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Large-Scale Asset Purchase Exit and Shadow Banking

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Abstract

I analyze the interaction between shadow banks and Large-Scale Asset Purchase (LSAP) exit strategies using a Markov-switching DSGE model calibrated to the Euro area. I introduce an actively traded long-term government bond market and an endogenous exit probability based on the inflation gap. Shadow banks amplify the economic contraction from a fast exit. Forward guidance about exit timing reduces investment during recovery if agents anticipate a fast exit and has heterogeneous effects across retail and shadow banks in the long run. Non-financial loan purchases yield the strongest stabilization during a crisis but generate the largest exit distortions and displacement of private lending. Government bond purchases cause shadow banks to rebalance towards private lending by reducing the effective supply of pledgeable collateral.

Keywords: DSGE, shadow banking, large-scale asset purchases, exit strategy, markov switching, forward guidance

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AI disclosure statement

I have nothing to disclose.

1 Introduction

I analyze the interaction between shadow banks and Large-Scale Asset Purchase (LSAP) exit strategies using a Markov-switching DSGE model calibrated to the Euro area. Shadow banks are financial intermediaries such as hedge funds, money market funds, and structured investment vehicles that conduct bank-like activities but operate without deposit insurance or access to central bank liquidity facilities. The ability of shadow banks to perform liquidity and maturity transformation without the regulatory requirements of traditional retail banks contributed to excessive leverage and systemic risk prior to the 2007-2009 financial crisis.

Unconventional monetary policy (UMP) such as LSAPs has become a standard set of instruments of central banks when policy rates are at or near the zero lower bound (ZLB). Unlike changing the policy rate, LSAPs work by directly changing the prices and effective supply of assets on intermediary balance sheets. Shadow banks' stricter funding constraints and higher leverage compared to traditional retail banks make them more sensitive to asset price fluctuations caused by LSAP exit.

I develop a model with a New Keynesian real sector and a financial sector consisting of retail banks and shadow banks. I extend this framework to feature an actively traded long-term government bond market. These bonds are more *pledgeable* (easier to use as collateral) than private loans, enabling the study of effects on shadow banks' portfolio choices. In the model, an LSAP exit is a regime switch after which the central bank reduces its asset holdings. An LSAP exit strategy consists of (1) the timing of this switch, determined by an exit probability, and (2) the speed of the reduction, which depends on parameters in the UMP rules. I endogenize the exit probability to depend on the inflation gap to capture forward guidance about exit timing. This allows me to study how information about future exit timing affects outcomes before the exit actually happens.

The calibration targets the Euro area financial system. I match the shadow banking sector's size (30% of assets) to the holdings of Money-Market Funds and Other Financial Institutions (European Systemic Risk Board, 2025, Annex III). I set leverage ratios (4 vs 8) to capture structural differences between bank types and I choose asset market parameters to match Euro area spreads. Fiscal and monetary rules target the debt-to-GDP ratio and the peak magnitude of the ECB's Public Sector Purchase Programme (PSPP). The structural mapping ensures that simulations of financial crises reflect the fragility of the Euro area financial system. I then conduct multiple experiments to investigate the transmission of LSAP exit across exit strategies that vary in timing (fixed, endogenous) and speed (slow, fast).

I find that shadow banks amplify the feedback loop between falling asset prices and fire sales. Retail banks transmit stress to the shadow sector through higher interbank spreads, causing shadow banks to deleverage aggressively. Conse-

quently, this mechanism deepens the contraction during a fast exit from LSAPs. Second, forward guidance about when the central bank will exit impacts the recovery after a financial crisis if exit speed is fast. As agents internalize that a stronger rebound shortens the expected holding duration, they respond by reducing investment before exit happens. In the long run, faster exit speeds cause retail banks to expand private lending, whereas shadow banks rebalance portfolios toward government bonds. An endogenous exit probability has heterogeneous effects across intermediary types, muting both the precautionary behavior of shadow banks and the expansion of retail bank private lending.

Finally, non-financial loan purchases yield the strongest stabilization effects but generate the largest exit distortions and displacement of private lending, as the central bank crowds out the private sector. The marginal effects of individual policies differ across retail and shadow bank portfolios. The liquidity facility most effectively supports retail bank lending. Government bond purchases, by removing a substantial amount of pledgeable assets in the economy, cause shadow banks to rebalance towards non-financial loans.

2 Literature

This paper models the financial sector in the tradition of Gertler and Kiyotaki (2010) and Gertler and Karadi (2011), where households are limited in their participation in financial markets and extend deposits to a bank that then intermediates credit to the real economy, causing a financial friction. These models are formulated to study the role of banks in intermediating credit and their effects on asset prices, investment, and the real economy. A defining feature of this class of models is the agency problem between bankers and households, which leads to leverage constraints on banks' balance sheets. I explain this friction in detail in subsection 3.3 when describing the financial sector of the model. A key finding in the literature is that bank net worth is a crucial determinant of the level of aggregate investment, and that low intermediary net worth leads to credit crunches and higher expected returns.

The literature has extended this setup to include a shadow banking sector, which serves as the blueprint for the model presented in this paper. Gertler et al. (2016) extend the Gertler-Kiyotaki framework to study the transmission of crises from the shadow banking sector to the real economy. Meeks et al. (2017) explicitly model shadow bank securitization and find that high leverage makes the economy more sensitive to financial shocks. These models include both retail banks that collect deposits from households and shadow banks that fund themselves through wholesale funding markets. A common assumption in the literature is that shadow banks are more efficient than retail banks in their intermediation of credit. The motivation is that shadow banks perform a sort of regulatory arbitrage as they are not subject to the same regulatory requirements as retail banks (Kirchner, 2020; Adrian and Ashcraft, 2012). The model in this paper follows this literature and assumes that shadow banks have a cost advantage in intermediating financial assets, which enables them to earn higher returns than

retail banks on the same underlying assets. Kirchner (2020) reviews the literature on shadow banking and DSGE, and finds that information asymmetries, search for yield, and financial specialization are other motivations for the explicit modeling of shadow banks.

This formulation of the financial sector enables the study of UMP, since these policies can affect the balance sheet constraints of banks. The modeling of UMP in this paper follows the structure presented in Gertler and Karadi (2011) and Kirchner and Schwanebeck (2017) closely, modeling the liquidity facility à la Dedola et al. (2013). The literature shows that UMP can stimulate the economy during financial distress, even away from the ZLB (Gertler and Karadi, 2011). Kirchner and Schwanebeck (2017) demonstrate that shadow banks, while amplifying recessions, also increase the effectiveness of UMP. Generally, these models highlight the sensitivity of intermediary leverage to fluctuations in asset prices, the presence of meaningful contagion given links across the balance sheets of financial intermediaries, and the capacity of LSAPs to relax binding balance sheet constraints. The effects explored in this paper build on these findings.

The model presented in the paper focuses on capturing three channels of UMP identified by Casola (2021): the premium channel, the portfolio balance channel, and the signaling channel. The premium channel refers to the increase in asset prices and the corresponding decrease in yields due to central bank purchases. LSAPs can have contagion effects and impact the portfolio choices of investors, known as the portfolio balance channel. Finally, LSAPs convey information about future monetary policy decisions through the signaling channel, captured in my model by the Markov-switching setup.

LSAP exit has become an important topic of research as central banks have started to unwind their balance sheets. However, the DSGE literature that centers on exit remains sparse. Erceg et al. (2024) study exit in a two-economy model and show that exit can have significant spillover effects through the exchange rate channel. Foerster (2015) studies LSAP exit strategies in a Markov-switching DSGE and shows that expectations about exit strategy influence both initial effects of LSAPs and the pre-crisis economy.

This paper thus inherits the structure of the financial sector and UMP modeling from Gertler et al. (2016), Kirchner and Schwanebeck (2017), Meeks et al. (2017), and extends it to include the Markov-switching structure of Foerster (2015) to study exit strategies. I introduce an actively traded long-term government bond market following Bocola (2016). Finally, I extend the Markov-switching setup to include an endogenous exit probability, allowing me to study forward guidance about LSAP exit.

3 Model

3.1 Overview

I develop a closed, medium-sized Markov-switching DSGE with households, capital producers, intermediate good producers, final good producers, retail banks, shadow banks, and a consolidated government that conducts fiscal and monetary policy. Time is discrete with an infinite horizon. To ease notation, I often suppress the expectations operator for forward-looking variables and only denote state dependence explicitly for variables directly influenced by Markov-switching processes.

The real sector of the model is a standard New Keynesian setup in the style of Galí (2015) with price stickiness à la Christiano et al. (2005). The financial sector follows Gertler et al. (2016), and the modeling of shadow banks and unconventional monetary policy builds on Gertler and Karadi (2011), Kirchner and Schwanebeck (2017), Meeks et al. (2017), and Foerster (2015).

The baseline Markov-switching setup follows Foerster (2015) closely. The process for capital quality determines whether the economy is in normal or crisis times. Another process governs the unconventional monetary policy rules, deciding whether the central bank intervenes or not. The realization of the process for the unconventional policy rules depends on the realization of the capital quality process, creating four possible regimes. This setup helps capture agents' expectations of future policy responses, which allows modeling of complex and realistic LSAP exit strategies. The model contributes by endogenizing the exit probability to capture the effects of forward guidance.

