi_t\right)\Phi_{t-1} - \left(R_{t-1}/\Pi_t\right)\left(\Phi_{t-1}-1\right)\right]N_{t-1}. \tag{25}$$

Defining gross nominal profits as $\texttt{prof}_t \equiv \Pi_t N_t / N_{t-1}$ and rearranging terms yields

$$\texttt{prof}_t = \left(R_{b,t} - R_{d,t-1}\right)\Phi_{t-1} + R_{d,t-1}. \tag{26}$$

Adding and subtracting $\mathbb{E}_{t-1}R_{b,t}\Phi_{t-1}$, gross nominal profits can be written as

$$\texttt{prof}_t = \left(R_{b,t} - \mathbb{E}_{t-1}R_{b,t}\right)\Phi_{t-1} + \texttt{cs}_{t-1}\Phi_{t-1} + R_{d,t-1}, \tag{27}$$

where $\texttt{cs}_t \equiv \mathbb{E}_t R_{b,t+1} - R_{d,t}$ is the nominal credit spread. Substituting for the gross nominal

[12] As described in Section 2.3, exogenous balance sheet variations are implemented with a persistence $\rho_{\text{qe}} = 0.80$ to make their transmission comparable to iid interest rate shocks on an inertial policy rule with $\rho_r = 0.80$. This is just for illustrative purposes, all results continue to hold in the absence policy persistence.

return on outstanding debt, $R_{b,t} = (1+\kappa Q_t)/Q_{t-1}$, this can further be rewritten as

$$\texttt{prof}_t = [(1+\kappa Q_t)/Q_{t-1} - \mathbb{E}_{t-1}(1+\kappa Q_t)/Q_{t-1}]\,\Phi_{t-1} + \texttt{cs}_{t-1}\Phi_{t-1} + R_{d,t-1}. \tag{28}$$

This non-linear definition of gross nominal profits can be log-linearized and decomposed into one surprise term and three predetermined terms given by

$$\hat{\texttt{prof}}_t = \underbrace{\frac{\kappa Q}{1+\kappa Q}\frac{\Phi}{\texttt{prof}}\left(\hat{q}_t - \mathbb{E}_{t-1}\hat{q}_t\right)}_{\text{Surprise: Capital gain}} + \underbrace{\frac{\texttt{cs}\Phi}{\texttt{prof}}\hat{\texttt{cs}}_{t-1}}_{\text{Credit spread}} + \underbrace{\frac{\texttt{cs}\Phi}{\texttt{prof}}\hat{\phi}_{t-1}}_{\text{Leverage}} + \underbrace{\frac{R_d}{\texttt{prof}}\hat{r}_{d,t-1}}_{\text{Deposit rate}}. \tag{29}$$

where hats denote log-deviations from steady state and variables without subscripts are steady states. This completes the derivation of the bank profit decomposition.

Bank net worth is inertial and slow-moving. As an exogenous shock – such as an unexpected monetary contraction – materializes, on impact, the windfall component in capital gains and losses drives the response in gross nominal profits and thereby net worth. This directly result from banks' role in maturity transformation. As outlined in Section 2.1, banks derive a state-contingent nominal return from a portfolio of long-term debt obligations, $R_{b,t}$ while having committed to pay a predetermined nominal deposit rate on their liabilities, $R_{d,t-1}$. It is because of this that banks are subject to interest rate risk in the form of surprise capital gains and losses on their loan portfolio. Without a maturity mismatch, $\kappa = 0$, the windfall component drops out.[13] The three predetermined terms in the decomposition are the evolution of the credit spread, leverage, and the policy rate. These predetermined terms adjust in the period following the shock and govern the endogenous return of nominal net worth back to equilibrium as the impact of the exogenous disruption subsides.

The right-most panels in Figure 3 make use of this decomposition, plotting bank profits in response to the policy rate and balance sheet contraction, respectively. On impact, profits sharply decrease as both instruments impose capital losses in the form of revaluations of banks' debt portfolio. These losses are complemented by an additional small decline due to deflation in the case of the interest rate contraction (less relevant for the balance sheet contraction given the more muted inflation response). More importantly, the absolute

[13] In the absence of capital in the model, I term leveraged surprise changes in the price of the loan portfolios 'capital gains'. The bank balance sheet can easily be expanded to include additional assets. This would change the composition of windfall gains and losses – for example, (real) productive capital holdings would add surprise terms on inflation and dividends to the decomposition – but not the overall quantity, in so far as additional assets would not eliminate the maturity mismatch between assets and liabilities.

