Monetary Tightening, Quantitative Easing, and Financial Stability*

Ivan Shchapov†

Institut Polytechnique de Paris

CREST

PRELIMINARY DRAFT

March 2025

Abstract

This paper analyses how central bank balance sheet policies affect financial stability in a framework with endogenous disruptions in financial intermediation. Central bank balance sheet expansions increase the frequency of financial stress episodes and their duration over the business cycle by inducing financial intermediaries to take on more risk in normal times and slowing their recapitalisation during a stress episode. In a tightening cycle, balance sheet expansions come at a significant cost to price stability. The optimal monetary policy mix balances the welfare costs of inflation and financial stress against the efficiency costs of balance sheet interventions.

Keywords: Quantitative easing, financial stability, monetary policy, financial crises.
JEL Codes: E52, E44, E58.

*I am grateful to Guido Ascari, David Bounie, and Jean-Baptiste Michau for their guidance and supervision. I thank Ambrogio Cesa-Bianchi, Gregory Corcos, Andrea Ferrero, Tom Holden, Olivier Loisel, Niki Papadopoulou, Alessandro Riboni, Giovanni Ricco, Annukka Ristiniemi, David Murakami, Ganesh Viswanath-Natraj, Pablo Winant, and Yifan Zhang for helpful discussions and advice. I also thank seminar and conference participants at IP Paris, CREST, University of Milan, University of Pavia, HEC Paris, University of Oxford, EEA-ESEM 2024, Sailing the Macro Worksop, Pavia Macro Forum, and 3rd Dynare Workshop for Advanced Users for helpful comments. I am grateful to *Chaire Finance Digitale* for funding my work at Institut Polytechnique de Paris. First draft: 16 August 2024.

†Centre for Research in Economics and Statistics, Institut Polytechnique de Paris, Télécom Paris, CNRS. Address: Route de Saclay, 91123 Palaiseau, France. Email: ivan.shchapov@ensae.fr

1 Introduction

Central bank balance sheet policies have been widely used as a stabilisation tool in times of financial stress since the Great Financial Crisis of 2008 by major central banks. While balance sheet interventions have been shown to be effective in mitigating recessionary effects of financial stress episodes (Del Negro et al. 2017), it is not clear whether such a policy contributes to the moral hazard problem of financial intermediaries inducing them to take on more risk which, in turn, might make financial stress episodes more likely to happen.

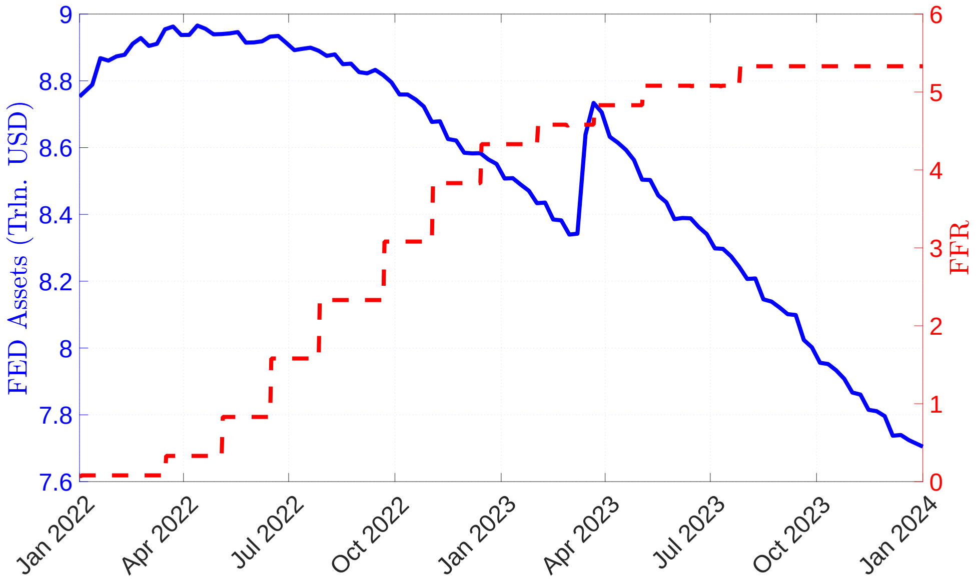
Prior to 2022, balance sheet expansions (QE) were used to complement cuts to conventional policy rates. More recently, QE was paired with policy rate hikes. In 2022, an unprecedented increase in inflation rates prompted major central banks to undertake substantial interest rate hikes. Surge in interest rates led to a decline in financial stability and triggered several instances of financial turmoil – Silicon Valley Bank and Credit Suisse collapse in March 2023, and UK Liability Driven Investment Crisis, amongst others. In the wake of financial turmoil, FED, Bank of England, and Swiss National Bank resorted to balance sheet expansions whilst continuing to raise their policy rates. Figure 1 illustrates an instance of unconventional pairing of QE and policy rate tightening in the US around March 2023.

Does QE increase the likelihood and duration of financial stress events? Can central bank balance sheet expansions in a tightening cycle address financial fragility without severely compromising price stability? What is the optimal conventional and balance sheet policy mix that ensures price and financial stability? This paper addresses these questions thought the lens of a New-Keynesian general equilibrium model with a state-dependent financial friction, that can well account for both long-run business cycle moments and stylised financial stress facts presented in Akinci and Queralto (2022).

In the model, banks intermediate funds between households and non-financial firms. Banks, modelled following Gertler and Karadi (2011) and Akinci and Queralto (2022), can abscond with a fraction of assets, that consist of firm equity and safe assets, if their value is greater than bank's franchise value. It is more difficult for a bank to divert safe assets than firm equity. These assumptions translate into an incentive compatibility constraint, which is more likely to bind when safe asset to portfolio ratio of the bank is smaller. The constraint is assumed to be occasionally binding and, thus, frictions in financial intermediation are state-dependent. In tranquil times, when the constrain is not binding, financial intermediation is frictionless. In times of financial stress, however, when the constraint is binding, financial intermediation is frictional. Once banks hit their leverage constraints, they start a fire sale of firm equity, that depresses equity prices and investment, and leads to a credit crunch.

The central bank is able to mitigate the adverse implications of a financial stress

Figure 1: Federal Reserve Assets and Policy Rate



Note: Federal Reserve Assets (left, solid blue line, Trillions of US Dollars), Effective Federal Funds Rate (right, dashed red line, percentage points).

episode via a balance sheet expansion that leads to an increase in reserves provision to the financial intermediaries and stabilises asset prices. This intervention, however, decrease banks' incentives to exhibit precautionary behaviour and, conditional on a financial stress episode, distort banks' earnings that prevents faster recapitalisation and exit from financial stress.

I find that QE targeted at financial stress is able to alleviate recessionary pressures of crippling credit frictions but increases the duration of financial stress episodes and their frequency. Two distinct channels drive this result. First, QE reduces banks' precautionary incentives. In the model, banks face a fundamental trade-off between increasing their earnings in tranquil times and avoiding hitting their leverage constraints; the higher the banks earnings are in tranquil times, the closer they are to the leverage constraint. If banks do not anticipate the central bank to intervene in times of financial stress, they pick lower leverage to decrease the probability of hitting their leverage constraints and triggering a financial stress episode. If banks anticipate a central bank intervention, however, they pick higher leverage, and are thus closer to their leverage constraint in normal times. Second, a balance sheet intervention of the central bank is distortionary and adversely affects banks' returns during financial stress episodes. Lower excess returns of commercial banks in times of financial stress do not allow them to recapitalise as quickly as they otherwise would under no intervention. Thus, financial stress episodes last longer and are more likely to happen under QE.

Moreover, QE is effective at stabilising output in a financial stress episode triggered by a rapid tightening cycle. This stabilisation, however, comes at a significant cost to price stability. QE depresses long-term yields and deposit rates which results in higher demand and higher inflation than under no intervention.

Furthermore, optimal monetary policy mix consists in aggressive price and financial stabilisation if QE does not bear efficiency costs. If QE is costly, the central bank should react less aggressively to inflation to reduce the likelihood of financial stress and limit the amount of balance sheet interventions.

Related literature First, this paper relates to a vast strand of literature on central bank balance sheet policies for macroeconomic stabilisation that emerged past the Great Financial Crisis of 2008. Crucially, contributions of this literature break the irrelevance result described in Wallace (1981) along two dimensions. The balance sheet policies have been found to have real effects in environments with scarce liquidity and financial frictions. Seminal papers such as Gertler and Kiyotaki (2010), Gertler and Karadi (2011), Cúrdia and Woodford (2011), Chen, Cúrdia, and Ferrero (2012), Harrison (2017), Del Negro et al. (2017), and Haas (2023) have found that balance sheet policies have significant real effects on macroeconomic stability. In contrast to this strand of literature, that focuses on the effects of balance sheet interventions in the frameworks where financial frictions are always present, I allow for the financial frictions to be state-dependent. This allows to analyse the implications of QE, triggered in times of financial stress, on the economy over the business cycle.

Second, since the model economy endogenously switches between tranquil periods, when financial intermediation is frictionless, and financial stress times, when bank leverage constraint is binding, the paper relates to the literature on non-linearities in DSGE models. Seminal contributions include Bianchi (2010), Mendoza (2010), Akinci and Queralto (2022), Akinci et al. (2023) amongst others. The model framework used in the paper is close to the one in Akinci and Queralto (2022), with the difference being that this paper uses a general equilibrium monetary model, whereas Akinci and Queralto (2022) uses a real partial-equilibrium model where the real interest rate is exogenous. Compared to this strand of literature, this paper emphasises central bank balance sheet interventions and changes in precautionary behaviour of banks that arise therefrom.

Third, this paper contributes to an emerging strand of literature on the optimal sequencing of central bank balance sheet interventions and interest rate policies. Benigno and Benigno (2022) examine the trade-offs linked to raising policy rates and reducing the central balance sheet. Airaudo (2023) studies the effects of quantitative tightening under passive monetary and active fiscal policy. Within this strand of literature, this paper is close to Haas (2023) as it also looks into the implications of pairing central bank balance sheet expansion with interest rate hikes. Haas (2023) finds that a balance sheet expansion can foster financial stability without compromising price stability. Similar to Haas (2023), this paper presents evidence that QE can indeed attenuate negative implications of financial stress on economic activity in a tightening cycle. This, however, comes at a significant cost to price stability.

The paper proceeds as follows. Section 2 outlines the model and calibration. Section 3 shows that the calibrated model produces empirically relevant financial stress dynamics and can account for long-run business cycle moments. Section 4 looks into stabilisation properties of QE and its implications on financial stress frequency and duration. Further, it presents the policy counterfactuals in a financial stress episode driven by rapid monetary tightening. Section 5 studies the optimal conventional and balance sheet policy mix. Section 6 concludes.

2 Model

The model framework comprises households, production sector, financial intermediaries, central bank, and treasury.

A representative household consumes final goods, supplies labour to non-financial firms, holds partially-liquid long-term public debt and deposits with banks.

Production sector comprises final goods firms, intermediate goods firms, and capital goods producers. Intermediate firms produce differentiated intermediate goods and are subject to price rigidities as in Calvo (1983). Competitive final good firms produce final goods using intermediate goods as inputs. Capital goods firms transform final goods into physical capital and are subject to investment adjustment costs as in Christiano, Eichenbaum, and Evans (2005).

Banks are modelled following Gertler and Kiyotaki (2010) and Akinci and Queralto (2022). Bankers are part of the representative household and are experts in intermediation of funds from households to non-financial firms; they use deposits and their retained net-worth (bank equity) to extend loans to non-financial firms and invest in safe assets.

Bankers can abscond with a fraction of their assets which results in a moral hazard problem and implies an incentive compatibility constraint (ICC) to ensure non-absconding in equilibrium. The severity of the moral hazard problem depends on the share of safe assets in bankers' portfolio. In contrast to Gertler and Kiyotaki (2010) and following Akinci and Queralto (2022), the ICC is assumed to be occasionally binding. When the ICC does not bind, financial intermediation is frictionless. If the constraint binds, however, financial intermediation becomes frictional and the economy enters a financial stress episode, which is characterised by volatile investment and spikes in credit spreads. During financial stress episodes, QE has real effects as it stabilises asset prices and injects safe assets into the financial system thus rendering the moral hazard problem less severe.

Central bank sets short-term interest rate and effects QE. When the central bank triggers QE, it can do so by purchasing either public long-term debt from households or private non-financial firm equity from banks. Treasury issues short- and long-term debt inelastically and levies lump-sum taxes from households.

The remainder of the section outlines the model and its calibration.

2.1 Households

The model economy is populated with representative households that consume final goods, C_t, supply labour, L_t, hold deposits with financial intermediaries, D_t, and purchase partially liquid long-term treasury debt, $B^H_{L,t}$. The household maximises the following infinite stream of discounted instantaneous utilities

$$\max_{\{C_t, L_t, D_t, B^H_{L,t}\}_{t=0}^{\infty}} \mathbb{E}_t \sum_{t=0}^{\infty} \beta^t U(C_t, L_t),$$

where β is discount factor.