Beyond the endogenization of the exit probability, I contribute theoretically by introducing an actively traded market for long-term government bonds in a model with both retail and shadow banks. Government bonds are more pledgeable and have higher collateral value than non-financial loans, which relaxes the leverage constraints of both retail and shadow banks and thus facilitates credit expansion. The structure of the long-term government debt market draws from the sovereign debt literature and follows Bocola (2016), while abstracting from sovereign default risk. This creates a market with positive net supply of long-term government bonds actively traded by both types of banks.

3.2 Real sector

This section describes the real sector of the model, consisting of households, capital producers, intermediate good producers, and retailers.

3.2.1 Households

A continuum of identical households of mass one maximize expected lifetime utility. In period t, households consume C_t units of final goods and supply N_t units of labor to intermediate good producers at wage W_t. Households save by depositing funds D_t in retail banks, earning the risk-free rate $R_{f,t}$. They pay

lump-sum taxes T_t to the government. Households solve

$$\max_{C_t, N_t, D_t} \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left[\log(C_t - hC_{t-1}) - \chi \frac{N_t^{1+\phi}}{1+\phi} \right] \tag{1}$$

where $0 < \beta < 1$ is the discount factor, h is the habit formation parameter, χ is the marginal disutility of labor, ϕ is the inverse Frisch elasticity of labor supply and log denotes the natural logarithm. The household is subject to the budget constraint

$$C_t + D_t \leq W_t N_t + R_{f,t} D_{t-1} - T_t + \Pi_t \tag{2}$$

where Π_t are net dividends from all firms, including profits from retailers and capital producers as well as all earnings from the financial sector, described in Section 3.3. Rearranging the household's first order conditions gives the equilibrium conditions

$$U_{C,t} W_t = \chi N_t^{\phi} \tag{3}$$

$$1 = \Lambda_{t,t+1} R_{f,t+1} \tag{4}$$

where

$$U_{C,t} = (C_t - hC_{t-1})^{-1} - \beta h \mathbb{E}_t \left(C_{t+1} - hC_t \right)^{-1} \tag{5}$$

$$\Lambda_{t,t+1} = \beta \frac{\mathbb{E}_t U_{C,t+1}}{U_{C,t}} \tag{6}$$

3.2.2 Intermediate Good Producers

Competitive intermediate good producers hire labor N_t^d from households and purchase capital K_t from capital producers in order to produce intermediate goods. Capital purchased in period $t-1$ is used in production in period t. In each period, intermediate good producers sell $Y_{m,t}$ intermediate goods to retailers at price $P_{m,t}$. Their production function is of Cobb-Douglas form:

$$Y_{m,t} = A_t (\psi_t(s_t) K_{t-1})^{\alpha} (N_t^d)^{1-\alpha} \tag{7}$$

where $\alpha \in (0,1)$ is the capital share, A_t is a technology process, and $\psi_t(s_t)$ is the state-dependent capital quality process, discussed in detail in Section 3.4.1. $\log A_t$ follows

$$\log A_t = \rho_A \log A_{t-1} + \sigma_A \varepsilon_{A,t} \quad \varepsilon_{A,t} \sim \mathcal{N}(0,1) \tag{8}$$

The first-order conditions to the intermediate good producer's profit maximization problem gives the equilibrium condition for labor demand:

$$W_t = P_{m,t}(1-\alpha) \frac{Y_{m,t}}{N_t^d} \tag{9}$$

The gross profits an intermediate good producer makes per unit of capital employed is

$$Z_t = P_{m,t} \alpha \frac{Y_{m,t}}{\psi_t(s_t) K_{t-1}} \tag{10}$$

Intermediate good producers finance their purchases of capital through debt issued to banks. The effective resources available to intermediate good producers depend on the price of these claims, $Q_{s,t}$, which reflects banks' willingness to supply credit given their balance sheet constraints. Capital chosen in period t to be used in period $t+1$ is thus directly tied to the value of debt issued at price $Q_{s,t}$, enforcing that:

$$Q_{s,t}K_t = Q_{s,t}S_t \iff K_t = S_t \tag{11}$$

Where S_t denotes the stock of non-financial loans. Capital evolves according to the law of motion

$$K_t = (1-\delta)\psi_t(s_t)K_{t-1} + I_t \tag{12}$$

where δ is the depreciation rate and I_t is aggregate investment, chosen by capital producers.

3.2.3 Capital Producers

Capital producers purchase final goods from retailers and turn them into capital, incurring investment adjustment costs. Capital producers sell the capital to intermediate good producers, returning any profit back to households. Capital producers solve

$$\max_{I_t} \mathbb{E}_0 \sum_{t=0}^{\infty} \Lambda_{0,t} \left(\left[Q_{s,t} - 1 + F\left(\frac{I_t}{I_{t-1}}\right) \right] I_t \right) \tag{13}$$

where $F(\cdot)$ is the investment adjustment cost function, assumed to be convex and quadratic:

$$F\left(\frac{I_t}{I_{t-1}}\right) = \frac{\xi}{2}\left(\frac{I_t}{I_{t-1}} - 1\right)^2 \tag{14}$$

The first-order condition for investment is

$$Q_{s,t} = 1 + F\left(\frac{I_t}{I_{t+1}}\right) + F'\left(\frac{I_t}{I_{t-1}}\right)\left(\frac{I_t}{I_{t-1}}\right) - \mathbb{E}_t \Lambda_{t,t+1} F'\left(\frac{I_{t+1}}{I_t}\right)\left(\frac{I_{t+1}}{I_t}\right)^2 \tag{15}$$

stating that the price of capital must equal the marginal cost of producing capital accounting for investment adjustment costs.

3.2.4 Retailers

Monopolistically competitive retailers aggregate intermediate goods and sell them to households and capital producers. I model nominal rigidity in the style of Christiano et al. (2005). Retailers solve

$$\begin{aligned} &\min_{Y_{i,t}} \int_0^1 P_{i,t} Y_{i,t} di \\ &\text{s.t. } Y_t = \left[\int_0^1 Y_{i,t}^{\frac{\varepsilon-1}{\varepsilon}} di \right]^{\frac{\varepsilon}{\varepsilon-1}} \end{aligned} \tag{16}$$

where Y_t is the CES aggregator. Solving the cost minimization problem gives:

$$Y_{i,t} = \left(\frac{P_{i,t}}{P_t}\right)^{-\varepsilon} Y_t \tag{17}$$

$$P_t = \left[\int_0^1 P_{i,t}^{1-\varepsilon} di\right]^{\frac{1}{1-\varepsilon}} \tag{18}$$

In each period, a retailer can reoptimize their price with probability (1 - ζ). In case a retailer cannot reoptimize, it indexes its price to last period's inflation and sets $P_{it} = (\pi_{t-1})^{\zeta_p} P_{it-1}$, where π_t denotes inflation and ζ_p is the indexation parameter. Since retailers merely repackage intermediate goods, the marginal cost is the same as the intermediate good producer's price, $P_{m,t}$. Retailers choose the optimal reset price P_t^* to maximize their profits:

$$\max_{P_t^*} \mathbb{E}_t \sum_{j=0}^{\infty} \zeta^j \Lambda_{t,t+j} \left[\frac{P_t^*}{P_{t+j}} \prod_{k=1}^{j} \pi_{t+k-1}^{\zeta_p} - P_{m,t+j}\right] Y_{i,t+j} \tag{19}$$

The FOCs are

$$\mathbb{E}_t \sum_{j=0}^{\infty} \zeta^j \Lambda_{t,t+j} \left[\frac{P_t^*}{P_{t+j}} \prod_{k=1}^{j} \pi_{t+k-1}^{\zeta_p} - \frac{\varepsilon}{\varepsilon - 1} P_{m,t+j}\right] Y_{i,t+j} = 0 \tag{20}$$

with aggregate price index

$$P_t = \left[(1-\zeta)(P_t^*)^{1-\varepsilon} + \zeta(\pi_{t-1}^{\zeta_p} P_{t-1})^{1-\varepsilon}\right]^{\frac{1}{1-\varepsilon}} \tag{21}$$

3.3 Financial sector

The financial sector consists of retail banks and shadow banks, that both conduct financial intermediation. Each household owns a retail bank and a shadow bank, and each bank type is managed by a banker. Bankers are finitely lived, and have a probability σ of surviving each period. Thus, on average, bankers live for $\frac{1}{1-\sigma}$ and each period a fraction $(1-\sigma)$ of bankers exit. $(1-\sigma)$ can also be interpreted as the dividend payout rate of banks. Upon exit, bankers return their net worth to their respective household and leave the banking sector. This mechanism ensures that bankers optimally use leverage in equilibrium and cannot accumulate sufficient net worth to self-finance (Gertler et al., 2016). When a banker exits, a new one enters, receiving start-up funds from its household. The fraction of bankers in the economy thus remains constant over time. Retail banks collect deposits from households, lend to intermediate good producers, and purchase government bonds. Retail banks also extend wholesale funds to shadow banks, which in turn lend to intermediate good producers and purchase government bonds.