size of capital losses is significantly larger for the contractionary balance sheet policy and concentrated in revaluations of the long-term portfolio. As the central bank shrinks the size of its balance sheet and cuts its role in credit intermediation, the supply of debt relative to demand increases and the price of debt falls. From the following period on, wider credit spreads – due to a tighter incentive compatibility constraint – boost earnings and return net worth back to target. To a lesser degree, higher leverage and deposit rates also have a role to play in this but it is much smaller across a wide range of model specifications. This is in line with empirical evidence on banks' exposure to interest rate risk and the role of interest margins in the transmission of monetary policy through the banking sector.[14]

3.3 QE in a Tightening Cycle

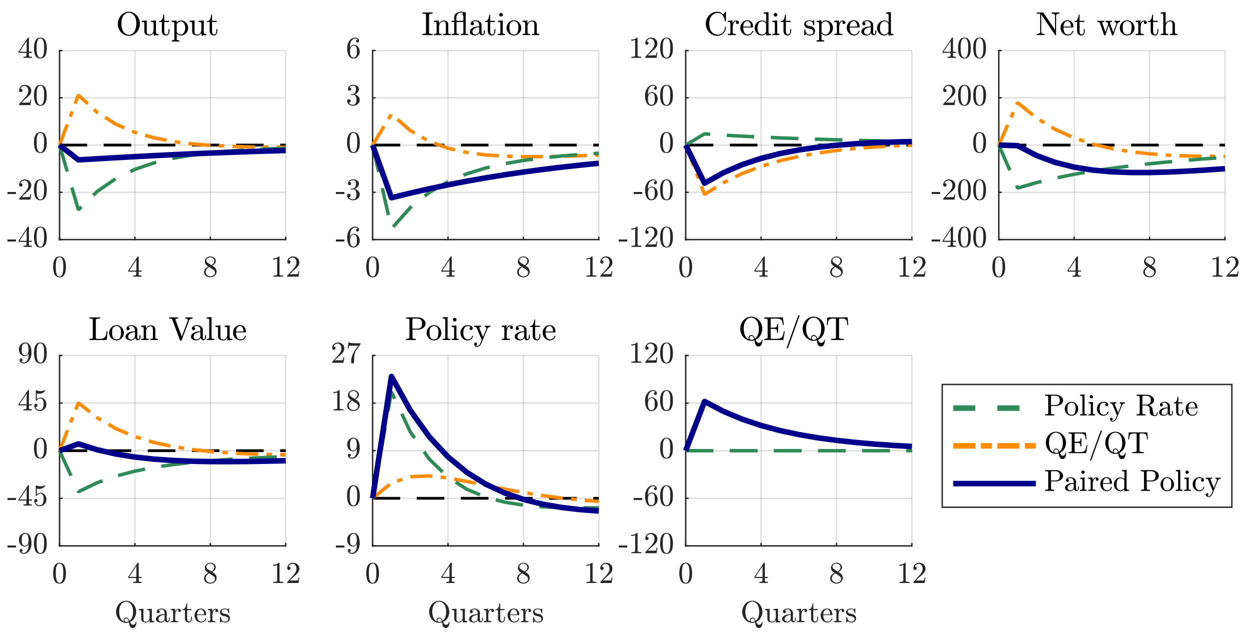
A monetary tightening in policy rates restrains inflation at a cost to financial intermediation. With banks exposed to interest rate risk, higher nominal interest rates impose capital losses on bank balance sheets and depress net worth. Central bank balance sheet policies have qualitatively similar effects but are quantitatively different. Rather than through intertemporal substitution and households' IS equation, their transmission directly affects loan values and thereby bank net worth through a change in loan supply and demand.

This implies that both monetary instruments – despite their expected dominant aggregate demand dimension moving output and inflation in the same direction – have a widely differential impact in an inflation-net worth space. Figure 4 illustrates this, depicting a full set of impulse responses to a +25 basis point contractionary monetary policy shock (as seen before, green dash) and a recalibrated +62 basis point balance sheet expansion (orange dot-dash). This time, making use of the bank balance sheet decomposition, the size of the expansionary balance sheet policy is normalized to neutralize the sum of banks' capital losses on short- and long-term loans due to the contractionary interest rate policy.[15] In line with the previous discussion, in the baseline calibration of this model, the interest rate policy has comparably strong effect on inflation while the balance sheet policy directly affects frictional intermediation through loan values, bank net worth, and credit spreads.

[14] Berry et al. (2019) offers a concise overview on empirical evidence on interest margins in tightening cycles. Begenau et al. (2015) and Begenau and Stafford (2022) provide evidence on banks' heavy exposure to interest rate risk while Drechler et al. (2021) argue maturity transformation by itself does not necessarily expose banks to interest rate risk if the deposit franchise comes with market power and an insensitive cost structure.