Per-period household budget constraint in real terms is given by

$$C_t + D_t + (1 + \xi_{L,t}) B^H_{L,t} = w_t L_t + \frac{R^d_{t-1}}{\pi_t} D_{t-1} + \frac{R_{L,t}}{\pi_t} B^H_{L,t-1} + \Xi_t,$$

where $\pi_t = P_t / P_{t-1}$ is the gross inflation rate, D_t is deposits, w_t is real wage, $B^H_{L,t}$ is real market value of long-term debt belonging to the household, Ξ_t denotes proceeds from ownership of banks and non-financial firms, and $\xi_{L,t}$ is adjustment cost of long-term debt holdings given by

$$1 + \xi_{L,t} = \bar{\xi}_L \left(\frac{B^H_{L,t}}{B^H_L} \right)^{\xi},$$

where ξ denotes the elasticity of the adjustment cost with respect to long-term debt holdings and $\bar{\xi}_L$ is steady-state term premium.

2.2 Non-financial firms

Production sector comprises capital goods producers, final goods producers, and intermediate goods firms. Capital goods producers transform final goods into investment goods and are subject to investment adjustment costs as in Christiano, Eichenbaum, and Evans (2005). Final goods producers use intermediate inputs for production of a synthetic consumption good and are perfectly competitive. Intermediate goods producers use labour and capital to produce varieties of intermediate goods, are monopolistically competitive, and are subject to nominal rigidities in price setting as in Calvo (1983).

Capital goods producers Capital goods are produced by perfectly competitive firms. Aggregate capital stock grows according to a standard law of motion

$$K_t = I_t + (1-\delta)K_{t-1},$$

where I_t is investment and $\delta \in (0,1)$ is the depreciation rate.

The objective of the capital good producing firm is to choose I_t to maximise revenue, $Q_t I_t$. I assume that capital goods producing firm is subject to investment adjustment cost as in Christiano, Eichenbaum, and Evans (2005). Thus, the representative capital good producing firm's objective function is:

$$\max_{I_t} \Lambda_{t,t+s} \{Q_{t+s} - 1 - \Phi(I_t)\} I_{t+s},$$

where $\Lambda_{t,t+s}$ is households' stochastic discount factor given by

$$\Lambda_{t,t+s} = \beta \frac{U_{C_{t+1}}}{U_{C_t}}.$$

Final goods producers Final goods producers are perfectly competitive and use differentiated inputs $y_t(i)$ to produce final goods y_t. They maximise the following profit function

$$\max_{y_t(i)} \left(P_t y_t - \int_0^1 P_t(i) y_t(i) di \right)$$

subject to the production constraint

$$y_t = \left[\int_0^1 y_t(i)^{\frac{\epsilon_t - 1}{\epsilon_t}} di \right]^{\frac{\epsilon_t}{\epsilon_t - 1}},$$

where ϵ denotes elasticity of substitution between differentiated inputs.

Optimisation yields the demand schedule for intermediate goods

$$y_t(i) = \left(\frac{P_t(i)}{P_t} \right)^{-\epsilon_t} y_t. \tag{1}$$

Intermediate goods producers Intermediate goods firm that produces input variety i uses a constant returns to scale Cobb-Douglas production technology to produce differentiated inputs for final production. As in Calvo (1983), with an exogenous probability θ they cannot adjust their prices in a given period. Their objective is, thus, to choose prices and production inputs, labour $l_t(i)$ and capital $k_t(i)$ to maximise the following discounted stream of profits

$$\max_{P_t(i), l_t(i), k_t(i)} \mathbb{E}_0 \sum_{s=0}^{\infty} \theta^s \Lambda_{t,t+s} \left\{ \left(\frac{P_t(i)}{P_{t+s}} - mc_{t+s}(i) \right) y_{t+s}(i) \right\},$$

subject to demand for intermediate goods (1) and the production technology constraint

$$y_t(i) = A_t k_{t-1}(i)^{\alpha} l_t(i)^{1-\alpha},$$

where α denotes capital share in output and $mc_t(i)$ denotes i'th firm's marginal cost.

Solution to the problem yields a standard New-Keynesian Phillips curve and demand schedules for labour and capital.

2.3 Financial intermediaries

There is a continuum of bankers who act as specialists in intermediating funds between households and non-financial firms. Bankers are part of a representative household whom they share a consumption insurance scheme with. An individual banker uses its net-worth, n_t[1], and deposits obtained from households, d_t, to issue loans to non-financial firms, k_t^I, and accumulate safe assets, $b_{S,t}^I$. Safe assets are composed of public short-term debt and central bank reserves; since these assets are assumed to have the same risk-return profile, they are aggregated in a single variable. Individual banker's balance sheet is thus given by

$$Q_t k_t^I + b_{S,t}^I = n_t + d_t. \tag{2}$$

Each period, bankers stay in business with an exogenous probability σ_b and exit with a complementary probability $1 - \sigma_b$. If they exit, they transfer their franchise value V_t to households. Every period, $1 - \sigma_b$ new bankers get a start-up fraction γ of total firm equity $Q_t K_t^I$.

Bankers can abscond with a fraction $\Theta(x_t)$ of their assets, $Q_t k_t^I + b_{S,t}^I$, and will only do so if this fraction of assets exceeds their franchise value. This gives rise to the agency problem: Bankers do not abscond if the following incentive compatibility constraint is satisfied

$$V_t \geq \Theta(x_t)(Q_t k_t^I + b_{S,t}^I), \tag{3}$$

where $\Theta(x_t)$ is proportion of divertible assets and x_t is safe asset to portfolio ratio

$$x_t = \frac{b_t^I}{Q_t k_t^I + b_{S,t}^I}. \tag{4}$$

The function $\Theta(\cdot)$ that determines proportion of assets that can be diverted is decreasing, $\Theta(x_t)' < 0$, and convex, $\Theta(x_t)'' > 0$, indicating that a banker can divert a smaller portion of assets when the portfolio includes more safe assets. Nevertheless, when the share of safe assets is substantial, the incremental increase in x_t leads to a smaller reduction in the divertible proportion. This assumption implies that the moral hazard problem of financial intermediaries in more severe when their safe asset holdings are low, and gives rise to the real effects of central bank balance sheet policies in financial stress episodes. In times of financial stress, central bank can increase its provision of safe assets to the financial intermediaries thus reducing the severity of the constraint.

1. Variables pertaining to an individual banker are lowercase.

Bank optimisation problem The banker maximises the present discounted franchise value

$$\max_{k_t^I, b_{S,t}^I, d_t} V_t = \mathbb{E}_t \sum_{s=0}^{\infty} \sigma_b^s (1-\sigma_b) \left(\Lambda_{t,t+s+1} n_{t+s+1} + \Lambda_{t,t+s+1} \zeta_{t+s}^b b_{s,t+s}^I \right),$$

where ζ_t^b denotes an exogenous shock process that governs banker's preference for safe assets.

The flow budget constraint of a typical banker is given by

$$Q_t k_t^I + b_{s,t}^I + \frac{R_{t-1}^d}{\pi_t} d_{t-1} = R_t^k Q_{t-1} k_{t-1}^I + \frac{R_{t-1}}{\pi_t} b_{S,t}^I + d_t, \tag{5}$$

which, combined with Equation (2), yields the law of motion for net-worth:

$$n_t = \left(R_t^k - \frac{R_{t-1}^d}{\pi_t} \right) Q_{t-1} k_{t-1}^I + \left(\frac{R_{t-1}}{\pi_t} - \frac{R_{t-1}^d}{\pi_t} \right) b_{S,t-1}^I + \frac{R_{t-1}^d}{\pi_t} n_{t-1}.$$

Defining leverage ratio as

$$\phi_t \equiv \frac{Q_t k_t^I + b_{S,t}^I}{n_t} \tag{6}$$

and franchise value to net-worth ratio, $\psi_t = V_t / n_t$, allows to rearrange the banker's problem such that the banker picks safe asset and leverage ratios:

$$\psi_t = \max_{x_t, \phi_t} \left((\mu_t^K + \mu_t^B)(1 - x_t) + (\mu_t^B + \zeta_t^b) x_t \right) \phi_t + \upsilon_t$$

subject to incentive compatibility constraint

$$\left((\mu_t^K + \mu_t^B)(1 - x_t) + (\mu_t^B + \zeta_t) x_t \right) \phi_t + \upsilon_t \geq \Theta(x_t) \phi_t, \tag{7}$$

where the following definitions of banker's stochastic discount factor, discounted equity spread, safe asset spread, and return on deposits are made use of

$$\Omega_{t,t+1} \equiv \mathbb{E}_t \Lambda_{t,t+1} (1 - \sigma_b + \sigma_b \psi_{t+1}) \quad , \quad \upsilon_t \equiv \mathbb{E}_t \Omega_{t,t+1} \frac{R_t^d}{\pi_{t+1}},$$

$$\mu_t^K \equiv \mathbb{E}_t \Omega_{t,t+1} \left(R_{t+1}^k - \frac{R_t}{\pi_{t+1}} \right) \quad , \quad \mu_t^B \equiv \mathbb{E}_t \Omega_{t,t+1} \left(\frac{R_t}{\pi_{t+1}} - \frac{R_t^d}{\pi_{t+1}} \right).$$

Optimisation yields the following FOC for x_t

$$\mu_t^K = \zeta_t^b - \frac{\bar{\lambda}_t}{1 + \bar{\lambda}_t} \Theta'(x_t), \tag{8}$$

where $\bar{\lambda}_t$ denotes the Lagrange multiplier on the constraint in Equation (7). Note that when the constraint is not binding, the condition collapses to

$$\mathbb{E}_t \Omega_{t,t+1} \left(R_{t+1}^k - \frac{R_t}{\pi_{t+1}} \right) = \xi_t^b,$$

which pins down credit spread in equilibrium with no financial stress. Absent of bankers' preference for safe assets, i.e. $\xi_t^b = 0$, this condition implies that, in tranquil times, equity spread is zero.

Optimisation with respect to ϕ_t yields

$$\bar{\mu}_t \equiv (\mu_t^K + \mu_t^B)(1 - x_t) + (\mu_t^B + \zeta_t)x_t = \frac{\bar{\lambda}_t}{1 + \bar{\lambda}_t}\Theta(x_t), \tag{9}$$

where $\bar{\mu}_t$ denotes total excess returns of the financial sector.

Using the definition of $\bar{\mu}_t$, divide (9) by (8) to get

$$\mu_t^K = \zeta_t^B - \bar{\mu}_t \frac{\Theta'(x_t)}{\Theta(x_t)}. \tag{10}$$

The incentive constraint (7) can be expressed to define the upper bound on leverage

$$\bar{\phi}_t = \frac{\upsilon_t}{\Theta(x_t) - \bar{\mu}_t}. \tag{11}$$

This condition highlights the mechanism through which central bank interventions alleviate the severity of a financial stress episode. Central bank balance sheet expansion directly affects the upper bound for leverage through safe asset ratio, x_t. When the central bank expands its balance sheet, it directly affects the amount of central bank reserves, thus increasing safe asset ratio of financial intermediaries. When the constraint in (7) does not bind, i.e. $\bar{\lambda}_t = 0$, total excess returns of the banker are equal to zero, $\bar{\mu}_t = 0$. Financial intermediation is thus frictionless which implies $\bar{\phi}_t > \phi_t$. If the ICC binds, the excess returns are no longer zero, $\bar{\mu}_t > 0$, but realised leverage is equal to its upper bound, $\bar{\phi}_t = \phi_t$. Hence, the following regime determination condition holds

$$\bar{\mu}_t(\bar{\phi}_t - \phi_t) = 0. \tag{12}$$

Aggregating across bankers who continue in business and new bankers yields the following equation for evolution of net-worth

$$\begin{aligned} N_t = \sigma_b &\left[\left(R_t^k - \frac{R_{t-1}^d}{\pi_t} \right) Q_{t-1}K_{t-1}^I + \frac{\left(R_{t-1} - R_{t-1}^d \right)}{\pi_t} B_{S,t-1}^I + \frac{R_{t-1}^d}{\pi_t} N_{t-1} \right] \\ &+ (1 - \sigma_b)\gamma Q_{t-1}K_{t-1}^I. \end{aligned} \tag{13}$$

2.4 Central Bank

Monetary authority sets the policy rate and effectuates asset purchases. Policy rate is set according to a Taylor-type rule of the form

$$\frac{R_t}{R} = \left(\frac{R_{t-1}}{R} \right)^{\rho_R} \left(\pi_t^{\phi_\pi} X_t^{\phi_y} \right)^{1-\rho_R} \exp \varepsilon_t^R, \tag{14}$$

where ρ_R denotes policy rate inertia, ϕ_π and ϕ_y are denote coefficients of feedback to inflation and output gap deviations, respectively, ε_t^R is an exogenous disturbance, and X_t is defined as an output gap between the realised output Y_t and a counterfactual measure of real activity that would have occurred in the same economy with no price rigidities and frictions in financial intermediation.