Retail bank activities are subject to management costs. The motivation is that retail banks incur these costs in supervising debtors as well as complying with regulation. Each household contracts with its retail bank as follows: the household has a mandate to provide management services for the bank, and thus incurs

the cost when it is realized. In return, they impose fees on the retail bankers proportional to the price. The costs are quadratic and proportional to lending activity:

$$\begin{aligned} F_{s,t}(s_{r,t}) &= \tau_s \frac{(s_{r,t})^2}{2} \\ F_{g,t}(b^g_{r,t}) &= \tau_g \frac{(b^g_{r,t})^2}{2} \end{aligned} \tag{22}$$

where τ_s and τ_g are management cost parameters, and $s_{r,t}$ and $b^g_{r,t}$ denote a retail bank's non-financial loans and government bond holdings, respectively. Households receive

$$\begin{aligned} F'_{s,t}(s_{r,t}) &= f_{s,t}(s_{r,t}) = \tau_s s_{r,t} \\ F'_{g,t}(b^g_{r,t}) &= f_{g,t}(b^g_{r,t}) = \tau_g b^g_{r,t} \end{aligned} \tag{23}$$

per unit managed of the respective asset. This has a few consequences, primarily that it creates a main *raison d'être* for shadow banks. I assume that shadow banks do not incur these management costs, and are thus more efficient financial intermediators. Consequently, they perform a sort of regulatory arbitrage (Kirchner, 2020; Adrian and Ashcraft, 2012). Further, shadow banks are able to earn higher returns on non-financial loans and government bonds than their retail counterparts. The returns on non-financial loans for a retail- and shadow bank, respectively, are thus

$$R_{rs,t+1} = \frac{Z_{t+1} + (1-\delta)\psi_{t+1}(s_{t+1})Q_{s,t+1}}{Q_{s,t} + f_{s,t}(s_{r,t})} \tag{24}$$

$$R_{ws,t+1} = \frac{Z_{t+1} + (1-\delta)\psi_{t+1}(s_{t+1})Q_{s,t+1}}{Q_{s,t}} \tag{25}$$

which both hold simultaneously in equilibrium for a single price $Q_{s,t}$. The main conceptual differences between the two types of banks are thus that shadow banks (1) do not have access to central bank liquidity facilities, and (2) do not incur management costs in providing their financial services.

3.3.1 Retail Banks

Competitive retail banks collect deposits d_t from households on which they pay the risk-free rate $R_{f,t}$. Given that unconventional monetary policy is active, they have access to a liquidity facility at the central bank where they borrow m_t at the rate $R_{m,t}$. On the asset side, they have non-financial loans $s_{r,t}$, wholesale funds $b^w_{r,t}$ lent to shadow banks, and government bonds $b^g_{r,t}$. A retail bank's balance sheet identity is

$$(Q_{s,t} + f_{s,t}(s_{r,t}))s_{r,t} + b^w_{r,t} + (Q_{g,t} + f_{g,t}(b^g_{r,t}))b^g_{r,t} = d_t + m_t + n_{r,t} \tag{26}$$

where $n_{r,t}$ is the retail bank's net worth, $Q_{s,t}$ is the price of non-financial loans, and $Q_{g,t}$ is the price of government bonds. Writing the net worth in terms of returns yields

$$\begin{aligned} n_{r,t} = {} & (Z_t + (1-\delta)\psi_t(s_t)Q_{s,t})s_{r,t-1} + R_{w,t}b^w_{r,t-1} \\ & + (\eta + (1-\eta)Q_{g,t})b^g_{r,t-1} - R_{f,t}d_{t-1} - R_{m,t}m_{t-1} \end{aligned} \tag{27}$$

Which can be combined with the balance sheet identity to get the recursive formulation of net worth

$$\begin{aligned} n_{r,t} = &\left(R_{rs,t} - R_{f,t}\right)\left(Q_{s,t-1} + f_{s,t-1}(s_{r,t-1})\right)s_{r,t-1} \\ &+ \left(R_{w,t} - R_{f,t}\right)b^{w}_{r,t-1} + \left(R_{rg,t} - R_{f,t}\right)\left(Q_{g,t-1} + f_{g,t-1}(b^{g}_{r,t-1})\right)b^{g}_{r,t-1} \\ &+ R_{f,t}n_{r,t-1} - \left(R_{m,t} - R_{f,t}\right)m_{t-1} \end{aligned} \tag{28}$$

Retail bankers maximize the franchise value of the bank, i.e., they maximize the value function

$$V_{r,t} = \mathbb{E}_t \Lambda_{t,t+1}\left[(1-\sigma)n_{r,t+1} + \sigma V_{r,t+1}\right] \tag{29}$$

Since retail banks earn a positive spread on their loans, they would like to expand lending indefinitely. To prevent this, they face a balance sheet constraint that limits their leverage. This mechanism is standard in the literature and comes from the limited participation of households. It gives the banker the option to divert funds, i.e., simply taking a fraction θ_t of its assets for private gain. The other households could then recover a fraction $1-\theta_t$ of the assets and force the banker into bankruptcy. This creates the incentive constraint (IC) that the franchise value of the bank must be equal to or greater than the value of diverted assets, i.e.,

$$V_{r,t} \geq \theta_t\left[(Q_{s,t} + f_{s,t}(s_{r,t}))s_{r,t} + \gamma_t b^{w}_{r,t} + \iota_t(Q_{g,t} + f_{g,t}(b^{g}_{r,t}))b^{g}_{r,t} - \lambda m_t\right] \tag{30}$$

The value of diverting depends on the divertible fraction θ_t as well as the relative divertibility of the different assets. γ_t is the relative divertibility of wholesale funds and ι_t is the relative divertibility of government bonds. λ is the relative divertibility of loans from the liquidity facility, where $\gamma_t \in (0,1)$ and $\iota_t \in (0,1)$.

The relative divertibilities capture that some assets are easier to monitor than others, and thus more difficult for the bank to divert. The lower the relative divertibility, the more difficult it is for the bank to divert that asset, and thus the more pledgeable it is as collateral. This is important because it implies an ordering of how much banks can lever up against different assets, and thus how much changes in the prices of these assets relax or tighten the IC. Both wholesale funds and government bonds are assumed to be less divertible than non-financial loans. Under normal calibration, the IC binds and the bank is always at the maximum leverage possible given asset prices and its net worth.

To solve the retail bank's problem, guess and verify that the value function is linear in assets and net worth:

$$\begin{aligned} V_{r,t} = &\mu_{rs,t}(Q_{s,t} + f_{s,t}(s_{r,t}))s_{r,t} + \mu_{rw,t}b^{w}_{r,t} \\ &+ \mu_{rg,t}(Q_{g,t} + f_{g,t}(b^{g}_{r,t}))b^{g}_{r,t} + \nu_{r,t}n_{r,t} - \mu_{m,t}m_t \end{aligned} \tag{31}$$

where $\mu_{rs,t}$ is the excess return on non-financial loans, $\mu_{rw,t}$ is the excess return on wholesale funds, $\mu_{rg,t}$ is the excess return on government bonds, $\nu_{r,t}$ is the marginal value of net worth, and $\mu_{m,t}$ is the excess cost of borrowing from the

liquidity facility. Maximizing the value function (31) subject to the IC (30) gives the equilibrium conditions

$$\mu_{rs,t} = \frac{1}{\gamma_t}\mu_{rw,t} \tag{32}$$

$$\mu_{rs,t} = \frac{1}{\iota_t}\mu_{rg,t} \tag{33}$$

$$\mu_{rs,t} = \frac{1}{\lambda}\mu_{m,t} \tag{34}$$

Combine the binding IC (30), the value function guess (31), and the equilibrium conditions (32, 33, 34) to formulate the retail bank's leverage ratio:

$$\begin{aligned}\phi_{r,t} &\equiv \frac{(Q_{s,t} + f_{s,t}(s_{r,t}))s_{r,t} + \gamma_t b^w_{r,t} + \iota_t(Q_{g,t} + f_{g,t}(b^g_{r,t}))b^g_{r,t}}{n_{r,t}} \\ &= \frac{\nu_{r,t}}{\theta_t - \mu_{rs,t}} + \frac{\lambda m_t}{n_{r,t}}\end{aligned} \tag{35}$$

Leverage reflects "limited pledgeability", i.e., banks cannot promise all of their assets as collateral to the household. In equilibrium, the leverage ratio is decreasing in θ_t, since a larger divertible fraction disciplines the bank to take on less leverage.

A negative shock to the retail bank's net worth forces the bank to deleverage and reduce its investment, though in my setup the liquidity facility at the central bank partially smooths this effect. Despite this partial smoothing, equation (35) contains one of the main insights of limited participation; the net worth of the bank is a crucial determinant of its investment. When deleveraging occurs and banks cut back on lending, the price of loans $Q_{s,t}$ falls, which in turn reduces the value of its assets, triggering further deleveraging, the standard "financial accelerator".