[15] This full stabilization policy is adopted to illustrate the potential of a forceful 'Repurposed QE in a Tightening Cycle' intervention. It is descriptive and not to be taken as an optimal policy prescription at this point. All results continue to hold with a more nuanced balance sheet operation as Section 3.4 illustrates.

Figure 4. 'Repurposing QE in a Tightening Cycle' | Impulse Responses

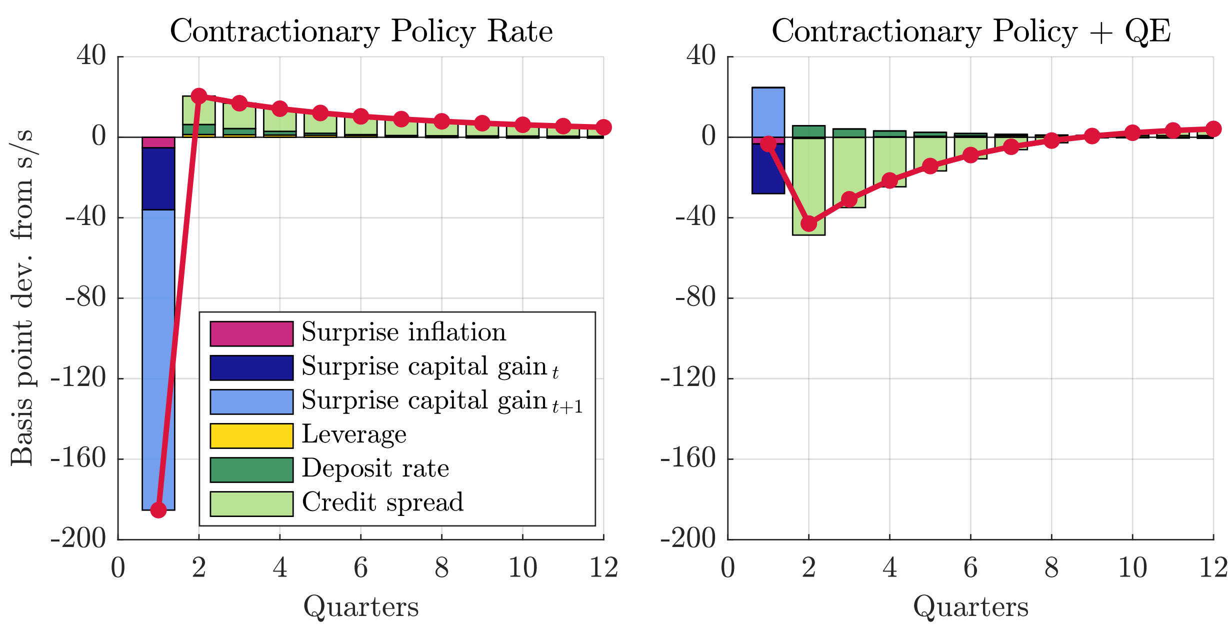


Note. Impulse responses to a contractionary +25bp policy rate shock (green dash), an expansionary +62bp balance sheet shock (orange dot-dash), and the pairing of both policy shocks (dark blue). All variables are in basis point deviation from steady state. Inflation, credit spread, and the policy rate are annualized.

Considering these divergent transmission channels, pairing both policies in an illustrative 'Repurposing QE in a Tightening Cycle' scenario (dark blue) indicates possibly attractive properties from a monetary and financial stability angle. The paired policy creates demand for loans, counteracting capital losses and the decline in loans values due to the monetary contraction, and fully stabilizes bank net worth on impact (as calibrated). Credit spreads fall as the decline in net worth is attenuated and spread out over the following quarters. This more gradual decline does not imply though that the tightening in policy rates is without effect on inflation. In fact, in the baseline parametrization of the model, output losses are strongly diminished while 60% of the contractionary effect on inflation are preserved. Figure 5 provides insights on this, comparing the bank profit implications of a contractionary interest rate shock with its adverse effect on net worth (as seen before, left panel) with the paired policy (right panel). The policy pairing fully attenuates and smooths the bank balance sheet impact of a contractionary interest rate policy. The highly interventionist balance sheet policy shown here reduces the peak decline in bank net worth to slightly more than 40 basis points in the period following the interest rate tightening, compared to a 180 basis point deterioration on impact without the intervention.