Balance sheet policy Balance sheet policy consists in purchases of long-term government debt and non-financial firm equity and provision of reserves to financial intermediaries. If central bank balance sheet expansion is done through acquisition of private non-financial firm equity, it is referred to as private QE, whereas if the monetary authority expands its balance sheet via acquisition of public long-term debt from households, it is referred to as public QE.

The budget constraint of the monetary authority is given by

$$\frac{R_{t-1}}{\pi_t} B^{cb}_{S,t-1} + \frac{R_{L,t}}{\pi_t} B^{cb}_{L,t-1} + R^k_t Q_{t-1} K^{cb}_{t-1} = B^{cb}_{L,t} + B^{cb}_{S,t} + Q_t K^{cb}_t + \Lambda^{cb}_t + C_t, \tag{15}$$

where Λ^{cb}_t denotes the transfers from the central bank to treasury. Note that $B^{cb}_{S,t}$ is a composite of public short-term debt holdings of the central bank and the central bank reserves, which, by assumption, have the same risk-return profile and, hence, are aggregated in a single variable. K^{cb}_t denotes holdings of non-financial firm equity. C_t denotes a reduced-form proxy for unmodelled distortions and political costs of balance sheet expansions, as in Karadi and Nakov (2021), and takes the following form

$$C_t = \varkappa \left\{ \left(\frac{B^{cb}_{L,t}}{B^{cb}_L} \right)^2 + \left(\frac{Q_t K^{cb}_t}{K^{cb}} \right)^2 \right\}, \tag{16}$$

where $\varkappa$ is scaling parameter.

When the central bank effectuates balance sheet policy, the following revenue-neutrality condition holds

$$B^{cb}_{L,t} + Q_t K^{cb}_t + B^{cb}_{S,t} = 0. \tag{17}$$

This condition implies that if the central bank expands its assets via acquisition of either public or private assets, it has to expand its liabilities by issuing central bank reserves.

Transmission of QE Both private and public QE have real effects on the economy only if the financial intermediaries are at their leverage constraint and financial intermediation is frictional. In times of financial stress, banks seek to alleviate the severity of their leverage constraint by increasing the proportion of safe assets in their portfolio. Since individual commercial banks cannot influence the supply of safe assets in the economy, they can only increase their safe asset holdings by selling firm equity. In times of financial stress, this creates a vicious circle of equity fire sales that trigger decline in price of equity which, in turn, triggers another round of fire sales.

To mitigate the adverse pressures of financial stress episodes, central bank can initiate QE that injects central bank reserves into the financial system and alleviates the severity of the leverage constraint. QE increases the proportion of safe assets on banks' balance sheets and mitigates the adverse implications of a credit crunch. This channel is ineffective when banks' leverage constraints are not binding; increase in safe assets provision will not have any real effects on the unconstrained financial intermediaries.

There are, however, fundamental differences in the transmission mechanisms of private and public QE. First, the two types of QE differently affect balance sheets and leverage of banks. Private QE consists in swapping non-financial firm equity for central bank reserves on the balance sheets of banks. This swap, all else being equal, does not alter the size of the balance sheet of commercial banks but rather changes its composition increasing the safe assets proportion. At the same time, private QE does not lead to an increase in bank leverage but alleviates the severity of leverage constraint as it increases banks' safe asset holdings. In contrast, a public QE operation, that entails purchase of long-term government debt from households and issuance of central bank reserves, increases banks' balance sheet size, their leverage, and safe asset proportion.

Second, public and private QE create different distortions. Private QE implies that central bank takes on part of intermediation of funds to non-financial firms. If it is done in times of a financial stress episode where yields of private assets are high, this intervention distorts banks' returns; central bank exchanges low-yield safe assets for high-yield private assets which decreases banks' returns and directly affects their ability to recapitalise. In contrast, public QE distorts long-term yields and, by implication, deposit rates. When the central bank purchases partially liquid long-term government debt, the long-term yield decreases, which leads to a decrease in deposit rates via household no-arbitrage condition between long-term debt and deposits. Lower deposit rates have distortionary effects on bank profitability and affect banks' ability to recapitalise in the event of financial stress.

2.5 Treasury

Treasury collects lump-sum taxes from households τ_t, receives transfers from the central bank Λ_t^{cb}, and issues short-term and long-term debt inelastically. The budget constraint of the treasury reads as

$$\tau_t + \bar{B}_L + \bar{B}_S + \Lambda_t^{cb} = \frac{R_{t-1}}{\pi_t}\bar{B}_S + \frac{R_{L,t}}{\pi_t}\bar{B}_L. \tag{18}$$

Issuance of public debt follows a constant maturity structure, $\bar{B}_S = \varrho \bar{B}_L$, with ϱ determining the ratio of short-term to long-term debt.

Public short-term debt issued by the treasury is held by financial intermediaries or the central bank

$$\bar{B}_S = B_{S,t}^{cb} + B_{S,t}^{I}. \tag{19}$$

Long-term debt issued by the treasury is held by the central bank or by households

$$\bar{B}_L = B_{L,t}^{cb} + B_{L,t}^{H}. \tag{20}$$

Combining budget constraint of the central bank (15), that of treasury (18), and using market clearing conditions for short- and long-term debt, (19) and (20), yields consolidated budget constraint of the government

$$\tau_t + R^k_{t-1} Q_t K^{cb}_t + B^H_{L,t} + B^I_{S,t} = \frac{R_{t-1}}{\pi_t} B^I_{S,t-1} + \frac{R_{L,t}}{\pi_t} B^H_{L,t-1} + Q_t K^{cb}_t + \mathcal{C}_t, \qquad (21)$$

which is cast in terms of public debt held by the private sector and central bank holdings of non-financial firm equity.

The assumption on inelastic supply of long- and short-term government debt is not innocuous. In practice, governments tend to introduce debt-financed fiscal stimulus programmes in recessions. Introduction of elastic government debt issuance in the model would mute the effects of QE and create further distortions in long-term debt markets.

The assumption that treasury levies non-distortionary lump-sum taxes is not innocuous either. Large-scale central bank interventions potentially require substantial transfers from treasury to central bank. If these transfers are financed via distortionary taxes, there are potential negative implications on macroeconomic stabilisation and household welfare.

As this paper focuses on the effects of QE, it is agnostic of modelling distortionary effects of fiscal policy. The effects of fiscal policy and its interplay with central bank policy are, thus, left for future research.

2.6 Market clearing and equilibrium

Non-financial firm equity holdings either belong to financial intermediaries or the central bank

$$K_t = K^I_t + K^{cb}_t.$$

Output of final goods is either consumed, invested, or wasted on central bank balance sheet interventions

$$Y_t = C_t + (1 + \Phi(I_t))\, I_t + \mathcal{C}_t.$$

The competitive equilibrium is a set of 38 variables: 15 quantities $\{\, C_t, L_t, K_t, K^I_t, K^{cb}_t, I_t, Y_t, N_t, B^{cb}_{S,t}, B^I_{S,t}, B_{S,t}, B^{cb}_{L,t}, B^H_{L,t}, B_{L,t}, \tau_t \,\}$, 9 prices $\{\, mc_t, z^k_t, w_t, \pi_t, Q_t, R^k_t, R^d_t, R_t, R_{L,t} \}$, 9 banker variables $\{\, \Omega_{t,t+1}, \mu^K_t, \mu^B_t, \upsilon_t, \psi_t, \phi_t, x_t, \bar{\mu}_t, \bar{\phi}_t \,\}$, and 3 exogenous processes $\{A_t, M_t, \zeta^b_t\}$ that satisfy the equilibrium conditions outlined in Appendix A.

2.7 Functional forms, calibration, and solution strategy

Functional forms I assume that households' utility functions takes the form as in Greenwood, Hercowitz, and Huffman (1988)

$$U(C_t, L_t) = \frac{\left(C_t - \chi \frac{L_t^{1+\nu}}{1+\nu}\right)^{1-\sigma}}{1-\sigma}, \tag{22}$$

where ν is inverse-Frisch elasticity of labour supply, and σ is coefficient of relative risk aversion. This functional form implies non-separability between consumption and leisure and makes marginal rate of substitution between labour and leisure independent of consumption.

Capital goods producers are made subject to the investment adjustment costs as in Christiano, Eichenbaum, and Evans (2005)

$$\Phi(I_t) = \frac{\kappa_I}{2}\left(\frac{I_{t+s}}{I_{t+s-1}} - 1\right)^2, \tag{23}$$

where κ_I is a scaling parameter.

Finally, banks' absconding proportion is given by the following function of the ratio of safe assets on their balance sheet

$$\Theta(x_t) = \left(1 - \frac{\lambda_b}{\kappa} x_t^{\kappa}\right), \tag{24}$$

where $\kappa > 0$ is elasticity of absconding proportion with respect to safe assets and λ_b is scaling parameter.

Calibration Some parameters are calibrated to match first moments in the data. β is set to match an average interest rate of 2%, short-term debt to GDP is set to 15%, while ϱ is set such that long-term debt to GDP is around 100%. Assets of the central bank to GDP are set to 45%. Steady state term premium matches the average of 1%.

Other parameters are calibrated to the values that are standard in the literature. Constant relative risk aversion coefficient σ is set to 2. Inverse-Frisch elasticity of labour supply is set to 1/3. Elasticity of substitution across intermediate inputs is set to match 20% markup. Capital depreciation δ is standard and is set to 0.025, the probability of not being able to adjust the price in a given period, θ is set to 3/4. Feedback coefficients to inflation and output gap deviations are assumed to be equal to 2 and 0.1, respectively, consistent with estimates in Bianchi, Faccini, and Melosi (2022).Taylor rule inertia is set equal to 0.55. Elasticity of long-term yield to long-term debt holdings is set equal to the estimate in Chen, Cúrdia, and Ferrero (2012).

Parameters of the banking sector are calibrated as follows. Parameters that govern the severity of incentive compatibility constraint, θ^b, κ, and λ^b, are set to match average occurrence of financial stress of around 10% and such that $\Theta(x_t)$ is decreasing and convex. Other banker parameters, γ and σ_b, are calibrated to match steady state leverage of approximately 6.

Parameters that pertain to exogenous processes are calibrated to match the data moments of 6 developed economies: Germany, France, Italy, Spain, Germany, UK, and US. I pick autoregressive coefficients and standard deviations of TFP and markup processes $(\rho_A, \rho_M, \sigma_A, \sigma_M)$ to match standard deviation and auto-correlation of growth rates of GDP, consumption, and investment. Safe asset preference shock parameters (ρ_B, σ_B) are calibrated to match volatility of credit spreads in times of financial tranquillity. Table 2 summarises the ability of the model to match business cycle moments. Additionally, the table reports other moments related to cross-correlations between output, consumption, and investment growth rates as well as credit spreads and inflation, that are used to check external validity of the calibration exercise. Given the calibration, the model can indeed deliver reasonable cross-correlations between output, consumption and investment growth rates and credit spread moments.

Solution strategy The model is solved using third-order perturbation around stochastic steady state using the methodology described in Holden (2023) and the corresponding toolkit. The occasionally binding leverage constraint is present in the information set of the agents; this is instrumental to the results as the proximity to the constraint alters the leverage choice of the banks both dynamically and in stochastic steady state. As further explained below, if banks anticipate a non-zero probability of hitting the constraint in the future, even if it is not binding in the current period, they exhibit precautionary behaviour when picking leverage. This is in contrast to the approach used by, for example, Guerrieri and Iacoviello (2015) that assumes that agents are not aware of the existence of an occasionally binding constraint. This assumption would preclude any meaningful approximation of the precautionary behaviour which is central to the results of this paper.

First-order Caratheodory-Tchakaloff monomials are used to approximate the risk of the leverage constraint becoming binding. Agents are assumed to factor in uncertainty about hitting the constraint up to 16 quarters ahead[2].

2. I conduct robustness check using both higher order approximation of the risk and higher number of uncertainty periods which turn to be quantitatively unimportant for the results yet drastically decrease computational speed.