Combining the recursive value function formulation (29), the guess (31), the IC (30), the equilibrium conditions (32, 33, 34), the leverage ratio (35), and the recursive net worth formulation[1] (27), the value function can be written as

$$\begin{aligned}V_{r,t} = \mathbb{E}_t\Omega_{r,t+1}\Big[&(R_{rs,t+1} - R_{f,t+1})(Q_{s,t} + f_{s,t}(s_{r,t}))s_{r,t} \\ &+ (R_{w,t+1} - R_{f,t+1})b^w_{r,t} \\ &+ (R_{rg,t+1} - R_{f,t+1})(Q_{g,t} + f_{g,t}(b^g_{r,t}))b^g_{r,t} \\ &+ R_{f,t+1}n_{r,t} - (R_{m,t+1} - R_{f,t+1})m_t\Big]\end{aligned} \tag{36}$$

where

$$\Omega_{r,t+1} = \Lambda_{t,t+1}\left(1 - \sigma + \sigma(\nu_{r,t+1} + \mu_{rs,t+1}\phi_{r,t+1})\right) \tag{37}$$

[1] see Appendix A.1 for details.

which verifies the guess if the coefficients are set to

$$\mu_{rs,t} = \mathbb{E}_t \Omega_{r,t+1} \left(R_{rs,t+1} - R_{f,t+1} \right) \tag{38}$$
$$\mu_{rw,t} = \mathbb{E}_t \Omega_{r,t+1} \left(R_{w,t+1} - R_{f,t+1} \right) \tag{39}$$
$$\mu_{rg,t} = \mathbb{E}_t \Omega_{r,t+1} \left(R_{rg,t+1} - R_{f,t+1} \right) \tag{40}$$
$$\mu_{m,t} = \mathbb{E}_t \Omega_{r,t+1} \left(R_{m,t+1} - R_{f,t+1} \right) \tag{41}$$
$$\nu_{r,t} = \mathbb{E}_t \Omega_{r,t+1} R_{f,t+1} \tag{42}$$

To aggregate retail banks, their net worth and balance sheets are combined. The aggregate balance sheet identity is

$$(Q_{s,t} + f_{s,t}(S_{r,t}))S_{r,t} + B^w_{r,t} + (Q_{g,t} + f_{g,t}(B^g_{r,t}))B^g_{r,t} = D_{r,t} + M_t + N_{r,t} \tag{43}$$

In each period, a fraction $1-\sigma$ of retail banks exit the banking sector, returning their net worth to their respective households. Simultaneously new bankers enter the sector. The aggregate net worth of retail banks is thus the sum of net worth of surviving banks and the net worth of entering banks. Entering banks are provided startup funds

$$\frac{\zeta_r}{1-\sigma} \Big[R_{rs,t}(Q_{s,t-1} + f_{s,t-1}(S_{r,t-1}))S_{r,t-1} + R_{rg,t}(Q_{g,t-1} + f_{g,t}(B^g_{r,t}))B^g_{r,t-1} + R_{w,t}B^w_{r,t-1} \Big]$$

which are based on a fraction of the average assets that exiting banks would have held had they not exited. Surviving banks have aggregate net worth

$$\sigma \Big[(R_{rs,t} - R_{f,t}) (Q_{s,t-1} + f_{s,t-1}(S_{r,t-1}))S_{r,t-1} + (R_{w,t} - R_{f,t}) S^w_{r,t-1} + (R_{rg,t} - R_{f,t}) (Q_{g,t-1} + f_{g,t-1}(B^g_{r,t-1}))B^g_{r,t-1} + R_{f,t}N_{r,t-1} - (R_{m,t} - R_{f,t}) M_{t-1} \Big]$$

Aggregate net worth is thus[2]

$$\begin{aligned} N_{r,t} = & \Bigg(\Big[(\sigma + \zeta_r)R_{rs,t} - \sigma R_{f,t} \Big] - (\sigma + \zeta_r)(R_{rs,t} - R_{rg,t})b^{*g}_{r,t-1} \\ & - (\sigma + \zeta_r)(R_{rs,t} - R_{w,t})b^{*w}_{r,t-1} \Bigg) A_{r,t-1} \\ & + \sigma R_{f,t}N_{r,t-1} - \sigma(R_{m,t} - R_{f,t})M_{t-1}. \end{aligned}$$

where

$$\begin{aligned} A_{r,t-1} &= (Q_{s,t-1} + f_{s,t-1}(S_{r,t-1}))S_{r,t-1} + (Q_{g,t-1} \\ &\quad + f_{g,t-1}(B^g_{r,t-1}))B^g_{r,t-1} + B^w_{r,t-1} \\ b^{*g}_{r,t-1} &= \frac{(Q_{g,t-1} + f_{g,t-1}(B^g_{r,t-1}))B^g_{r,t-1}}{A_{r,t-1}} \\ b^{*w}_{r,t-1} &= \frac{B^w_{r,t-1}}{A_{r,t-1}} \end{aligned} \tag{44}$$

[2] see Appendix A.2 for details.

where $A_{r,t-1}$ is total assets of retail banks, $b^{*g}_{r,t-1}$ is the retail bank asset share of government bonds, and $b^{*w}_{r,t-1}$ is the retail bank asset share of wholesale funds.

3.3.2 Shadow Banks

In general, the program of shadow banks is similar to that of retail banks, except that they do not collect deposits from households, but instead are funded by wholesale funds from retail banks, denoted $b^w_{w,t}$. They also do not have access to the liquidity facility at the central bank. On the asset side, they hold non-financial loans $s_{w,t}$ and government bonds $b^g_{w,t}$. Their period balance sheet identity is

$$Q_{s,t}s_{w,t} + Q_{g,t}b^g_{w,t} = b^w_{w,t} + n_{w,t} \tag{45}$$

And their period net worth is

$$n_{w,t} = (Z_t + (1-\delta)\psi_t(s_t)Q_{s,t})s_{w,t-1} + (\eta + (1-\eta)Q_{g,t})b^g_{w,t-1} - R_{w,t}b^w_{w,t-1} \tag{46}$$

Combining yields the recursive formulation of net worth

$$n_{w,t} = (R_{ws,t} - R_{w,t})\, Q_{s,t-1}s_{w,t-1} + (R_{wg,t} - R_{w,t})\, Q_{g,t-1}b^g_{w,t-1} + R_{w,t}n_{w,t-1} \tag{47}$$

The principal-agent relationship between the shadow bank and the retail bank is similar to that between the retail bank and the household. The shadow bank maximizes their franchise value, written recursively as

$$V_{w,t} = \mathbb{E}_t\Lambda_{t,t+1}\left[(1-\sigma)n_{w,t+1} + \sigma V_{w,t+1}\right] \tag{48}$$

subject to the IC:

$$V_{w,t} \geq \theta_t\left[Q_{s,t}s_{w,t} + \iota_t Q_{g,t}b^g_{w,t} - b^w_{w,t} + \omega b^w_{w,t}\right] \tag{49}$$

Where ω is the relative divertibility of wholesale funds for shadow banks, with $\omega \in (0,1)$. Like retail banks, shadow banks can divert a fraction θ_t of assets financed by their net worth. However, since interbank loans are more easily monitored by retail banks, shadow banks can only divert a fraction $\omega\theta_t$ of assets financed by wholesale funds. As for retail banks, I assume that the shadow bank IC (49) binds in equilibrium.

To solve the shadow bank's problem, guess and verify that the value function is linear in assets and net worth:

$$V_{w,t} = \mu_{ws,t}Q_{s,t}s_{w,t} + \mu_{wg,t}Q_{g,t}b^g_{w,t} + \nu_{w,t}n_{w,t} \tag{50}$$

After maximizing 50 subject to the incentive constraint 49, the equilibrium condition is

$$\mu_{ws,t} = \frac{1}{\iota_t}\mu_{wg,t} \tag{51}$$

Combine the binding IC (49), the value function guess (50), and the equilibrium condition (51) to get the leverage ratio

$$\begin{aligned}\phi_{w,t} &\equiv \frac{Q_{s,t}s_{w,t} + \iota_t Q_{g,t}b^g_{w,t}}{n_{w,t}} \\ &= \frac{\nu_{w,t}}{(\theta_t - \mu_{ws,t})} + \frac{\theta_t(1-\omega)b^w_{w,t}}{(\theta_t - \mu_{ws,t})n_{w,t}}\end{aligned} \tag{52}$$

Combining the recursive value function formulation (48), the guess (50), the IC (49), the equilibrium condition (51), the leverage ratio (52), and the recursive net worth formulation[3] (47), the value function can be written as

$$\begin{aligned}V_{w,t} = \mathbb{E}_t\Omega_{w,t+1}\Big[&(R_{ws,t+1} - R_{w,t+1})Q_{s,t}s_{w,t} \\ &+ (R_{wg,t+1} - R_{w,t+1})Q_{g,t}b^g_{w,t} + R_{w,t+1}n_{w,t}\Big]\end{aligned} \tag{53}$$

where

$$\Omega_{w,t+1} = \mathbb{E}_t\Lambda_{t,t+1}\left(1 - \sigma + \sigma(\nu_{w,t+1} + \mu_{ws,t+1}\phi_{t+1})\right) \tag{54}$$

which verifies the guess if the coefficients are set to

$$\mu_{ws,t} = \mathbb{E}_t\Omega_{w,t+1}\left(R_{ws,t+1} - R_{w,t+1}\right) \tag{55}$$

$$\mu_{wg,t} = \mathbb{E}_t\Omega_{w,t+1}\left(R_{wg,t+1} - R_{w,t+1}\right) \tag{56}$$

$$\nu_{w,t} = \mathbb{E}_t\Omega_{w,t+1}R_{w,t+1} \tag{57}$$

Aggregating shadow banks is similar to aggregating retail banks. The aggregate balance sheet identity is

$$Q_{s,t}S_{w,t} + Q_{g,t}B^g_{w,t} = B^w_{w,t} + N_{w,t} \tag{58}$$

Startup funds to entering shadow banks are

$$\frac{\zeta_r}{1-\sigma}\left[R_{ws,t}Q_{s,t-1}S_{w,t-1} + R_{wg,t}Q_{g,t-1}B^g_{w,t-1}\right]$$