Interest rate and balance sheet policies are often perceived as mere substitutes. In times of below-target inflation – as experienced in most advanced economies from 2007/08 to 2020/21 – this is very much in line with both lived practice and the literature on this subject. As concerns about financial stability peaked during the Great Financial Crisis and the March-2020 COVID crisis, cuts in policy rates and central bank balance sheet expansions provided liquidity in times of turmoil. At the effective lower bound on nominal rates, central bank balance sheet expansions became a natural extension of a conventional rates easing. The results in this paper indicate that in times of above-target inflation, a contractionary interest rate and balance sheet policy might not necessarily be mere substitutes. As a contractionary interest rate policy imposes capital losses on banks and concerns about financial instability arise, an expansionary central balance sheet policy can address the deterioration of bank net worth without impeding monetary stabilization. In this sense, in an environment of high inflation and financial instability, an expansionary balance sheet policy can be an effective complement to a contractionary rates policy. The differential transmission of the two monetary instruments in an inflation-net worth space allows for this temporary pairing in the interest of both monetary and financial stabilization.

Figure 5. 'Repurposing QE in a Tightening Cycle' | Financial Sector

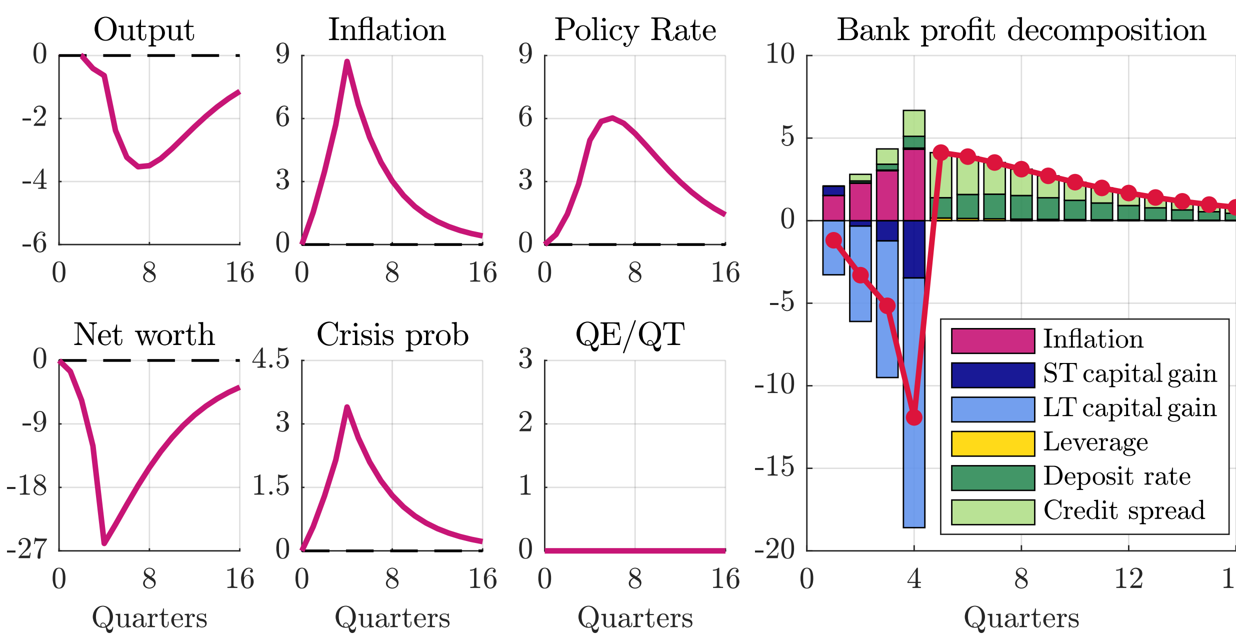


Note. Bank profits and their decomposition for a contractionary +25bp policy rate shock only (left panel), and a combination of contractionary policy shock and a +62bp expansionary balance sheet shock (right panel). Relative to the decomposition derived in the main text, windfall capital losses are further decomposed into real and nominal components as well as a contemporaneous and expected surprise adjustment.