Table 1: Parameter values

Symbol	Value	Description	Source/Target
Households			
β	0.99	Discount factor	Interest rate 3%
σ	2	Relative risk aversion	Standard
χ	2.1	Relative disutility of labour	Labour 1/3 of time
ν	1/3	Inverse Frisch	Gertler and Kiyotaki (2010)
ξ	0.025	Elasticity of LTD adj. cost	Chen, Cúrdia, and Ferrero (2012)
$\bar{\xi}_L$	0.0028	s.s. term premium	1% term premium
Production			
ϵ	5	Elasticity of sub. across int. inputs	25% Markup
δ	2.5%	Capital depreciation	Standard
α	1/3	Capital share	Standard
κ_I	1.35	Investment adjustment cost	–
θ	0.75	Calvo probability	–
Bankers			
θ_b	0.705	Fraction of divertible funds	5% frequency of fin. stress
κ	0.1266		–
λ_b	0.117		–
σ_b	0.925	Continuation probability	Av. bank survival 3.5y.
γ	0.2		Leverage 6
x	0.2	Safe asset to portfolio	Data
ζ^b	0.0025	Safe asset preference	1% equity spread
Monetary policy			
ρ_R	0.55	Policy rate inertia	-
ϕ_π	2	Inflation feedback coefficient	Bianchi, Faccini, and Melosi (2022)
ϕ_y	0.075	Output feedback coefficient	Bianchi, Faccini, and Melosi (2022)
$B_L^{cb}/4Y$	45%	SS value of LTD holdings	Data
Fiscal policy			
$B_S/4Y$	15%	ST Gov. debt to GDP	Data
ϱ	1/8	Maturity structure of public debt	Data
Exogenous Processes			
ρ_A	0.9	TFP persistence	
ρ_M	0.92	Markup shock persistence	
ρ_B	0.55	Safe asset preference persistence	
σ_A	0.55%	TFP std. deviation	
σ_R	0.05%	MP shock std. deviation	
σ_M	1.05%	Markup shock std. deviation	
σ_B	0.0202%	Safe asset preference std. deviation	

Table 2: Model v. Data performance

	g^Y	g^C	g^I	Spread	Inflation
Standard deviation					
Model	1.06	1.01	1.96	1.89	1.03
Data	0.91	0.99	2.41	0.74	1.00
	[0.66, 1.07]	[0.81, 1.24]	[1.77, 3.12]	[0.48, 0.94]	[0.76, 1.46]
Correlation with g^Y					
Model	-	0.96	0.76	-0.36	-0.09
Data	-	0.69	0.65	-0.55	-0.08
	-	[0.59, 1.00]	[0.46, 0.77]	[-0.69, -0.40]	[-0.36, 0.08]
Autocorrelation					
Model	0.38	0.20	0.40	0.94	0.97
Data	0.24	0.03	0.23	0.86	0.86
	[-0.01, 0.81]	[-0.14, 0.22]	[-0.08, 0.57]	[0.82, 0.90]	[0.78, 0.90]

Note: g^Y, g^C, and g^I denote growth-rates of output, consumption, and investment, respectively. Spread is annualised credit spread. The data are expressed in units of the GDP deflator. Data moments are calculated as the simple average across all the countries in our sample (Italy, Spain, Germany, France, the United Kingdom, and the United States). Square brackets denote the min-max range for each moment across the full sample of countries. Source: Akinci and Queralto (2022), author's calculations.

3 Quantitative properties

This section demonstrates empirical relevance of the model. In particular, I discuss how the model can account for long-run business cycle moments as well as the stylised facts related to financial stress episodes as presented in Akinci and Queralto (2022).

Long-run business cycle moments Table 2 summarises the key business cycle moments for Germany, France, Italy, Spain, UK, and Germany. The table shows standard deviations, cross-correlations, and auto correlations of growth rates of output, consumption, investment, credit spreads, and inflation.

As stated above, the exogenous processes in the model are calibrated to match standard deviations of growth rates of output, consumption, and investment, as well as autocorrelations of these variables. Standard deviations of output and consumption growth rates fall well within the data range. Model-implied output growth rates are, however, slightly more volatile than consumption, which is not the case in the data.

Investment growth rates implied by the model are towards the lower end of the data range. The model can well account for signs and magnitudes of the autocorrelations.

The model is able to account for the cross correlations of consumption and investment growth rates reasonably well; both model-implied moments fall within the data range and consumption growth rates are more strongly correlated with output than investment growth rates, as in the data. Moreover, the model can well account for autocorrelation and correlation of credit spreads with output growth rates. First, in the data, credit spreads are countercyclical; the model indeed delivers countercyclicality of the credit spreads but falls slightly short of matching the magnitude. Second, in the data credit spreads demonstrate strong autocorrelation. This is also the case in the model, however, model delivers higher autocorrelation of the credit spreads than in the data.

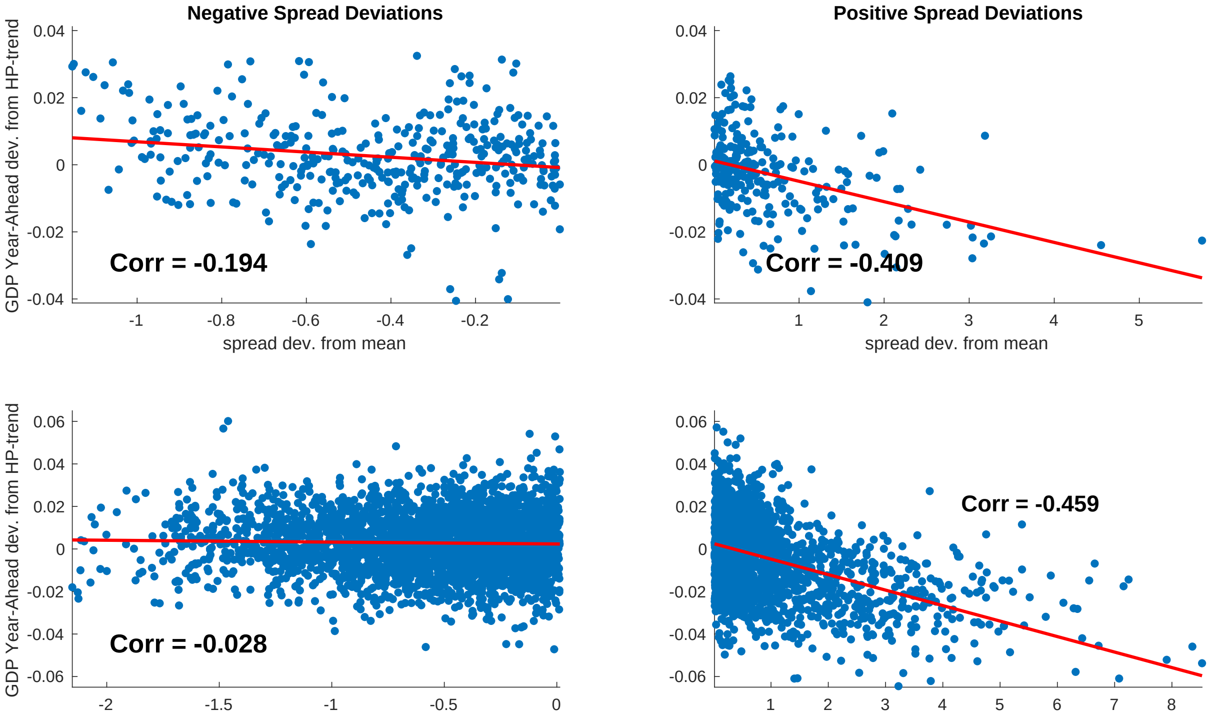
The model is also able to match inflation moments. First, the model delivers sensible standard deviation of inflation that falls very close to the median of the data range. Second, inflation is weakly negatively correlated with the output growth rates as in the data. The implied correlation coefficient is very close to the median of the data range. Third, inflation demonstrates strong autocorrelation, as in the data, although the model produces higher autocorrelation of inflation than that observed in the data.

I proceed with analysing the ability of the model to account for the stylised facts related to financial stress episodes.

Output deviations and credit spreads In the data, there is an asymmetric relationship between credit spreads and economic activity. Credit spreads are generally countercyclical. When credit spreads are below mean, they demonstrate mild countercyclicality. When credit spreads are above mean, however, they are more strongly correlated with output deviations. This is also the case in the model.

This relationship is due to the state-dependence of the financial friction. In normal times, when the banks are far from their leverage constraint, financial intermediation is frictionless; banks are able to effectively intermediate funds between households and non-financial firms. On the contrary, when financial intermediaries are in the constrained region, credit spreads demonstrate occasional spikes. As financial intermediation becomes frictional, banks are no longer able to effectively intermediate funds between households and non-financial firms. This leads to depressed invest-

Figure 2: Output and Credit Spreads

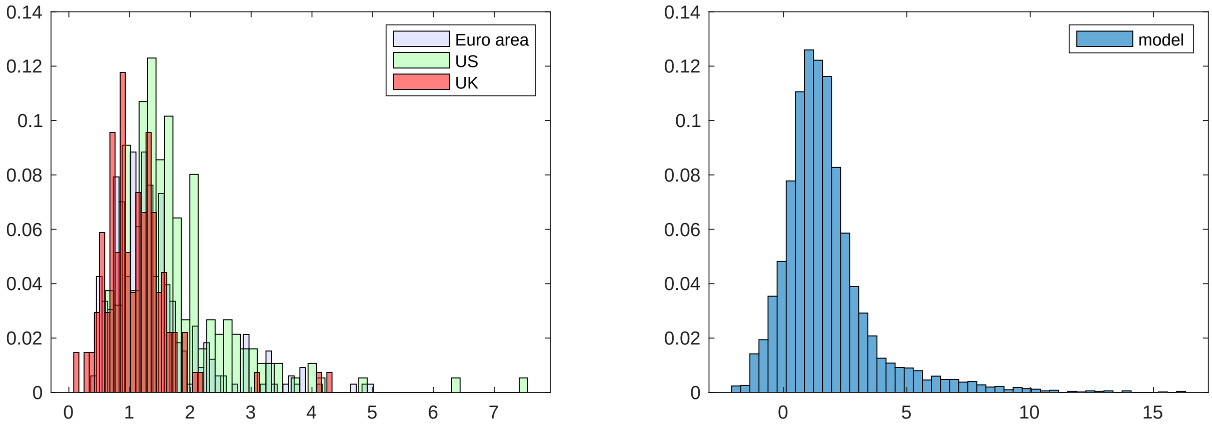


Note: The model is simulated for 10'000 periods. Leverage constraint binds around 10% of the simulated sample. Left panel plots the relationship between the cyclical component of output four periods ahead and the credit spread when credit spread is below sample mean. Right panel plots the same relationship when credit spread is above mean.

ment in physical capital, which, in turn, triggers a decline in its price and leads to a credit crunch. As banks engage in a fire sale of firm equity, its rate of return sharply increases, while the central bank, striving to stimulate economic activity, cuts interest rates. This creates a high and volatile credit spread. Figure 2 illustrates the nonlinear relationship between high and low credit spreads and output deviations in the data and in the model.

Distribution of credit spreads The model generates an empirically relevant distribution of credit spreads that is right-skewed in the data, as shown in Figure 3. In normal times, spreads are low, demonstrate low volatility, and are mainly driven by the banks' stochastic preference for safe assets. In times of infrequent financial stress, however,

Figure 3: Credit spreads: data and model

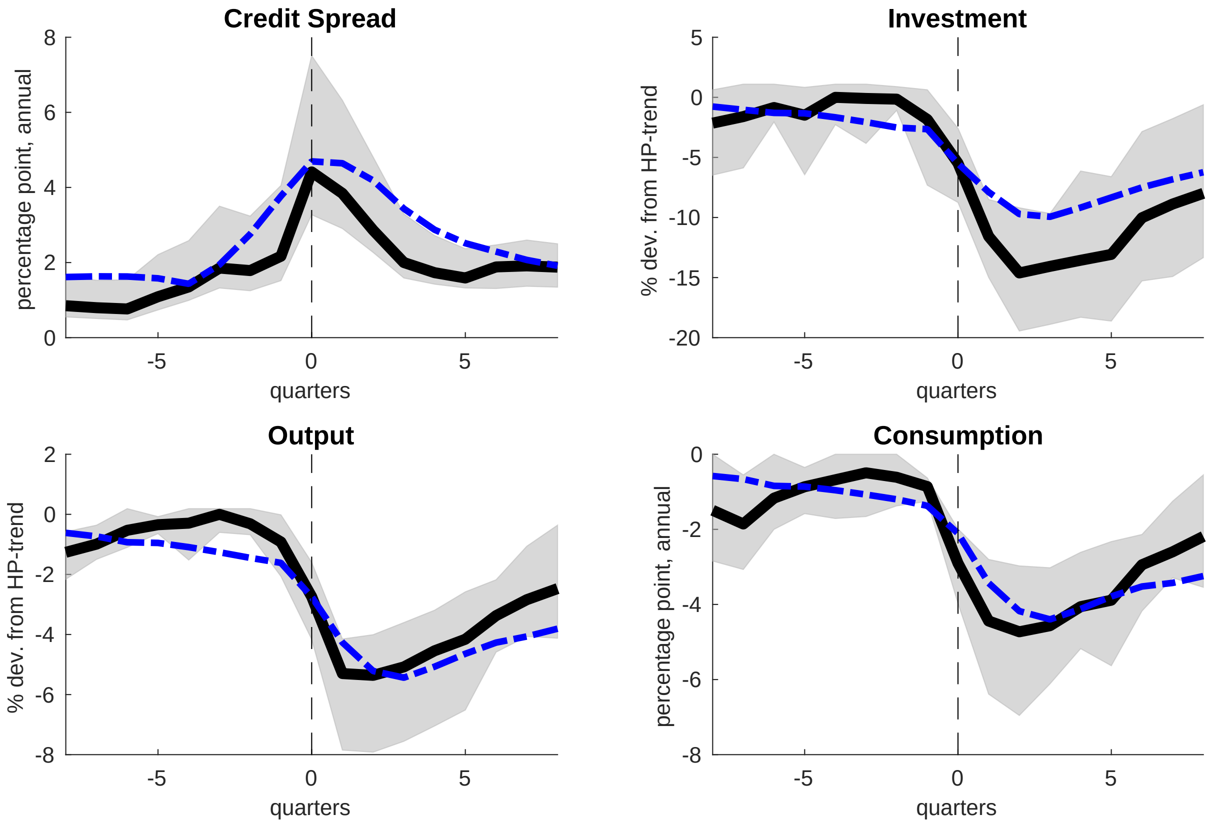


Note: data sourced from BoE, FRED, Akinci and Queralto (2022). Model is simulated for 10'000 periods.