Surviving shadow banks have aggregate net worth

$$\sigma\left[\left(R_{ws,t} - R_{w,t}\right)Q_{s,t-1}S_{w,t-1} + \left(R_{wg,t} - R_{w,t}\right)Q_{g,t-1}B^g_{w,t-1} + R_{w,t}N_{w,t-1}\right]$$

Aggregate net worth is thus[4]

$$\begin{aligned}N_{w,t} = &\left(\left[(\sigma+\zeta_w)R_{ws,t} - \sigma R_{w,t}\right] - (\sigma+\zeta_w)(R_{ws,t} - R_{wg,t})b^{*g}_{w,t-1}\right)A_{w,t-1} \\ &+ \sigma R_{w,t}N_{w,t-1}\end{aligned}$$

with

$$\begin{aligned}A_{w,t-1} &= Q_{s,t-1}S_{w,t-1} + Q_{g,t-1}B^g_{w,t-1} \\ b^{*g}_{w,t-1} &= \frac{Q_{g,t-1}B^g_{w,t-1}}{A_{w,t-1}}\end{aligned} \tag{59}$$

[3] see Appendix A.3 for details
[4] see Appendix A.4 for details

where $A_{w,t-1}$ is total assets of shadow banks, and $b^{*g}_{w,t-1}$ is the shadow bank asset share of government bonds.

3.4 Government Policy

The government is consolidated, combining the fiscal authority and the central bank. It issues both short- and long-term government bonds. Short-term bonds are one-period bonds in zero net supply, while long-term bonds are in positive net supply. To implement an actively traded market for long-term government bonds, I draw from the sovereign debt literature, following Bocola (2016). Government bonds are more pledgeable than non-financial loans, which enables retail and shadow banks to loosen their incentive constraints by including them in their portfolios. Together with a primary deficit that ensures the government wants to borrow, this generates a positive net supply for long-term government bonds. I abstract from sovereign default risk. Government debt as well as lump-sum taxes finance the liquidity facility and government spending, assumed to be a constant fraction of steady-state output, $G_t = \bar{g} \cdot Y_t$ where $\bar{g} \in (0, 1)$.

The government sets the nominal interest rate with a standard Taylor-like rule and engages in balance sheet policies. It has three unconventional policy rules: purchasing government bonds, purchasing non-financial loans, and providing a liquidity facility to retail banks.

On short-term bonds the government pays the risk-free rate. On long-term bonds, the retail bank earns $R_{rg,t}$ and the shadow bank earns $R_{wg,t}$. The difference in rates reflects the cost advantage of shadow banks. I assume that $R_{wg,t} > R_{rg,t} > R_{w,t} > R_{f,t}$, i.e., both retail- and shadow banks earn a positive spread on long-term bonds. A constant fraction η of the bonds mature each period, while the remaining fraction $1 - \eta$ continues to the next period. The gross returns are thus

$$R_{rg,t+1} = \frac{\eta + (1-\eta)(c + \mathbb{E}_t Q_{g,t+1})}{Q_{g,t} + f_{g,t}(B^g_{r,t})} \tag{60}$$

$$R_{wg,t+1} = \frac{\eta + (1-\eta)(c + \mathbb{E}_t Q_{g,t+1})}{Q_{g,t}} \tag{61}$$

Where c denotes the coupon and $Q_{g,t}$ is the price of long-term government bonds. The government budget constraint combines elements from Bocola (2016) with elements from Gertler et al. (2016), Kirchner and Schwanebeck (2017), and Foerster (2015). In its most general form, the government budget constraint is

$$\begin{aligned} &T_t + Q_{g,t}(B^g_t - (1-\eta)B^g_{t-1}) + R_{m,t}M_{t-1} + R_{rs,t}\psi_{s,t-1}Q_{s,t-1}S_{t-1} \\ &= G_t + B^S_{t-1} + (\eta + (1-\eta)c)B^g_{t-1} + \Xi_t(\psi_{g,t}Q_{g,t}B^g_t, \psi_{s,t}Q_{s,t}S_t, M_t) \end{aligned}$$

letting $B^S_t \equiv \psi_{s,t}Q_{s,t}S_t + M_t$ define the short term bond this can be rewritten as

$$\begin{aligned} &Q_{g,t}(B^g_t - (1-\eta)B^g_{t-1}) + (R_{m,t} - R_{f,t})M_{t-1} + (R_{rs,t} - R_{f,t})\psi_{s,t-1}Q_{s,t-1}S_{t-1} \\ &= (G_t - T_t) + (\eta + (1-\eta)c)B^g_{t-1} + \Xi_t(\psi_{b,t}Q_{g,t}B^g_t, \psi_{s,t}Q_{s,t}S_t, M_t) \end{aligned} \tag{62}$$

Equation 62 states that the net inflow from issuing long term debt plus the spread on the liquidity facility and non-financial loans over what is paid on short term bonds, must equal, the primary deficit plus coupons and the cost of maturing debt, as well as the resource cost of assets held. I assume that resource costs arise when the central bank intervenes in the economy. Following Kirchner and Schwanebeck (2017), governments incur real resource costs when purchasing assets that take a quadratic form:

$$\begin{aligned}\Xi_t(\psi_{g,t}Q_{g,t}B_t^g, \psi_{s,t}Q_{s,t}S_t, M_t) = \tau_1 \left(\psi_{s,t}Q_{s,t}S_t + M_t + \psi_{g,t}Q_{g,t}B_t^g\right) \\ + \tau_2 \left(\psi_{s,t}Q_{s,t}S_t\right)^2 + \tau_2 \left(M_t\right)^2 + \tau_2 \left(\psi_{g,t}Q_{g,t}B_t^g\right)^2\end{aligned} \tag{63}$$

The fiscal rule of the government is:

$$T_t = T + \varsigma B_t^g \tag{64}$$

where $T = \bar{t} * G$, $\bar{t} \in (0, 1)$. In sum, the government issues short term bonds to fund spending, LSAPs of long term bonds, non-financial loans, and the liquidity facility. The aggregate resource constraint of the economy is derived by combining the government budget constraint with the budget constraints of households, retail banks, and shadow banks as well as the production function of firms:

$$\begin{aligned}Y_t = C_t + \left[1 + F\left(\frac{I_t}{I_{t-1}}\right)\right] I_t + G_t \\ + F_{s,t}(S_{r,t}) + F_{g,t}(B_{r,t}^g) + \Xi_t(\psi_{g,t}Q_{g,t}B_t^g, \psi_{s,t}Q_{s,t}S_t, M_t)\end{aligned} \tag{65}$$

Conventional monetary policy follows a standard Taylor-type rule

$$i_t = i + \kappa_\pi \pi_t + \kappa_y \widehat{y}_t + \sigma_i \varepsilon_{i,t} \tag{66}$$

where i_t is the nominal interest rate, i is the steady-state nominal interest rate, π_t is inflation, and $\widehat{y}_t$ is the output gap. The Fisher equation links the nominal interest rate to the risk-free rate:

$$i_t = R_{f,t+1}\mathbb{E}_t \pi_{t+1} \tag{67}$$

3.4.1 Unconventional Monetary Policy and Markov Switching

The structure of unconventional monetary policy and the switching process for capital quality follow Foerster (2015) and Kirchner and Schwanebeck (2017). The baseline Markov-switching setup has two components. First, a switching process for capital quality captures the initiation of a financial crisis

$$\log \psi_t(s_t) = (1 - \rho_\psi(s_t)) \log \psi_{mean}(s_t) + \rho_\psi(s_t) \log \psi_{t-1}(s_{t-1}) + \sigma_{\psi,t}\varepsilon_{\psi,t} \tag{68}$$

where $\psi_{mean}(s_t)$ and $\rho_\psi(s_t)$ govern the mean and persistence of capital quality, respectively, and $s_t \in \{1, 2\}$ is a two-state Markov process representing normal and crisis times. During normal times, the mean capital quality is 1, while it is less than 1 during crises. Similarly, persistence lies between 0 and 1 during

normal times but is 0 during crises. In the baseline, an exogenous process drives s_t.

The second component of the Markov-switching framework, the unconventional monetary policy rules, collectively depends on the state variable s_t as realized in the capital quality process. Depending on s_t, the government may or may not intervene in the economy by turning on the unconventional policy rules. The model has three unconventional policy rules: government bond purchases, non-financial loan purchases, and provision of a liquidity facility to retail banks. While each rule has a separate equation, they all share the same structure: the asset share held by the government responds to deviations of spreads from their steady-state values, with the response coefficients and persistence parameters depending on the state variable s_t. This setup allows for different policy behaviors during normal times and crises, as well as during LSAP exit.