3.4 A Pandemic-Era Inflation Scenario

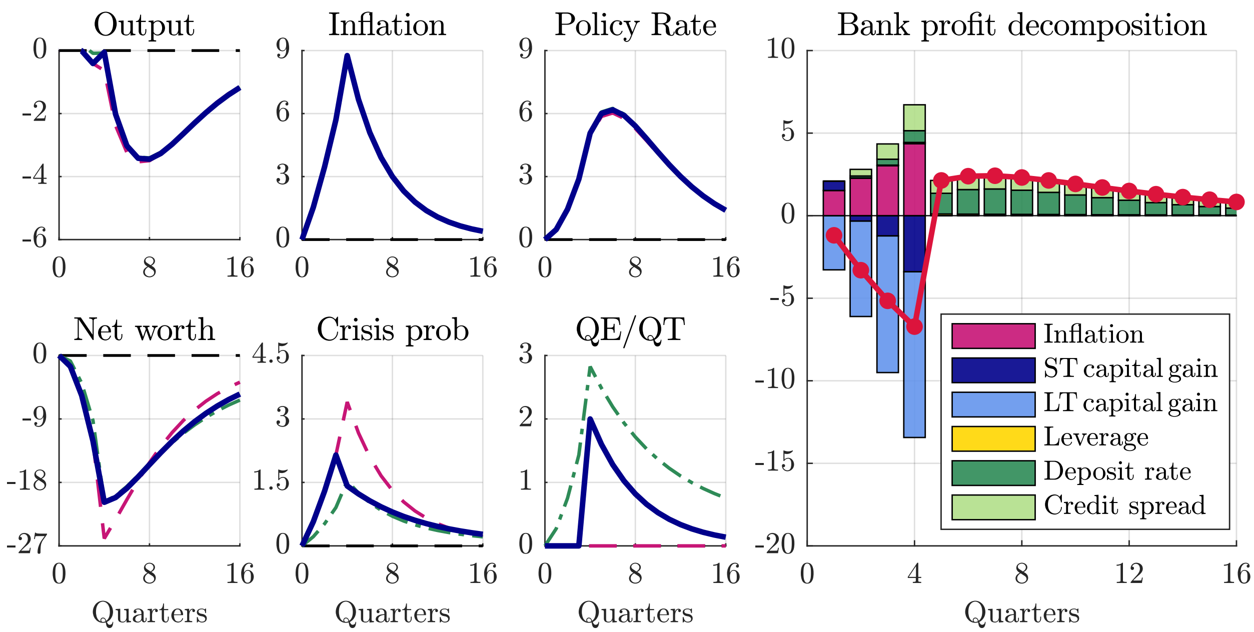
Figure 6 plots the evolution of a several endogenous variables in response to a sequence of four unexpected aggregate demand and cost-push shocks that generate a U.S. 'pandemic-era inflation' scenario. Contrary the Federal Reserve's expansionary balance sheet intervention at the height of the regional banking crisis in March 2023, it is assumed that the balance sheet is not used in the policy counterfactual. In response to the sequence of adverse shocks, inflation reaches a peak value of 9%. The endogenous contraction in the policy rate implies the policy rate gradually increases to over 6%. Over the course of the tightening cycle, this imposes significant capital losses on financial intermediaries. Bank net worth drops by 25% over the course of a year, the probability of a financial panic in the form of a roll-over crisis increases by more than 3%. This amounts to annualized crisis incidence of around 15% at its peak. Given the combination of aggregate demand and cost-push shocks as observed through post-pandemic fiscal stimulus and supply-bottleneck, output only falls gradually and ultimately declines by about 3.5% relative to its steady state level.

Figure 6. 'Pandemic-Era Inflation' | No policy intervention



Note. This Figure plots the evolution of a several endogenous variables in response to a sequence of four unexpected aggregate demand and cost-push shocks that generate a U.S. 'pandemic-era inflation' scenario. Monetary policy endogenously contracts but there is no balance sheet intervention. All variables are in basis point deviation from steady state. Inflation and the policy rate are annualized.

Figure 7. 'Pandemic-Era Inflation' | One-off QE intervention



Note. This Figure plots the evolution of a several endogenous variables in response to a sequence of four unexpected aggregate demand and cost-push shocks that generate a U.S. 'pandemic-era inflation' scenario. Monetary policy endogenously contracts. Three balance sheet policies are depicted: no use of the balance sheet (Figure 6, purple dash), an endogenous balance sheet expansion as a function of credit spreads (green, dot-dash), and an unexpected one-off balance sheet intervention as net worth losses peak (dark blue). The bank profit decomposition shows the results for the one-off intervention. All variables are in basis point deviation from steady state. Inflation and the policy rate are annualized.

Figure 7 depicts results for the same 'pandemic-era inflation' scenario but with two additional central bank policy interventions modelled: first, an endogenous balance sheet expansion in the form of a Taylor-type rule with the size of the balance sheet increasing in credit spreads (green, dot-dash); second, a unexpected 2% one-off balance sheet expansion – gradually phased out over the following periods – at the height of the crisis as inflation and net worth losses peak and risks for financial stability rise. Both 'repurposed QE'-type policies are broadly successful in stabilizing bank net worth (and crisis probabilities) without adding to inflationary pressures. A comparison of the bank profit decompositions in Figures 6 and 7 clearly illustrates this for the case of the unexpected one-off policy intervention. This finding underlines and confirms the more abstract discussion in Section 3.1-3.3 on divergences in the transmission of both monetary instruments. In times of rapidly rising inflation and mounting pressures on financial intermediaries due to their exposure to interest rate risk, an expansionary balance sheet policy can be an effective complement to a monetary tightening in rates. A more thorough investigation of this is to follow.