credit spreads are high and volatile. The model generates a right-skewed credit spread distribution as in the data. Skewness in the credit spread distribution is driven by the presence of the occasionally binding leverage constraint. When the constraint becomes binding, banks' ability to intermediate funds is constrained, which depresses investment and real activity, and triggers a sharp increase in return on equity. At the same time, banks experience a sharp decline in their net-worth which induces them to decrease leverage to exit the constrained region. To alleviate the effects of the tight leverage constraint in times of financial stress, banks sell their equity and strive to increase the proportion of safe assets on their balance sheets. As there is higher demand for safe assets and lower demand for equity, the return on safe assets declines and the return of equity increases. This explains the rise in credit spreads during a period of financial stress.

Average financial stress episode As documented in Akinci and Queralto (2022), financial crisis episodes are characterised by a severe decline in output, investment, consumption, and spikes in credit spreads. Figure 4 shows that an average financial crisis episode is the model is consistent with the empirical evidence. In an average financial crisis episode, output and consumption decline by around 4%, investment falls sharply by around 10%, and credit spreads demonstrate a spike of around 4%.

Figure 4: Average financial crisis



Note: Credit spread, policy rate, and inflation are percentage points. Other variables are in percent deviations from HP-trend. Solid black line - data mean, shaded regions - min. and max. values of variables in the data. Average financial crisis episode is defined as a period where the leverage constraint of the banking sector binds for at least 4 consecutive periods. Financial crisis starts in period zero. The plot shows dynamics of aggregate variables 20 periods prior to and after the first period where the leverage constraint starts to bind.
Sources: Akinci and Queralto (2022), FRED, Bank of England, author's calculations.

In the model, financial stress episodes are triggered by a sequence of adverse shocks that bring leverage of commercial banks to its upper bound. When leverage is at its upper bound, financial intermediation becomes frictional; adverse shocks trigger a decline in equity prices, bankers start to sell equity, which triggers a further decline in equity prices and leads to a credit crunch. As investment sharply declines, output and consumption decline as well.

Overall, the calibrated model can well account for the stylised facts related to financial stress episodes especially given the fact that it does not feature the usual mechanisms of medium-scale DSGE, such as wage Phillips curve and habits in consumption, and uses a very stylised way of modelling the friction in financial intermediation.

4 Balance Sheet Policy and Financial Stress

In this section, I analyse the implications of QE on macroeconomic and financial stability.

First, I look into the implications of rule-based QE on volatility of key macroeconomic aggregates and financial stress frequency. QE is assumed to target deviations of credit spreads as they demonstrate spikes in times of financial stress and, thus, serve as a natural target for a rule-based balance sheet intervention. Second, to understand the implications of QE in a tightening cycle, I conduct a financial stress experiment where I make the model economy subject to an inflationary shock that leads to a sharp increase in the policy rate which endogenously triggers a financial stress episode.

QE rules Throughout this section, I assume that the central bank operates the following rules for acquisition of long-term debt from households and private non-financial firm equity from banks:

$$\frac{B^{cb}_{L,t}}{B^{L,cb}} = \left(\frac{S_t}{S}\right)^{\phi^B_{QE}} \quad , \quad \frac{K^{cb}_t}{K^{cb}} = \left(\frac{S_t}{S}\right)^{\phi^K_{QE}} , \tag{25}$$

where $\phi^i_{QE} > 0, i \in \{B, K\}$ is a feedback coefficient that governs the elasticity of long-term debt and non-financial firm equity purchases with respect to the credit spread, $S_t \equiv \mathbb{E}_t\{R^K_{t+1} - R_t/\pi_{t+1}\}$; if the credit spread increases, indicating a financial stress episode, the central bank increases its holdings of either private or public assets which, in turn, leads to the reserves provision to financial intermediaries via Equation (17).

The policy rules in Equation (25) could be interpreted as financial stability QE; central bank balance sheet is only used to stabilise the financial sector and not to achieve other policy goals such as inflation stabilisation.

It is important to highlight the differences in transmission mechanisms of the two types of QE. First, when the central bank effects public QE, it only affects banks' balance sheet via an increase in the reserves provision, which, in turn, makes banks' moral hazard problem less severe, as discussed previously. Even though such an intervention increases bank leverage, it alleviates the leverage constraint by raising the upper bound for leverage, which is an increasing function of banks' safe asset proportion. Private QE, however, does not lead to higher bank leverage; when the central bank acquires private assets from commercial banks, it swaps them for safe assets such that the size of the bank balance sheet, and, thus, leverage, remains unchanged, all else equal.

Second, the two types of balance sheet expansions differ in their effects on the yield curve. If the central bank triggers public QE, it exerts downward pressure on the long-term yield. Households are, thus, incentivised to shift their portfolio towards bank deposits. Via a household no-arbitrage condition between long-term debt and deposits, this also leads to a lower deposit rate, which positively impacts banks' net-worth. This effect, however, is not present if central bank triggers private QE; this operation does not affect the yield curve and does not directly affect the deposit rate. Private QE, however, directly distorts banks' excess returns over the course of a financial stress episode. As the central bank effectively swaps high-yield private assets for relatively low-yield central bank reserves, it decreases banks' excess returns, which affects banks' ability to recapitalise and exit the financial stress episode.

Below, I analyse the effects of QE on macroeconomic stability and frequency of financial stress.

4.1 Stabilisation and Stress Frequency

To explore stabilisation properties of balance sheet rules, I simulate the model under the two balance sheet policy rules in Equation (25). Using the simulated data, I calculate standard deviations of key variables and frequency of financial stress episodes compared to the baseline case with $\phi^i_{QE} = 0$. The results are presented in Figure 5.

As is natural, balance sheet interventions effectively stabilise macroeconomic aggregates and bank variables; standard deviations of output, investment and net-worth of banks are significantly lower under QE. This is due to the fact that a balance sheet intervention increases the central bank reserves provision to commercial banks and, thus, mitigates the severity of their leverage constraints during financial stress.

The stabilisation effects of private QE are, however, slightly stronger. This is due to the fact that when central bank acquires private non-financial firm assets from commercial banks, it does not only increase the reserves provision but also reduces the banks' holdings of private assets, which is not the case under public QE. This leads to a relatively higher implied safe asset ratio under private QE than under public QE, all else being equal. When the safe asset ratio of the banks is higher, their leverage constraint is less severe, which, in turn leads to better stabilisation.

Balance sheet expansions targeted at quenching financial stress, however, increase the frequency of financial stress episodes. Under baseline, where central bank balance sheet size is constant, bank leverage constraint binds around 10% of the time. If the central bank adopts an expansionary balance sheet policy via acquisition of public long-term debt, the frequency of financial stress episodes rises to around 12% under $\phi^B_{QE} = 10$. If the central bank adopts a more aggressive rule with $\phi^B_{QE} = 100$, the frequency of financial stress episodes increases up to 17% of the simulated sample.

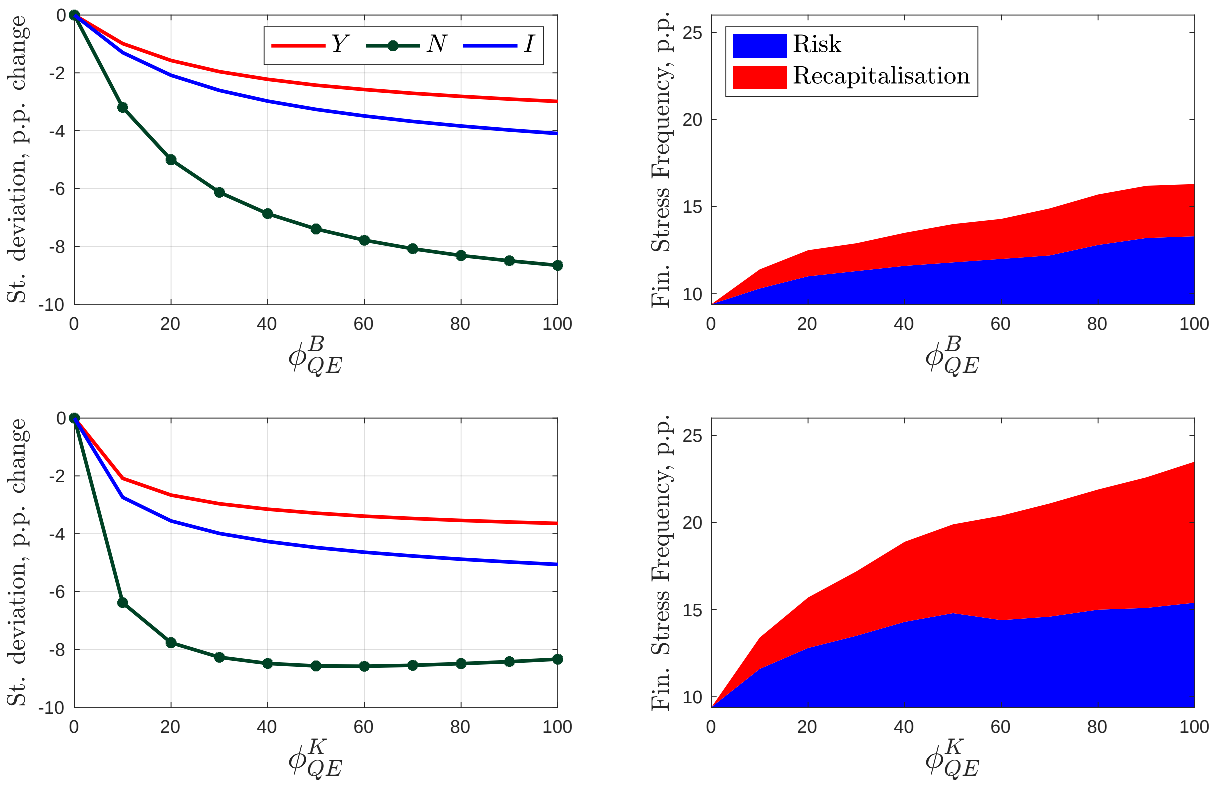
Private QE implies qualitatively similar results; the more aggressive the central bank intervention is, i.e. the higher is ϕ^K_{QE}, the more frequent the financial stress episodes are. The stress frequency is, however, different in magnitude. Under the most aggressive simulated private QE rule, $\phi^K_{QE} = 100$, financial stress episodes happen around 23.5% of the simulated sample, whereas under the same calibration of public QE rule, the implied stress frequency is only 17%.

QE and financial stress frequency Higher frequency of financial stress episodes, induced by balance sheet policies, is driven by changes in bank risk-taking behaviour (risk channel) and their ability to recapitalise during a financial stress episode (recapitalisation channel).

The importance of bank precautionary behaviour in the no-intervention case can be seen in Baseline column of Table 3. The first column presents the counterfactual simulation results when banks do not anticipate hitting their leverage constraint at any point in time, whereas the second column presents the results of the simulation where the risk of hitting the constraint is factored in and, thus, banks exhibit precautionary behaviour. When banks anticipate hitting their leverage constraint, their precautionary behaviour leads to a reduction in the frequency of financial stress episodes of around 10 p.p.