The government purchases government bonds according to the rule:

$$\psi_{g,t} = \kappa_{g,t}(s_t)\mathbb{E}_t\Big[(R_{rg,t+1} - R_{f,t+1}) - (R_{rg} - R_f)\Big] + \rho_g(s_t)\psi_{g,t-1} \tag{69}$$

it purchases non-financial loans according to the rule:

$$\psi_{s,t} = \kappa_{s,t}(s_t)\mathbb{E}_t\Big[(R_{rs,t+1} - R_{f,t+1}) - (R_{rs} - R_f)\Big] + \rho_s(s_t)\psi_{s,t-1} \tag{70}$$

and provides a liquidity facility according to the rule:

$$\psi_{m,t} = \kappa_{m,t}(s_t)\mathbb{E}_t\Big[(R_{rs,t+1} - R_{f,t+1}) - (R_{rs} - R_f)\Big] + \rho_m(s_t)\psi_{m,t-1} \tag{71}$$

where $\psi_{i,t}$ is the share of total asset i held by the government for $i \in \{g, s, m\}$. I use non-financial loans in the denominator for the liquidity facility, following Kirchner and Schwanebeck (2017) and Dedola et al. (2013). The parameters $\kappa_i(s_t)$ and $\rho_i(s_t)$ govern the response to spreads and the persistence of asset holdings, respectively, for $i \in \{g, s, m\}$.

Together, four possible regimes govern whether the economy is in a normal or crisis state, and whether the government intervenes with unconventional monetary policy or not. The transition matrix $\mathbb{T}$ summarizes the regimes, where $\mathbb{T}_{ij} = P(s_{t+1} = j | s_t = i)$ is the probability of moving from state i to state j.

$$\begin{array}{r} \text{Normal :} \\ \text{Crisis w/o LSAP :} \\ \text{Crisis w LSAP :} \\ \text{Post-crisis w LSAP :} \end{array} \quad \mathbb{T} = \begin{bmatrix} 1-p_c & p_c(1-p_i) & p_c p_i & 0 \\ p_e & 1-p_e & 0 & 0 \\ p_e p_s & 0 & 1-p_e & p_e(1-p_s) \\ (1-p_c)p_s & 0 & p_c & (1-p_c)(1-p_s) \end{bmatrix} \tag{72}$$

where p_c is the probability of crisis, p_i is the probability of intervention given crisis, p_e is the probability of leaving the crisis, and p_s is the probability of exiting from intervention while in the post-crisis state.

All agents in the model take the transition matrix as given and form expectations by integrating over all possible future paths of the Markov chain. Thus, agents understand the stochastic process governing the economy and take switching probabilities as given. The memorylessness property of Markov chains implies that agents only use the current state to form expectations about future states.

3.5 Equilibrium

The model is closed by clearing markets for goods, labor, government bonds, non-financial loans, and wholesale funds.

Definition 1. *An equilibrium is, given probabilities* $\{p_c, p_i, p_e, p_s\}$*, a set of allocations for*

$$\begin{aligned}
&\textit{households: } \{C_t, N_t, D_t\},\\
&\textit{intermediate good producers: } \{K_t, N_t^d\},\\
&\textit{capital producers: } \{I_t\},\\
&\textit{retailers: } \{P_{i,t}^*\},\\
&\textit{retail banks: } \{S_{r,t}, B_{r,t}^g, B_{r,t}^w, D_{r,t}, M_t\},\\
&\textit{shadow banks: } \{S_{w,t}, B_{w,t}^g, B_{w,t}^w\},
\end{aligned}$$

and prices

$$\{W_t, P_{m,t}, \pi_t, Q_{s,t}, Q_{g,t}, R_{f,t}, R_{m,t}, R_{rs,t}, R_{ws,t}, R_{w,t}, R_{rg,t}, R_{wg,t}\},$$

such that all agents optimize given prices and government policies, and all markets clear:

$$\begin{aligned}
Y_t &= C_t + I_t + G_t \\
&\quad + F_{s,t}(S_{r,t}) + F_{g,t}(B_{r,t}^g) \\
&\quad + \Xi_t(\psi_{s,t} Q_{s,t} S_t, M_t, \psi_{g,t} Q_{g,t} B_t^g) \\
N_t^d &= N_t \\
D_{r,t} &= D_t \\
(1-\psi_{g,t}) B_t^g &= B_{r,t}^g + B_{w,t}^g \\
(1-\psi_{s,t}) S_t &= S_{r,t} + S_{w,t} \\
B_{w,t}^w &= B_{r,t}^w
\end{aligned}$$

Appendix B provides a list of all main model equations.

4 Calibration and Solution

I solve the baseline model[5] using the "partition perturbation method" presented in Foerster et al. (2016). This method, by design, computes the steady state as a

[5] I implement the model with RISE, a MATLAB toolbox developed by Junior Maih, see `https://github.com/jmaih/RISE` and Maih (2015) for details on RISE.

weighted average of the steady states in each regime, weighted by the ergodic distribution of the Markov chain. It then takes a Taylor expansion of the equilibrium conditions around this reference point, perturbing only those Markov-switching parameters that affect the steady state while holding others fixed. Where it is preferred to have regime-specific steady states, the solution method presented in Maih (2015) is used to compute regime-specific steady states. Unless noted, the first-order solution is used.

I calibrate the model to the Euro area at quarterly frequency, externally calibrating all real sector parameters except labor disutility χ based on the literature (Christiano et al., 2005; Gertler et al., 2016; Foerster, 2015; Kirchner and Schwanebeck, 2017).

Financial sector parameters $(\theta, \lambda, \gamma, \iota, \tau_s, \tau_g, \omega)$ are calibrated to match Euro area spreads and shadow bank size. All targets for spreads are expressed in annual bps. By choosing the steady-state value of θ, the non-financial spread $R_{rs} - R_f$ is set to 100 bps, roughly equal to the difference between the Euro area cost of borrowing for corporations and the interest rate on ECB's main refinancing operations (ECB, 2025e,d). Targets for annual steady-state spreads for interbank loans and the liquidity facility follow Kirchner and Schwanebeck (2017). Relative divertibilities λ and steady-state γ pin down $R_w - R_f$ and $R_m - R_f$ at 50 bps. Likewise, the steady-state value of the relative divertibility of government bonds ι fixes the government bond spread $R_{rg} - R_f$ at 75 bps, close to the difference between the 10-year Euro area Government Benchmark bond yield and the ECB's main refinancing operations rate (ECB, 2025a). I set the spreads for shadow banks 50 annual bps higher than those for retail banks by choosing the management cost parameters τ_s and τ_g. Table 1 summarizes the steady-state spreads.

Table 1: Steady-State Spreads

Spread	Annual bps
$R_w - R_f$	50
$R_m - R_f$	50
$R_{rg} - R_f$	75
$R_{rs} - R_f$	100
$R_{wg} - R_w$	75
$R_{ws} - R_w$	100

Source: Own calculations based on calibration targets.

The relative divertibility of interbank loans ω targets the liability side of shadow banks' balance sheets and thus influences the overall size of the shadow banking sector. I calibrate ω such that shadow banks hold about 30% of assets in the steady state to match the proportion of financial assets held by Money-Market Funds and Other Financial Instirutions in the Euro area at year-end 2024 (European Systemic Risk Board, 2025, Annex III).

By choosing startup funds ζ_r and ζ_w, leverage ratios ϕ_r and ϕ_w are set to around 4 and 8 for retail and shadow banks, respectively, comparable to values in the literature (Meeks et al., 2017; Kirchner and Schwanebeck, 2017). The government debt stock is set to 88% of yearly output by choosing the fiscal rule parameter ς, matching government debt to GDP in the Euro area (ECB, 2025c). Yearly government spending relative to output G/Y is set to 49% to match the government spending to GDP ratio in the Euro area in 2024 (Eurostat, 2025). The primary deficit is set to 10% of government spending by choosing $\bar{t} = T/G$.

Table 2 summarizes the full baseline calibration, including both externally and internally calibrated parameters. All externally calibrated parameters are standard in the literature (Meeks et al., 2017; Foerster, 2015; Kirchner and Schwanebeck, 2017; Gertler and Karadi, 2018). I choose the internally calibrated parameters to match the targets described above.