4 Conclusion

With inflation reaching levels not seen in more than thirty years, central banks in many advanced economies have embarked on a rapid tightening cycle over the past eighteen months. The regional bank crisis in the U.S. and the collapse of Credit Suisse in Europe earlier this year are examples of the adverse effects of rising rates on financial institutions. This has reignited a debate on trade-offs between monetary and financial stability.

Interest rate hikes impose capital losses on bank balance sheets. As net worth declines, risks to financial stability grow. In the paper, I set up a new-Keynesian model with frictional financial intermediation to rationalize this. I then show that an expansionary central bank balance sheet policy can be an effective complement to a contractionary rates policy when bank net worth is a concern. A well-calibrated policy mix smooths out the impact of rising rates on net worth while preserving their contractionary effect on above-target inflation.

Differences in the transmission of both monetary instruments (and a redistributionary cost-push dimension of frictional intermediation) are relevant for this result. A novel decomposition of bank net worth illustrates this and provides insights on the financial sector implications of monetary policy. Furthermore, a simulation exercise implements a U.S. post-pandemic era inflation scenario as a laboratory to analyze policy counterfactuals against the backdrop of heightened inflation and declining bank net worth. In this environment, a temporary balance sheet expansion is successful in smoothing the adverse effects of a contractionary interest rate policy on bank net worth at little cost to inflation.

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— Appendix —

Monetary Policy in a Tightening Cycle

A Model

A.1 Set up: derivation of the banker's problem [Section 2.1]

A banker j solves

$$V_{f,t}(j) = \max_{\{B_{f,t}(j), A_t(j), D_t(j), N_t(j)\}} \mathbb{E}_t \Lambda_{t,t+1} \left[(1-\theta) N_{t+1}(j) + \theta V_{f,t+1}(j) \right], \tag{A1}$$

subject to

$$Q_t B_{f,t}(j) + A_t(j) = D_t(j) + N_t(j), \tag{A2}$$

$$V_{f,t}(j) \geq \lambda Q_t B_{f,t}(j), \tag{A3}$$

$$N_t(j) = \left(R_{b,t}/\Pi_t \right) B_{f,t-1}(j) - \left(R_{t-1}/\Pi_t \right) \left[D_{t-1}(j) - A_{t-1}(j) \right]. \tag{A4}$$

where the constraints are the balance sheet constraint, incentive compatibility constraint, and net worth accumulation, respectively. The model is calibrated such that the incentive constraint is always binding. Next, the system of constraints is simplified by substituting reserves, $A_t(j)$, and deposits, $D_t(j)$, making use of Equation (A2). The leverage ratio of a banker is defined as $\Phi_t \equiv Q_t B_{f,t}(j)/N_t(j)$ (and Φ_t is common across banks). Thus, the accumulation of net worth, Equation (A4), can be rewritten as

$$N_t(j) = \left[\left(R_{b,t}/\Pi_t \right) \Phi_{t-1} - \left(R_{t-1}/\Pi_t \right) \left(\Phi_{t-1} - 1 \right) \right] N_{t-1}(j). \tag{A5}$$

Furthermore, I conjecture the value function to take the form

$$V_{f,t}(j) = \left(\zeta_{b,t} \Phi_t + \zeta_{n,t} \right) N_t(j), \tag{A6}$$

where $\zeta_{b,t}$ and $\zeta_{n,t}$ are as yet undetermined.

Substituting Equations (A1) and (A5), the banker's problem can be rewritten as

$$\left(\zeta_{b,t}\Phi_t + \zeta_{n,t}\right) = \max_{\Phi_t} \mathbb{E}_t \Lambda_{t,t+1} \left((1-\theta) + \theta\left(\zeta_{s,t+1}\Phi_{t+1} + \zeta_{n,t+1}\right)\right) \times \left[\left(R_{b,t}/\Pi_t\right)\Phi_{t-1} - \left(R_{t-1}/\Pi_t\right)\left(\Phi_{t-1} - 1\right)\right], \tag{A7}$$

subject to the rewritten binding incentive compatibility constraint (A3),

$$\zeta_{b,t}\Phi_t + \zeta_{n,t} = \lambda\Phi_t. \tag{A8}$$

The incentive compatibility constraint can be rearranged and iterated one period forward to find optimal (and maximum) leverage given by