Banks exhibit precautionary behaviour if they assign non-zero probability to their

Figure 5: Stabilisation and Stress Frequency



Note: Left - standard deviations expressed as deviations from quarterly mean, change in p.p. relative to baseline with no balance sheet interventions. Right - frequency of financial stress episodes, i.e. banks' leverage constraint is binding, decomposed in recapitalisation and risk channels. $\rho_{QE} = 0$.

leverage constraint binding in the future; a binding leverage constrain is associated with a severe deterioration of their net-worth and, thus, franchise value, which banks seek to maximise. The more severe the impact of a financial stress episode on banks' net-worth, the more they want to avoid it and the stronger is the precautionary motive. If central bank adheres to a rule-based QE policy targeted at financial stress episodes, it leads to less severe implications of financial stress on banks' net-worth. Under QE, banks anticipate milder financial stress episodes that do not deteriorate their net-worth as much as they otherwise would under no central bank intervention. Thus, banks' precautionary behaviour under QE is less pronounced.

Further, QE leads to distortions that affect banks' ability to recapitalise during financial stress episodes. As QE leads to a reduction in credit spreads over a financial

Table 3: Stress frequency: risk and recapitalisation channels

	Baseline		Public QE			Private QE		
ϕ^i_{QE}	0*	0	10	50	100	10	50	100
Stress Frequency	19.08	9.39	11.39	13.99	16.28	13.39	19.88	23.48
Δ from Baseline	9.69	-	2.00	4.60	6.89	4.00	10.49	14.09
Recapitalisation	-	-	1.10	2.20	3.00	1.80	5.09	8.09
Risk	-	-	0.90	2.40	3.90	2.20	5.39	5.99

Note: Columns correspond to different intervention types: Baseline – no intervention, Public QE – CB intervenes via long-term debt purchases, Private QE – CB intervenes via non-financial firm equity. Stress frequency measured as ratio of number of periods when leverage constraint is binding to sample length. Δ from Baseline - increase in stress frequency under QE policies. Recapitalisation: contribution of QE to stress due to distortion in bank recapitalisation. Risk: contribution of QE to stress related to higher risk-taking by banks. Asterisk denotes simulation where risk of hitting the constraint is not approximated; agents put zero weight on the probability of leverage constraint becoming binding at any point. All values in percentage points.

stress episode, it implies lower excess returns of the banking sector. This effect is more pronounced under private QE. As a private QE operation effectively swaps banks' private non-financial firm equity, that pays an elevated rate of return during a financial stress episode, for a safe asset, that pays a relatively lower yield, this leads to lower excess returns than under public QE, where private assets remain on the banks' balance sheets.

Below, I decompose the relative increase in frequency of financial stress under QE into risk and recapitalisation channels.

Risk and recapitalisation channels I decompose the contribution of QE to relative frequency of financial stress into the risk and recapitalisation channels. Since the simulations are conducted conditional upon the same sequence of exogenous disturbances, one can infer the contribution of each channel relative to no-intervention Baseline as follows.

If a given financial stress episode happens only under QE but not under baseline, it is induced by the risk channel. In other words, if a financial stress episode only happens under QE and, conditional on the same sequence of shocks, does not happen without an intervention, it is caused by the change in banks' precautionary behaviour.

On the contrary, if a financial stress episode happens both under QE and baseline but lasts longer under QE, the difference in its duration is attributed to the recapitalisation channel. Right panels of Figure 5 presents the results of the decomposition of the change in stress frequency under public (top) and private (bottom) QE policies.

Under public QE, risk channel dominates for all calibrations of ϕ^{B}_{QE}. This is due to the fact that as elasticity of central bank asset purchases grows, it leads to uniformly better stabilisation of bank net-worth which reduces banks' precautionary motive. It is costly for the banks to hit their leverage constraints. The stronger intervention the banks expect (and thus smaller reduction in net-worth), the more they are reluctant to exhibit precautionary behaviour.

Under private QE, however, bigger interventions lead only to marginally better net-worth stabilisation; very aggressive private QE, $\phi^{K}_{QE} > 50$, does not lead to significantly better stabilisation of bank net-worth and, thus, only marginally reduces bank precautionary motive. Thus, as private QE interventions become more aggressive and, as a consequence, lead to larger distortions in intermediation, the recapitalisation channel dominates.

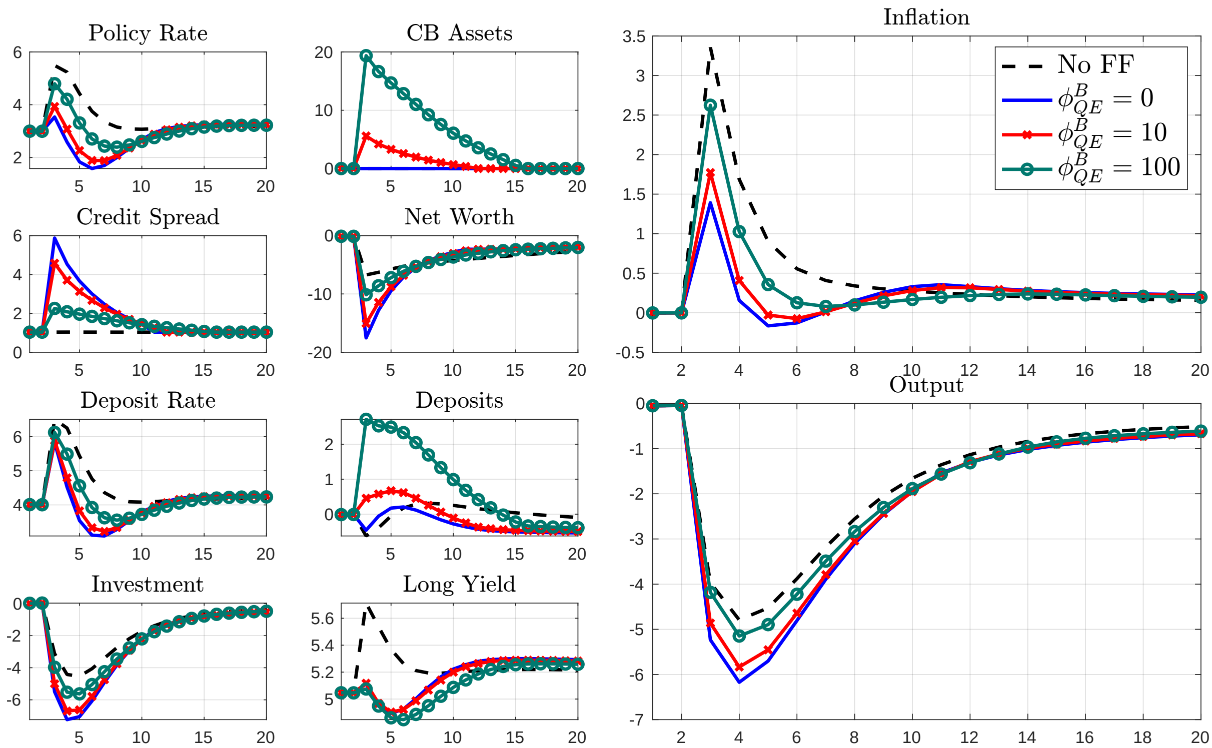
The difference in the magnitude of the recapitalisation channel under private and public QE lies in the way these interventions affect banks' excess return over a financial stress episode. Since a private QE intervention effectively swaps high-yield private assets on the balance sheet of banks for relatively low-yield safe assets, it severely reduces the ability of banks to recapitalise. Thus, as the elasticity of private QE intervention increases, the relative contribution of recapitalisation channel also increases.

Under public QE, excess returns of banks are higher than under private QE, all else equal, for two distinct reasons. First, under public QE high-yield private assets remain on the balance sheets of the commercial banks. Second, public QE reduces long-term yields which creates an incentive for households to shift their portfolio towards bank deposits, which in turn decreases deposit rates. This explains why the relative importance of the recapitalisation channel increases in the elasticity of private QE and slightly diminishes in the elasticity of public QE.

4.2 QE in a Tightening Cycle

To study the implications of QE in a tightening cycle, I make the model economy subject to a markup shock which drives up inflation, central bank policy rate, and triggers a

Figure 6: Does QE increase inflation in tightening cycle?



Note: 7% markup shock materialises in period 3. All variables are in deviations from stochastic steady state except inflation, interest rates, deposit rate, long yield, and credit spread, which are annualised rates. Dashed black line – no financial friction. Solid blue line – no intervention. Solid red line – public QE, $\phi^B_{QE} = 10$. Solid green line – public QE, $\phi^B_{QE} = 100$.

financial stress episode. I consider the implications of a public QE intervention on financial and price stability.

Figure 6 plots the simulated paths of selected variables under different calibration of the public QE rule conditional on a markup shock materialising in period 3. In response to the financial stress episode, the central bank either keeps its balance sheet constant ($\phi^B_{QE} = 0$, solid blue line) or expands its balance sheet via acquisition of public long-term debt ($\phi^B_{QE} = 10$ - solid red line, $\phi^B_{QE} = 100$ - solid green line). I also plot the counterfactual simulation of the same model without the financial friction (dashed black line).

First, consider the response of the economy to the shock when financial frictions are not present (black dashed line). Markup shock increases inflation, which prompts the monetary authority to start a tightening cycle. On impact, the markup shock leads to an increase in inflation of almost 3.5% and a drop in output and investment of around 4.5%. When financial frictions are present and the central bank does not trigger QE (blue line), markup shock leads to a less pronounced increase in inflation. As the markup shock brings the banks to their leverage constraint, financial intermediation becomes frictional and financial stress episode emerges. Banks start a round of fire sales of non-financial firm equity holding, which leads to a pronounced decline in investment and output, and a spike in credit spreads. The financial friction prevents inflation propagation as resulting decline in investment leads to a reduction in labour income of households and depressed aggregate demand. This explains why inflation is lower when financial frictions are present.

Second, if the central bank triggers QE in response to a financial stress episode (red and green solid lines), it leads to a less substantial decline in investment and output than under no balance sheet intervention. QE injects safe assets into the financial system which alleviates the leverage constraint of the banks. Furthermore, QE depresses the yield of long-term government debt which incentivises the households to shift their portfolio towards bank deposits and prevents the outflow of deposits from banks when they become constrained. As QE reinforces financial stability, the credit crunch becomes less severe.

As QE relaxes the financial friction and makes the decline in output less severe, the central bank gains more space for policy rate tightening. Even though the policy rate is higher under QE, inflation is higher. This is explained by the fact that the leverage constraint of the banks acts as a sudden stop that prevents inflation propagation which is a natural mechanism of monetary transmission; as banks hit their constraints, investment plummets, which leads to depressed labour demand and consumption. As demand is lower, inflation is lower as well. If QE stabilises the financial sector, the effects of financial frictions become less pronounced and, thus, inflation is higher under QE.

Under QE, the financial stress episode lasts longer because total excess returns of the banks are compressed. First, banks pay higher deposit rate on a broader deposit base under QE as the policy rate is higher. Second, credit spread is compressed under QE, which leads to a reduction in excess return of equity holdings. Third, banks hold more central bank reserves on their balance sheet which pays a lower yield that firm equity. These three factors explain lower excess returns during a financial stress episode if QE is triggered. Lower excess returns prevent banks from recapitalising as quickly as they otherwise would under no intervention, which leads to longer financial stress.

5 Optimal Monetary Policy

This section analyses optimal interest rate and QE policy mix. The central bank faces a non-trivial trade-off between price and financial stability; as shown previously, the commitment to QE in times of financial stress leads to more frequent and longer financial stress. Furthermore, QE during financial stress triggered by a tightening cycle compromises price stability.

Should the central bank allow more inflation by implementing a less aggressive interest rate policy to reduce incidence of financial stress? To what extent should the central bank commit to expanding its balance sheet in times of financial stress? How should the two monetary policy tools be used to ensure price and financial stability? These questions are addressed in this section.

First, I show that the monetary authority is able to reduce incidence of financial stress by attaching a higher weight to output gap stabilisation in its policy rate rule. Second, I analyse the optimal mix of interest rate and balance sheet policies.

Interest rate policy and stress incidence In the model, the banks are subject to interest rate risk; rapid increases in the real interest rate induced by aggressive monetary tightening lead to capital decumulation, decrease in price of capital, and contraction of financial sector net-worth leading to the leverage constraint becoming binding. To avoid rapid increases in the real rate and to decrease financial stress frequency, the central bank can react less aggressively to inflation by attaching more weight to the output gap stabilisation. To illustrate this, the model is simulated under different values of the central bank output gap feedback coefficient ϕ_y in Equation (14). The results are presented in Table 4.

By tolerating more inflation, the central bank is able to decrease the financial stress

Table 4: Conventional policy, financial stress incidence, and household welfare.