Table 2: Baseline Calibration

Externally calibrated

Param	Value	Description
β	0.99	Discount factor
h	0.815	Habit persistence
ϕ	0.276	Inverse Frisch elasticity
α	0.33	Capital share
δ	0.025	Depreciation rate
ξ	1.728	Capital adjustment cost
ε	4.167	Elasticity of substitution
ζ	0.779	Calvo stickiness
ζ_p	0.241	Indexation
τ_1	0.00001	Resource cost intervention 1
τ_2	0.0001	Resource cost intervention 2
η	0.056	Share of GVBs maturing
κ_π	1.5	Taylor rule inflation
κ_y	0.125	Taylor rule output gap
ρ_θ	0.8	Persistence divertibility shock
ρ_γ	0.8	Persistence fiscal shock
ρ_ι	0.8	Persistence preference shock
ρ_A	0.8	Persistence TFP shock
σ_A	0.01	Std dev TFP shock
σ_ψ	0.01	Std dev capital quality shock
σ_θ	0.01	Std dev divertibility shock
σ_γ	0.01	Std dev rel. div. NF loans shock
σ_ι	0.01	Std dev rel. div. GVB shock

Internally calibrated

Param	Value	Description	Target
χ	3.061	Labor disutility	$N = 1/3$
θ	0.3441	Divertibility	$R_{rs} - R_f = 100$ ann. bps
λ	0.5	Rel. div. liquidity facility	$R_m - R_f = 50$ ann. bps
γ	0.5	RB Rel. div. interbank loans	$R_w - R_f = 50$ ann. bps
ι	0.75	Rel. div. gov bonds	$R_{rs} - R_{rg} = 25$ ann. bps
σ	0.957	Survival probability	Approx 4.5% dividend
ζ_r	0.0058	Retail bank startup funds	$\phi_r \approx 4$
ζ_w	0.0018	SB startup funds	$\phi_w \approx 8$
τ_s	0.00035	Mgmt cost non-financial loans	$R_{ws} - R_{rs} = 50$ ann. bps
τ_g	0.0098	Mgmt cost gov bonds	$R_{wg} - R_{rg} = 50$ ann. bps
ω	0.6845	SB rel. div. interbank loans	$S_w/K \approx 0.30^a$
c	0.0075	GVB coupon	3% annual coupon
ς	0.071	Fiscal rule	$B_g/Y \cdot 4 = 0.88$
G/Y	0.13	Government spending share	$G/Y \cdot 4 = 0.49$
T/G	0.9	Taxes to spending	10% prim. deficit

Source: Own calculations based on calibration targets.

[a] ω governs the shadow bank IC and thus the total scale of the sector, proxied by the share of non-financial loans.

Baseline transition probabilities directly follow Foerster (2015). The baseline has a crisis probability $p_c = 0.005$ each period, implying that the economy enters a crisis, in expectation, once every 200 periods. The expected crisis duration is two periods, giving the probability of exiting a crisis $p_e = 0.5$. Post-crisis, the probability of stopping intervention is $p_s = \frac{1}{18}$. The baseline expected holding duration is thus 18 periods. The conditional probability of intervention given a crisis, p_i, is set to either 0 or 1 depending on the experiment. Table 3 describes the calibration of the regime-dependent parameters.

Table 3: Regime-dependent parameters

Parameter	Normal	Crisis w/o LSAP	Crisis w LSAP	Post-crisis Hold
ψ_{mean}	1	0.97	0.97	1
ρ_ψ	0.66	0	0	0.66
κ_g	0	0	30	0
κ_s	0	0	3	0
κ_m	0	0	3	0

Source: Own calculations based on calibration targets.

The parameters κ_i for $i \in \{g, s, m\}$ that govern the response of the unconventional monetary policy rules to spread deviations are equal to zero in all regimes except the crisis with LSAP regime. κ_s and κ_m are both set to 3 following Foerster (2015). I choose κ_g such that central bank holdings of government bonds during a crisis reach approximately 24%, closely aligned with the peak levels of the ECB's PSPP program (ECB, 2025b). The policy rule persistence parameters that define exit speed, ρ_i for $i \in \{g, s, m\}$, vary by experiment. In the baseline case they are all fixed at 0.95, implying that 5% of asset holdings are sold each period once exit has started.

4.1 Endogenous Switching Probability and Single Mandate

An exit strategy consists primarily of two components: the timing of exit and the exit speed. The persistence parameters ρ_i for $i \in \{g, s, m\}$ determine the exit speed. The switching probability p_s determines the timing of exit by implying an expected holding duration. In the baseline setup, p_s is exogenous.

Some authors have argued that the timing of exit must depend on economic conditions (Blinder et al., 2013). This paper addresses this by modeling the probability of exit as endogenous to the state of the economy. To enable exit timing and expectations of exit to depend on economic conditions, I formulate p_s as an endogenous switching probability (ESP). This way, the implied holding duration of LSAPs depends on economic conditions, enabling the study of forward guidance. Since agents always know the switching probabilities, this setup implicitly assumes that communication about future exit is perfect, credible, and follows a publicly known rule. Any forward guidance effects are thus to be viewed as an upper bound estimate for a given parameterization.

I implement the ESP through a single-mandate exit strategy, where the switching probability p_s depends solely on the inflation gap, $\widehat{\pi}_t$[6]. The motivation behind this formulation is the ECB's primary mandate of price stability as established in Article 127 of the Treaty on the Functioning of the European Union (EU, 2012). Following the literature on ESPs (see Diebold et al. (1994) and Filardo (1994)), I define $p_s(\widehat{\pi}_t)$ as the logistic function

$$p_{s,t}(\widehat{\pi}_t) = \frac{1}{1 + \exp\left(-\left[\log\left(\frac{z_0}{1-z_0}\right) + b\widehat{\pi}_t\right]\right)} \tag{73}$$

where $\widehat{\pi}_t$ denotes the inflation gap, $z_0 = 1/18$ determines the baseline exit probability, and b governs the sensitivity of the exit probability to the inflation gap. A higher value of b means that the exit probability increases faster as the inflation gap widens. Figure 1 shows the exit probability as a function of the inflation gap across different values of b.

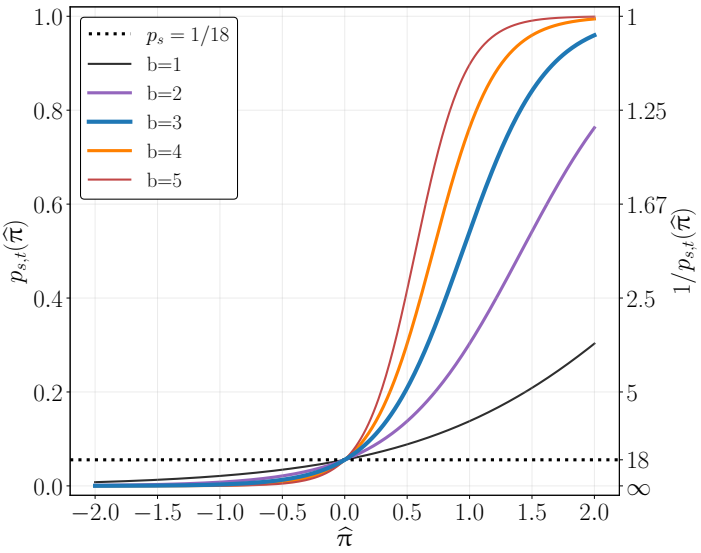

Figure 1: Endogenous Exit Probability as a Function of the Inflation Gap. Source: Own calculations.

In the baseline calibration, b is set to 3, implying that when inflation is about 0.5% above target quarterly, the expected holding duration is 5 quarters. I perform sensitivity analysis for all main experiments by varying b between 1 and 5[7]; all results presented in the main text are qualitatively unaffected.

[6] All relevant experiments were also run with a dual-mandate exit strategy with inflation bias as well as with equal weight between inflation and the output gap. Results remain qualitatively unchanged because Y and π are heavily correlated, the "divine coincidence". The analysis thus focuses solely on the single-mandate strategy.

[7] See Appendix C for details.

5 Experiments and Exit

5.1 Crisis and Unconventional Policy

The first experiment simulates a regime switch from the normal regime to a crisis with the purpose of providing intuition about the transmission of LSAPs through *the premium channel*. The regime switch changes ψ_{mean} from 1 to 0.97, equivalent to a three standard deviation shock. I run the experiment twice, once with intervention ($p_i = 1$) and once without intervention ($p_i = 0$).

The regime sequence is ex-ante unknown to agents, who know only $\mathbb{T}$ and the current regime before choosing controls. The regime sequence is $(2, 2, 4^{18}, 1, \ldots)$ for the no intervention case and $(3, 3, 4^{18}, 1, \ldots)$ for the intervention case, where 4^{18} denotes 18 consecutive periods in the post-crisis hold regime. Figure 2 displays paths as percentage point deviations from the pre-crisis steady state, except spreads which are in annual percentage point deviations.

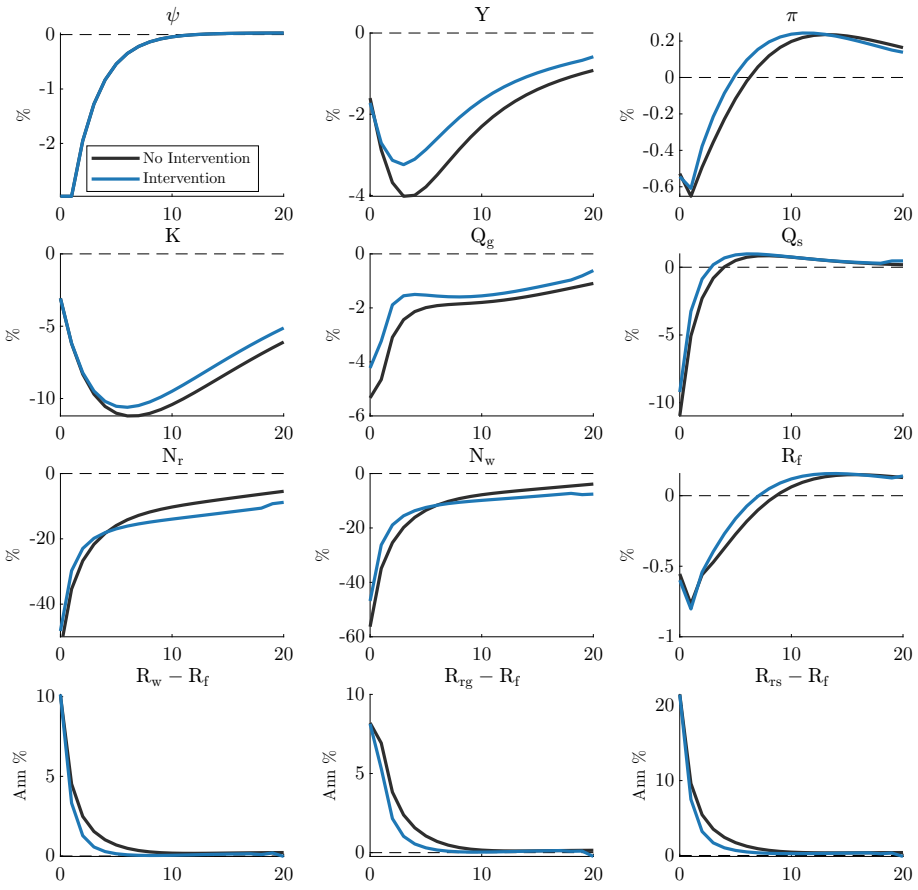

Figure 2: Crisis with and without intervention. Source: Own calculations.