$$\Phi_{t+1} = \frac{\zeta_{n,t+1}}{\lambda - \zeta_{b,t+1}}. \tag{A9}$$

Substituting (A9) and comparing the left and right hand side of (A7) verifies the conjectured functional form of the value function. Thus, the solution to the financial intermediary's problem can be summarized in a single binding incentive constraint given by

$$\lambda\Phi_t = \mathbb{E}_t \Lambda_{t,t+1} \frac{1-\theta+\theta\lambda\Phi_{t+1}}{\Pi_{t+1}} \left[R_{b,t+1}\Phi_t - R_{d,t}\left(\Phi_t - 1\right)\right]. \tag{A10}$$

Aggregate net worth in the financial sector evolves as a weighted sum of existing banks' accumulated net worth (A5) and start up funds new banks receive from the household, $\bar{N}$. Thus, the evolution of aggregate net worth is given by

$$N_t = \theta\left[\left(R_{b,t}/\Pi_t\right)\Phi_{t-1} - \left(R_{t-1}/\Pi_t\right)\left(\Phi_{t-1} - 1\right)\right]N_{t-1} + (1-\theta)\bar{N}, \tag{A11}$$

In the absence of roll-over crises (runs on deposits), Equations (A10) and (A11) summarize the financial sector problem in just two equations. This completes the derivation.

A.2 Equilibrium: derivation [Section 2.2]

New-Keynesian IS equation The household problems and first-order conditions are given in the main text. In steady state, $R_d = 1/\beta_s$. The log-linear form of the first-order conditions for the saver household are given by

$$c_{s,t} = \mathbb{E}_t c_{s,t+1} - \frac{1}{\sigma}\left(r_{d,t} - \mathbb{E}_t \pi_{t+1} - s_t\right), \tag{A12}$$

$$\varphi l_{s,t} = -\sigma c_{s,t} + w_{s,t}, \tag{A13}$$

where lower case letters refer to log-levels. The borrower household's conditions are

$$c_{b,t} = \mathbb{E}_t c_{b,t+1} - \frac{1}{\sigma}\left(r_{b,t+1} - \mathbb{E}_t \pi_{t+1} - s_t\right), \tag{A14}$$

$$\varphi l_{b,t} = -\sigma c_{b,t} + w_{b,t}, \tag{A15}$$

where, in steady state, $R_b = 1/\beta_b$. The log-linear aggregate resource constraint is given by $y_t = (1 - \mathrm{c})\, c_{s,t} + \mathrm{c} c_{b,t}$, where $\mathrm{c} \equiv C_b/Y$. Combining this definition with the two individual Euler equations gives the aggregate Euler equation:

$$y_t = \mathbb{E}_t y_{t+1} - \frac{1-\mathrm{c}}{\sigma}\left(r_{d,t} - \mathbb{E}_t \pi_{t+1} - s_t\right) - \frac{\mathrm{c}}{\sigma}\left(\mathbb{E}_t r_{b,t+1} - \mathbb{E}_t \pi_{t+1} - s_t\right). \tag{A16}$$

Next, substituting the transfer from savers to borrowers into the borrower household's budget constraint gives the following simple borrower household consumption function: $C_{b,t} = B_t$. Using the definition for leverage, $\Phi_t = B_t/N_t$, the log-linear form of the borrower household consumption function is given by $c_{b,t} = \phi_t + n_t$. Rearranging the borrower household's Euler condition, $\frac{1}{\sigma}\left(r_{b,t} - \mathbb{E}_t \pi_{t+1} - s_t\right) = \mathbb{E}_t c_{b,t+1} - c_{b,t}$, and combining it with the consumption function above, I can rewrite the aggregate Euler equation as

$$y_t = \mathbb{E}_t y_{t+1} - \frac{1-\mathrm{c}}{\sigma}\left(r_{d,t} - \mathbb{E}_t \pi_{t+1} - s_t\right) - \mathrm{c}\left(\mathbb{E}_t \phi_{t+1} - \phi_t + \mathbb{E}_t n_{t+1} - n_t\right). \tag{A17}$$

New-Keynesian Phillips curve Log-linearizing the production sector's first-order conditions yields the textbook new-Keynesian Phillips curve in terms of marginal cost,

$$\pi_t = \beta \mathbb{E}_t \pi_{t+1} + \frac{(1-\iota\beta)(1-\iota)}{\iota} mc_t. \tag{A18}$$

Log-linear marginal cost and aggregate output are given by $mc_t = \omega w_{s,t} + (1-\omega) w_{b,t}$ and $y_t = \omega l_{s,t} + (1-\omega) l_{b,t}$, respectively. Using the two labor-supply first-order conditions from the household problem, we can rewrite marginal cost as follows:

$$mc_t = (\varphi + \sigma) y_t, \tag{A19}$$

and the Phillips curve as

$$\pi_t = \beta \mathbb{E}_t \pi_{t+1} + \frac{(1-\iota\beta)(1-\iota)(\varphi+\sigma)}{\iota} y_t. \tag{A20}$$

Note that since we only consider disturbances to households' subjective discount factors, the output gap coincides with output and hence y_t can be relabeled as the output gap.