Output gap parameter (ϕ_y)	**Stress frequency (%)**	**Credit gap**	**Output loss**	**Inflation std. (%)**	**Welfare loss**
0.075	11.6	1.01	0.81	1.12	0.37
0.100	8.8	0.92	0.73	1.36	0.36
0.200	9.1	1.16	0.99	2.56	0.68
0.300	7.5	1.69	1.52	3.86	1.20
0.500	6.9	2.90	2.73	6.77	2.37

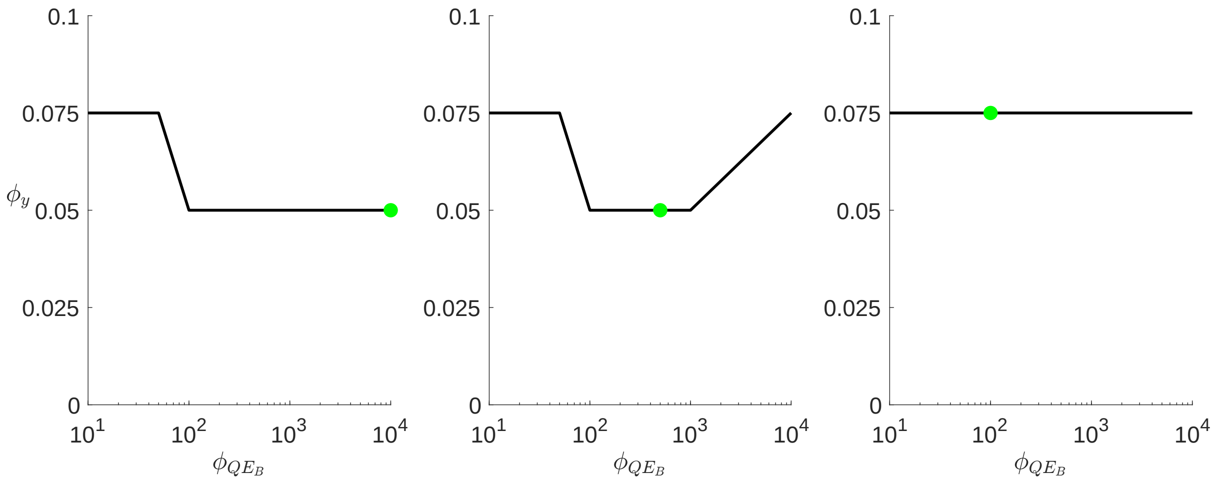
Note: Stress frequency – ratio of number of periods where bank leverage constraints are binding to sample length. Credit gap (output loss) – percent decline in non-financial firm equity (output) relative to baseline economy with no financial frictions. Welfare loss – change in household welfare relative to baseline economy without financial frictions.

frequency; as the weight of the output gap coefficient in the policy rule ϕ_y increases, the stress frequency decreases while the inflation standard deviation increases. Attaching more weight to output gap stabilisation, however, adversely impacts the credit gap and increases welfare loss; higher inflation deviations create dead-weight loss due to costly inflation adjustments.

As the central bank attaches more weight to output gap stabilisation in its policy rule, adverse supply shocks lead to relatively smaller changes in the real interest rate. This leads to lower volatility in the investment, the price of capital, and, thus, in the net-worth and leverage of financial intermediaries. As leverage is less volatile, the constraint becomes less likely to become binding and financial stress episodes happen less often.

Optimal policy mix The purpose of QE in the model is stabilisation of the financial sector in times of financial stress. When financial stress occurs, the central bank can intervene via a balance sheet expansion to close the credit gap and stabilise asset prices. If QE interventions do not bear any efficiency costs, the central bank can commit to fully stabilise the credit gap that arises due to the financial stress. In the extreme case, the central bank can, in principle, fully undertake financial intermediation without creating any welfare loss. This is intuitive as, unlike the private financial intermediaries, the central bank is not subject to the moral hazard problem and the balance sheet expansions are financed via non-distortionary taxes.

Figure 7: Optimal monetary policy mix



Note: Black solid line shows welfare-optimal correspondence between elasticity of QE, ϕ_{QE}^{B}, and the output gap feedback coefficient ϕ_y in the Taylor rule. The green solid dot shows the jointly-optimal parameter combination. Figure shows optimal policy combinations for efficient QE ($\varkappa = 0$, left panel), and for costly QE with $\varkappa = 0.005$ (center), and $\varkappa = 0.01$ (right). The horizontal axis is logarithmic.

Replacing private financial intermediation with central bank intermediation is, however, undesirable for reasons beyond the scope of this paper. It is, thus, reasonable to assume that QE is costly due to some unmodelled efficiency or political costs such that it is suboptimal for the central bank to undertake substantial financial intermediation. The optimal mix of conventional and QE policy will depend upon to what extent a balance sheet intervention is costly as given by $\varkappa$ in Equation (16).

To analyse the optimal policy mix, I simulate the model under different values of policy rate feedback coefficient, ϕ_y, the elasticity of QE, ϕ_{QE}, and the cost of QE, $\varkappa$. For different elasticities of QE, Figure 7 shows the corresponding optimal values of output gap feedback coefficient (solid black line) and the welfare-maximising parameter combination.

Under costless QE (Figure 7, left panel), if the central bank sets QE elasticity low, it is optimal to lean towards higher output gap feedback. As the elasticity of QE increases, it becomes optimal to attach less weight to output gap stabilisation. Optimal policy under costless QE implies that the central bank reacts aggressively to inflation and resorts to very reactive QE that fully stabilises the credit gap that arises due to financial stress via balance sheet expansions. Very reactive QE allows the central bank to avoid the welfare losses associated with the financial constraints of the financial intermediaries.

Similarly, under moderate efficiency costs of QE (Figure 7, central panel), it is optimal to attach higher weight to output gap stabilisation if the balance sheet policy is not very reactive to decrease incidence of financial stress. For very reactive QE ($\phi^B_{QE} = 10^4$), aggressive reaction to inflation is not desirable; it is optimal for the central bank to lean towards a less aggressive interest rate policy to decrease frequency of financial stress. Optimal policy mix consists in moderate QE and aggressive inflation stabilisation.

As QE efficiency costs rise further (Figure 7, right panel), the optimal policy mix consists in less aggressive conventional monetary policy. It is no longer optimal to aggressively pursue inflation stabilisation regardless of the elasticity of QE; the central bank needs to lean towards stabilising the output gap with the optimal balance sheet expansions becoming even more limited.

Taken together, these findings show that the optimal policy mix crucially depends on the efficiency costs of QE. If QE is costless, the central bank can optimally use the interest rate policy to ensure price stability, while its balance sheet is used to quench financial instability. As QE efficiency costs rise, optimal policy mix shifts towards less aggressive financial stabilisation via balance sheet expansions and more moderate reaction to inflation which allows to decrease financial stress frequency.

6 Conclusion

This paper has analysed the implications of central bank balance sheet policies on financial and price stability through the lens of an empirically relevant general equilibrium model.

First, QE interventions used as a financial stability tool lead to more frequent and longer lasting financial stress episodes. This result is driven by two distinct channels. One, banks exhibit weaker precautionary behaviour in normal times if central bank resorts to QE in times of financial stress. As financial stress is milder under QE, banks are willing to take on more risk if they expect the central bank to intervene if intermediation is disrupted. Two, if the central bank deploys a balance sheet expansion in a financial stress episode, it has adverse effects on commercial banks' ability to recapitalise. Balance sheet expansions suppress banks' excess returns over the course of a financial stress episode which does not allow them to recapitalise as quickly as they otherwise would in the no-intervention case. This explains why financial stress episodes last longer.

Second, if a financial stress episode is triggered by inflationary pressures and subsequent interest rate hikes, QE has a benign impact on economic activity at a cost to price stability. Thus, balance sheet interventions are unable to resolve the fundamental trade-off between price and financial stability in a tightening cycle.

Third, reactive balance sheet expansions and aggressive interest rate response to inflation are optimal if QE is efficient. If QE bears efficiency costs, the monetary authority should pursue less aggressive interest rate policy, which decreases likelihood of financial stress, and commit to limited QE interventions.

References

Airaudo, Florencia. 2023. "Exit Strategies from Quantitative Easing: The role of the fiscal-monetary policy mix." *ECB working paper.*

Akinci, Ozge, Gianluca Benigno, Marco Del Negro, and Albert Queralto. 2023. "The Financial (In)Stability Real Interest Rate, r**."

Akinci, Ozge, and Albert Queralto. 2022. "Credit Spreads, Financial Crises, and Macroprudential Policy." *American Economic Journal: Macroeconomics* 14 (2): 469–507.

Benigno, Gianluca, and Pierpaolo Benigno. 2022. "Managing monetary policy normalization." *Federal Reserve Bank of New York Staff Report.*

Bianchi, Francesco, Renato Faccini, and Leonardo Melosi. 2022. *A Fiscal Theory of Trend Inflation.* NBER Working Paper Series. NBER.

Bianchi, Javier. 2010. "Credit Externalities: Macroeconomic Effects and Policy Implications." *American Economic Review* 100, no. 2 (May): 398–402. ISSN: 0002-8282. https://doi.org/10.1257/aer.100.2.398. http://dx.doi.org/10.1257/aer.100.2.398.

Calvo, Guillermo A. 1983. "Staggered Prices in a Utility-Maximising Framework." *Journal of Monetary Economics* 12 (3): 383–398.

Chen, Han, Vasco Cúrdia, and Andrea Ferrero. 2012. "The Macroeconomic Effects of Large-Scale Asset Purchase Programmes." *The Economic Journal* 122 (564): 289–315.

Christiano, Lawrence J., Martin S. Eichenbaum, and Charles L. Evans. 2005. "Nominal Rigidities and the Dynamic Effects of a Shock to Monetary Policy." *Journal of Political Economy* 113 (1): 1–45.

Cúrdia, Vasco, and Michael Woodford. 2011. "The Central-Bank Balance Sheet as an Instrument of Monetary Policy." *Journal of Monetary Economics* 58 (1): 54–79.

Del Negro, Marco, Gauti B. Eggertsson, Andrea Ferrero, and Nobuhiro Kiyotaki. 2017. "The Great Escape? A Quantitative Evaluation of the Fed's Liquidity Facilities." *American Economic Review* 107 (3): 824–857.

Gertler, Mark, and Peter Karadi. 2011. "A Model of Unconventional Monetary Policy." *Journal of Monetary Economics* 58 (1): 17–34.

Gertler, Mark, and Nobuhiro Kiyotaki. 2010. "Financial Intermediation and Credit Policy in Business Cycle Analysis." *Handbook of Monetary Economics* 3:547–599.

Greenwood, Jeremy, Zvi Hercowitz, and Gregory Huffman. 1988. "Investment, Capacity Utilization, and the Real Business Cycle." *American Economic Review* 78 (3): 402–417.

Guerrieri, Luca, and Matteo Iacoviello. 2015. "OccBin: A Toolkit for Solving Dynamic Models with Occasionally Binding Constraints Easily." *Journal of Monetary Economics* 70 (C): 22–38.

Haas, Alexander. 2023. "Monetary Policy in a Tightening Cycle Raising nominal rates without causing a financial crisis." *Working paper.*

Harrison, Richard. 2017. *Optimal Quantitative Easing.* Staff Working Paper 678. Bank of England.

Holden, Tom D. 2023. "Existence and Uniqueness of Solutions to Dynamic Models with Occasionally Binding Constraints." *Review of Economics and Statistics* 105, no. 6 (November): 1481–1499. ISSN: 1530-9142. https://doi.org/10.1162/rest_a_01122. http://dx.doi.org/10.1162/rest_a_01122.

Karadi, Peter, and Anton Nakov. 2021. "Effectiveness and addictiveness of quantitative easing." *Journal of Monetary Economics* 117 (January): 1096–1117. ISSN: 0304-3932. https://doi.org/10.1016/j.jmoneco.2020.09.002. http://dx.doi.org/10.1016/j.jmoneco.2020.09.002.

Mendoza, Enrique G. 2010. "Sudden Stops, Financial Crises, and Leverage." *American Economic Review* 100 (5): 1941–1966.

Wallace, Neil. 1981. "A Modigliani-Miller Theorem for Open-Market Operations." *American Economic Review* 71 (3): 267–274.

A Equilibrium conditions

Households Household optimisation implies the conditions for labour supply

$$w_t = \chi L_t^{\nu} \tag{A1}$$

Euler equation for long-term debt

$$\mathbb{E}_t \Lambda_{t,t+1} \left(\frac{R_{L,t+1}}{\pi_{t+1}} \right) = 1 + \xi_{L,t} \tag{A2}$$

Euler equation for deposits

$$\mathbb{E}_t \Lambda_{t,t+1} \left(\frac{R_t^d}{\pi_{t+1}} \right) = 1 \tag{A3}$$

where $\Lambda_{t,t+s}$ is households stochastic discount factor given by

$$\Lambda_{t,t+s} = \beta^s \mathbb{E}_t \left\{ \frac{U_{C_{t+s}}}{U_{C_t}} \right\}$$

Capital goods producers Law of motion for capital

$$K_t = I_t + (1 - \delta) K_{t-1}, \tag{A4}$$

Price of equity

$$Q_t = 1 + \frac{\kappa_I}{2} \left(\frac{I_t}{I_{t-1}} - 1 \right)^2 + \kappa_I \left(\frac{I_t}{I_{t-1}} - 1 \right) \frac{I_t}{I_{t-1}} - \kappa_I \mathbb{E}_t \Lambda_{t,t+1} \left(\frac{I_{t+1}}{I_t} - 1 \right) \frac{I_{t+1}^2}{I_t^2} \tag{A5}$$

Intermediate goods producers Producer optimisation implies the following conditions for capital-labour ratio, capital demand, and output

$$Y_t = \frac{A_t K_{t-1}^{\alpha} L_t^{1-\alpha}}{\vartheta_t} \tag{A6}$$

$$mc_t = \frac{1}{A_t} \left(\frac{z_t^k}{\alpha} \right)^{\alpha} \left(\frac{w_t}{1 - \alpha} \right)^{1-\alpha} \tag{A7}$$

$$\frac{1 - \alpha}{\alpha} = \frac{w_t L_t}{z_t^k K_{t-1}}. \tag{A8}$$

Inflation determination As indicated in the main text, proportion θ of firms cannot adjust their prices and a complimentary proportion $1 - \theta$ can do so, hence inflation is given by

$$\pi_t^{1-\epsilon} = (1 - \theta)(\pi_t^*)^{1-\epsilon} + \theta, \tag{A9}$$

where π_t^* is growth rate of optimal price given by

$$\pi_t^* = M_t \frac{X_{1,t}}{X_{2,t}}$$

$$X_{1,t} = U_{C_t} mc_t Y_t + \beta \theta \pi_{t+1}^{\epsilon} X_{1,t+1}$$

$$X_{2,t} = U_{C_t} Y_t + \beta\theta\pi_{t+1}^{\epsilon-1} X_{2,t+1}$$

Price dispersion is given by

$$\vartheta_t = (1-\theta)\left(\frac{\pi_t}{\pi_t^*}\right)^{\epsilon_t} + \theta\pi_t^{\epsilon_t}\vartheta_{t-1}$$

Banks I use the following auxiliary definitions for banker SDF, discounted equity spread, discounted safe asset spread, and discounted real deposit rate:

$$\Omega_{t,t+1} = \mathbb{E}_t\Lambda_{t,t+1}(1-\sigma_b+\sigma_b\psi_{t+1}) \tag{A10}$$

$$\mu_t^K = \mathbb{E}_t\Omega_{t,t+1}\left(R_{t+1}^k - \frac{R_t}{\pi_{t+1}}\right) \tag{A11}$$

$$\mu_t^B = \mathbb{E}_t\Omega_{t,t+1}\left(\frac{R_t}{\pi_{t+1}} - \frac{R_t^d}{\pi_{t+1}}\right) \tag{A12}$$

$$\upsilon_t = \mathbb{E}_t\Omega_{t,t+1}\frac{R_t^d}{\pi_{t+1}} \tag{A13}$$

Safe asset to portfolio ratio

$$x_t = \frac{B_{S,t}^I}{Q_t K_t^I + B_{S,t}^I} \tag{A14}$$

Franchise value to net-worth

$$\psi_t = \upsilon_t + \bar{\mu}_t\phi_t \tag{A15}$$

Maximum leverage ratio

$$\bar{\phi}_t = \frac{\upsilon_t}{\theta(1-\frac{\lambda}{\kappa}x_t^\kappa) - \bar{\mu}_t} \tag{A16}$$

Total excess returns

$$\bar{\mu}_t = (\mu_t^K + \mu_t^B)(1-x_t) + (\mu_t^B + \zeta_t^B)x_t \tag{A17}$$

Realised leverage

$$\phi_t = \frac{Q_t K_t^I + B_{S,t}^I}{N_t} \tag{A18}$$

Banker optimality condition

$$\mu_t^K = \zeta_t^b + \bar{\mu}_t\frac{\lambda x_t^{\kappa-1}}{(1-\frac{\lambda}{\kappa}x_t^\kappa)} \tag{A19}$$

Net-worth evolution

$$\begin{aligned} N_t = \sigma_b & \left[\left(R_t^k - \frac{R_{t-1}^d}{\pi_t}\right)Q_{t-1}K_{t-1}^I + \frac{(R_{t-1}-R_{t-1}^d)}{\pi_t}B_{S,t-1}^I + \frac{R_{t-1}^d}{\pi_t}N_{t-1}\right] \\ & + (1-\sigma_b)\gamma Q_{t-1}K_{t-1}^I \end{aligned} \tag{A20}$$

Regime determination equation

$$\bar{\mu}_t(\bar{\phi}_t - \phi_t) = 0 \tag{A21}$$

Return on equity

$$R_t^k = \frac{z_t^k + (1-\delta)Q_t}{Q_{t-1}} \tag{A22}$$

Central Bank Conventional monetary policy is governed by a Taylor rule

$$\frac{R_t}{R} = \left(\frac{R_{t-1}}{R}\right)^{\rho_R} \left(\pi_t^{\phi_\pi} X_t^{\phi_y}\right)^{1-\rho_R} \exp \varepsilon_t^R \tag{A23}$$

Long-term debt purchases

$$\frac{B_{L,t}^{cb}}{B^{L,cb}} = \left(\frac{S_t}{S}\right)^{\phi_{QE}^B(1-\rho_{QE})} \left(\frac{B_{L,t-1}^{cb}}{B^{L,cb}}\right)^{\rho_{QE}} \tag{A24}$$

Non-financial firm equity purchases

$$\frac{K_t^{cb}}{K^{cb}} = \left(\frac{S_t}{S}\right)^{\phi_{QE}^K(1-\rho_{QE})} \left(\frac{K_{t-1}^{cb}}{K^{cb}}\right)^{\rho_{QE}} \tag{A25}$$

Reserves provision is given by the following revenue neutrality condition

$$Q_t K_t^{cb} + B_{L,t}^{cb} + B_{S,t}^{cb} = 0 \tag{A26}$$

Treasury Consolidated budget constraint

$$\tau_t + R_t^k Q_{t-1} K_{t-1}^{cb} + B_{L,t}^H + B_{S,t}^I = \frac{R_{t-1}}{\pi_t} B_{S,t-1}^I + \frac{R_{L,t}}{\pi_t} B_{L,t-1}^H + Q_t K_t^{cb} + \mathcal{C}_t, \tag{A27}$$

where

$$\mathcal{C}_t = \varrho \left\{ \left(\frac{B_{L,t}^{cb}}{B_L^{cb}}\right)^2 + \left(\frac{Q_t K_t^{cb}}{K^{cb}}\right)^2 \right\}$$

Constant maturity structure condition

$$\bar{B}_S = \varrho \bar{B}_L \tag{A28}$$

Short-term debt issuance

$$B_{S,t} = \bar{B}_S \tag{A29}$$

Market clearing and equilibrium Resource constraint is given by

$$Y_t = C_t + I_t \left(1 + \frac{\kappa_I}{2}\left(\frac{I_t}{I_{t-1}} - 1\right)^2\right) + \mathcal{C}_t \tag{A30}$$

Short-term bond markets clear

$$\bar{B}_S = B_{S,t}^{cb} + B_{S,t}^I \tag{A31}$$

Long-term bond markets clear

$$\bar{B}_L = B_{L,t}^{cb} + B_{L,t}^H \tag{A32}$$

Firm equity markets clear

$$K_t = K_t^{cb} + K_t^I \tag{A33}$$

Exogenous processes Total Factor Productivity

$$A_t = 1 - \rho^A + \rho^A A_{t-1} + \varepsilon_t^A \tag{A34}$$

Markup shock

$$M_t = \bar{M}(1 - \rho^M) + \rho^M M_{t-1} + \varepsilon_t^M \tag{A35}$$

Banker's safe asset preference

$$\xi_t^b = \bar{\xi}^b(1 - \rho^b) + \rho^b \xi_{t-1}^b + \varepsilon_t^b \tag{A36}$$

B Unconstrained static equilibrium

Wider economy. I drop time sub-indices for variables in steady state. In a non-inflationary steady state $\pi = 1$, $R^d = 1/\beta$. Cost of capital is equal to unity, $Q = 1$. Since the leverage constraint is not binding, $R^k = R^d = 1/\beta$, and $R = (R^k - \xi^b)/\beta$. It follows that

$$z^k = R^K - 1 + \delta \tag{B1}$$

Marginal cost is equal to inverse of markup, $\mathcal{M} = \frac{\epsilon}{\epsilon-1} = mc^{-1}$.

The definition of marginal cost implies

$$mc = \left(\frac{z^k}{\alpha}\right)^{\alpha}\left(\frac{w}{1-\alpha}\right)^{1-\alpha} \implies w = (1-\alpha)\left[\frac{\alpha mc^{\frac{1}{\alpha}}}{z_k}\right]^{\frac{\alpha}{1-\alpha}}. \tag{B2}$$

Using the condition for labour supply yields labour

$$L = \left(\frac{w}{\chi}\right)^{\frac{1}{\nu}} \tag{B3}$$

Output is then given by

$$Y = \frac{wL}{(1-\alpha)mc} \tag{B4}$$

Capital is given by

$$K = \frac{\alpha mcY}{z^k} \tag{B5}$$

Investment is given by

$$I = \delta K \tag{B6}$$

It is straightforward to solve for consumption given market clearing.

Government Steady-state values of B_S and B_L^{cb} are calibrated.

$$B_S^{cb} = -B_L^{cb} \tag{B7}$$

Safe assets and central bank reserves are given by

$$B_S^I = B_S - B_S^{cb} \tag{B8}$$

Long-term government debt

$$B_L = \varrho^{-1} B_S \tag{B9}$$

Private holdings of long-term debt

$$B_L^H = B_L - B_L^{cb} \tag{B10}$$

Consolidated government budget constraint yields

$$\tau = (R_L - 1)B_L^H + (R-1)B_S^I \tag{B11}$$

Financial sector Bank reserves and short-term assets B^I is determined residually. Thus, safe asset ratio is given by

$$x = \frac{B^I}{K^I + B^I} \tag{B12}$$

From evolution of net-worth

$$N = \left(\frac{(1 - \sigma_b)\gamma K^I - \xi^b \sigma_b B_S^I}{1 - \sigma_b R^d} \right) \tag{B13}$$

Leverage is given by

$$\phi = \frac{K^I + B_S^I}{N} \tag{B14}$$

and deposits are determined residually via balance sheet

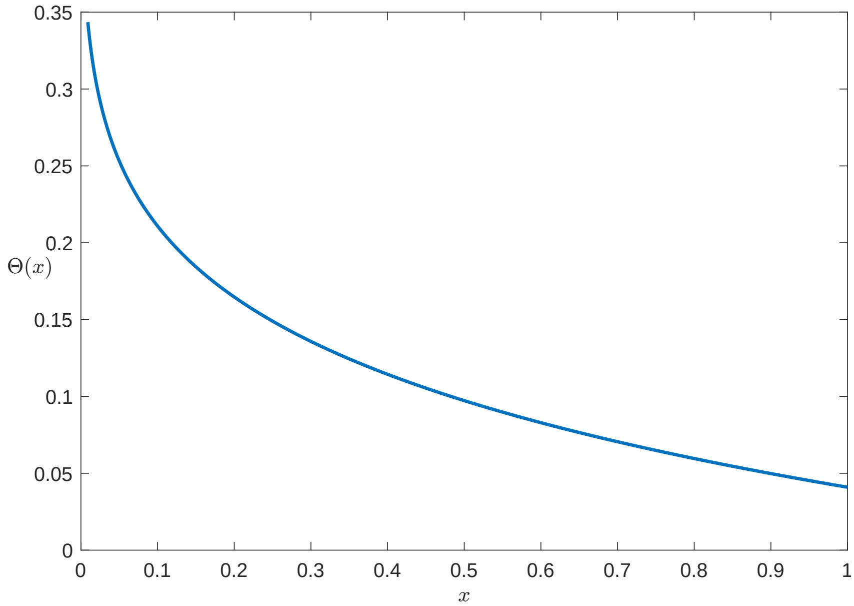
$$D = K^I + B_S^I - N \tag{B15}$$

Steady state expressions for other bank variables immediately follow. This completes the steady state solution.

C Functional form of divertible asset proportion

Functional form of $\Theta(x_t)$ is crucial for analysis of financial stress episodes as it governs the severity of the ICC in Equation (11). $\Theta(x_t)$ is assumed to be decreasing and convex in safe asset ratio x_t. These assumptions imply that if the banker's portfolio consists mostly of safe assets, the proportion of divertible funds is low and, by implication, the ICC is less severe. If the proportion of safe assets in portfolio, x_t, is high, however, increasing it further does not render the constraint a lot less severe.

Figure 8: Functional form of $\Theta(x)$



Note: Functional form of $\Theta(x_t)$. Horizontal axis shows values of safe asset proportion in bankers' portfolio. Vertical axis shows the proportion of divertible funds.