Financial sector equilibrium conditions Steady state leverage is given by $\bar{N}$. The log-linear net worth evolution equation is given by

$$n_{t+1} = \theta R \left(n_t + \Phi \left(r_{b,t+1} - \pi_{t+1} \right) - (\Phi - 1) r_{d,t} - \pi_{t+1} \right). \tag{A21}$$

When $\theta = 0$, then $n_{t+1} = 0$. The log-linear incentive compatibility constraint is given by

$$\phi_t = \left(\mathbb{E}_t m_{t,t+1} - \pi_{t+1} \right) + \theta \mathbb{E}_t \phi_{t+1} + \left(\Phi r_{b,t+1} - (\Phi - 1) r_{d,t} \right). \tag{A22}$$

where $m_{t,t+1}$ is the log-linear stochastic discount factor of the saver household.

Substituting for $r_{b,t}$ using the borrower household's Euler equation gives

$$\begin{aligned} \phi_t = & -r_{d,t} + \theta \mathbb{E}_t \phi_{t+1} + \Phi\sigma \left(\mathbb{E}_t \phi_{t+1} - \phi_t + \mathbb{E}_t n_{t+1} - n_t \right) \\ & + \Phi \left(\mathbb{E}_t \pi_{t+1} + s_t \right) - (\Phi - 1) r_{d,t}. \end{aligned} \tag{A23}$$

When $\theta > 0$, the model is described by five endogenous variables, $\{\pi_t, y_t, \phi_t, n_t, r_{d,t}\}$, and four private-sector conditions, (A17), (A20), (A21), and (A23).

A.3 Calibration: further details [Section 2.3]

Table 1 in the main text presents the baseline parameterization of the model. This section provides details on the financial sector calibration, in particular leverage and credit spreads.

Leverage Obtaining an appropriate data counterpart for aggregate leverage in the model poses a challenge. During the period from 2009 to 2019, the US commercial banking sector maintained an average leverage ratio of 9.4.[16] This calculation excludes non-bank financial institutions like hedge funds and broker-dealers, which are generally more leveraged. In 2021, estimates for the total assets of the non-bank financial sector exceeded the total assets of commercial banks by a factor of 1.86. Additionally, also from 2009 to 2019, the non-financial corporate business sector exhibited a leverage ratio of 1.9, indicating a substantially lower leverage ratio across the entire economy. I follow the approach taken in de Groot and Haas (2023) in the spirit of Gertler and Karadi (2011), aggregating across these heterogeneous sectors while assuming that leverage in the non-bank financial sector is approximately twice that of the commercial banking sector. This conservative approach yields an estimate of aggregate leverage, amounting to 3.6. Given the inherent uncertainty in these calculations, we have chosen to calibrate the model to a leverage ratio of 4.

Credit Spreads Calibrating the steady-state credit spread presents its own set of challenges. Figure 2 shows three alternative spread measures commonly used in the literature. The first measure represents the spread between the BAA corporate bond yield and the federal funds rate (purple dash). The interest rates that constitute this spread align with the expected return on capital and the short-term policy rate in the model. However, when it comes to matching the steady-state credit spread, this measure is less than ideal given a maturity mismatch. The corporate bond yields are derived from long-term bonds with a maturity of 20 years and above, while the federal funds rate is a short-term rate. As a result, this series likely encompasses not only a pure risk premium but also liquidity and term premia. To get a sense of these distinct premia, the spread between the BAA corporate bond yield and the 10-year Treasury yield (green dot-dash) and the spread between the BAA and AAA corporate bond yields (dark blue) are also depicted in Figure 2. For the credit spread in the model, I match its steady state to 1% annualized, which corresponds to the mean of the "BAA-AAA" series in the sample. This series is widely regarded as an empirically sound measure of the safety or quality premium captured by the financial friction in the model (Krishnamurthy and Vissing-Jorgensen, 2012).

[16] Where leverage is defined as $A/(A-L)$, with A being total assets and L total liabilities.