The transmission mechanism of the no intervention case follows standard financial accelerator logic with shadow banks, analogous to that described in Meeks et al. (2017) and Kirchner and Schwanebeck (2017). The quality of capital ψ

installed last period is suddenly lower, which lowers the value of the assets held by both retail and shadow banks. Banks must deleverage to comply with their respective leverage constraints, causing asset prices Q_s and Q_g to fall. This feeds back into lower asset demand, causing further deleveraging. Credit spreads go up for all assets and both retail and shadow bank net worth N_r and N_w decrease, decreasing aggregate investment and capital K. Since non-financial loans are less pledgeable than government bonds, the non-financial loan price Q_s falls more than the government bond price Q_g, causing the non-financial spread $R_{rs} - R_f$ to rise more than the government bond spread $R_{rg} - R_f$.

Interbank loans $B_r^w = B_w^w$ are more pledgeable than government bonds B^g, yet the interbank spread $R_w - R_f$ rises more than the government bond spread $R_{rg} - R_f$. The capital quality shock creates a demand shock for government bonds but leaves their slow-moving supply largely unchanged. In contrast, both sides of the interbank market move: retail banks deleverage, reducing supply, while shadow banks increase demand for pledgeable assets to satisfy leverage constraints. The net effect is that retail banks transmit losses to shadow banks through the higher interbank spread.

Shadow banks have higher leverage than retail banks and are exposed to financial conditions on both sides of their balance sheets. Lower asset prices and interbank loans thus force aggressive deleveraging in order to comply with their incentive constraint. As the crisis propagates into the real economy, labor N, output Y, and inflation π go down, and in response the central bank decreases the nominal interest rate i_t.

Unconventional monetary policy helps buffer the decrease. By helping to stabilize bank net worth and spreads it supports the recovery of aggregate investment and thus the real economy. The central bank purchases government bonds, non-financial loans, and provides a liquidity facility to retail banks when the crisis hits. This supports asset prices, allowing spreads and bank net worth to recover faster. This is the premium channel: the negative effect on yields caused by higher asset prices. As a result, aggregate investment, output, and inflation fall less.

The introduction of an actively traded government bond does not change the qualitative transmission mechanism of the premium channel. Interestingly, the government bond price partially plateaus during the post-crisis period after the non-financial loan price has recovered. This divergence reflects differing elasticities in the demand for credit. The government bond's price lags because its inelastic supply ties recovery only to the slow repair of bank net worth, unlike the non-financial loan price, which is driven by the comparatively elastic rebuilding of capital through aggregate investment. In the model, the demand for credit intermediation to finance non-financial loans recovers faster than the government increases its debt stock because of lower tax revenues, leading to a divergence in prices during the post-crisis period.

5.2 Exit Strategies

Having built intuition about the premium channel of LSAPs during a crisis, we turn attention to the main focus of the paper, LSAP exit. For this experiment, all unconventional policy rules are active. As discussed in subsection 4.1, an exit strategy consists of two components: the exit speed and the holding duration. Varying the persistence parameters ρ_i for $i \in \{g, s, m\}$ changes the exit speed, while changing the rule for p_s impacts the expected holding duration. I model the latter through the ESP formulation.

Figure 3 displays the simulated paths for four exit strategies: slow exit, fast exit, as well as their ESP counterparts. In the fast exit strategy, I set the persistence parameters ρ_i for $i \in \{g, s, m\}$ to 0.0, following Foerster (2015), implying that the central bank unwinds all asset holdings immediately. The slow strategy keeps the baseline persistence 0.95 for all three unconventional policy rules. I likewise set the persistence parameters for the two ESP cases to 0.0 and 0.95, respectively. Values represent percentage point deviations from the steady state, except spreads which are in annual percentage point deviations. The regime sequence is $(3, 3, 4^{18}, 1, \ldots)$.

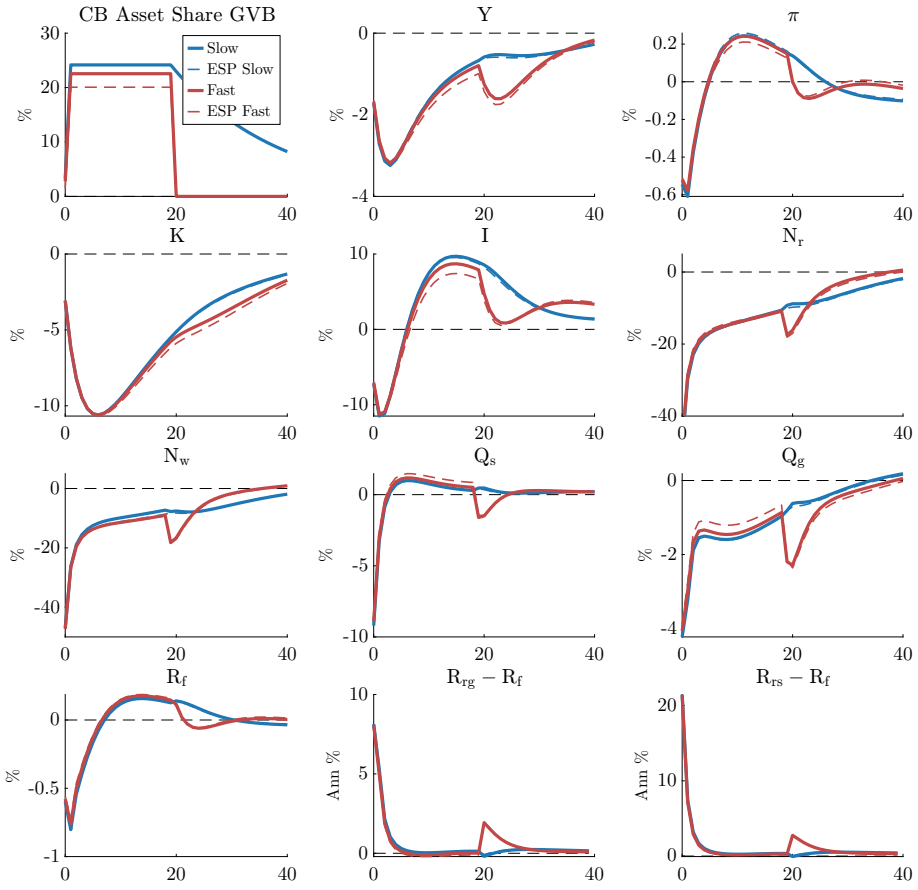

Figure 3: Exit Strategies: Slow, Fast, Slow ESP, Fast ESP. Source: Own calculations.

While the crisis and recovery dynamics are approximately identical across the fast and slow exit strategies, exit dynamics differ. In the fast exit strategy, I observe similar dynamics to those documented in Foerster (2015). Quick unwinding creates a "double dip" recession, as asset prices fall again once exit begins, causing spreads to rise, and investment to decrease. However, once the second dip has occurred, real variables recover faster. The slow exit strategy avoids this entirely by keeping asset prices more stable during exit.

The two strategies with ESP mirror their counterparts. In the slow case, the ESP has no qualitative effect. In the fast case, however, the ESP formulation changes the dynamics in the post-crisis hold regime slightly by introducing a "disciplinary effect": as the economy recovers in the post-crisis hold and inflation starts to move back towards the target, agents internalize that the expected holding duration will shorten. This causes them to be more conservative, leading investment to overshoot less and output to recover more slowly than in their baseline counterparts. Conversely, agents also know that if the economy remains weak and inflation stays lower, the expected holding duration will lengthen. During the post-crisis hold, the disciplinary effect dominates. Once exit has begun and inflation is roughly back to target, the ESP formulation essentially follows the path where the exit probability is exogenous.

Since the policy rule parameter κ_g is ten times higher than both κ_s and κ_m, government bond purchases proportionally dominate LSAP. Thus, on fast exit, Q_g falls proportionally more than Q_s, causing the government bond spread $R_{rg} - R_f$ to rise more than the non-financial spread $R_{rs} - R_f$.

As found in the previous experiment, shadow banks amplify the financial accelerator mechanism by having higher leverage and by having losses transmitted to them by retail banks. Thus, as spreads rise on fast exit, they contribute to deepening the contraction. Beyond this, I do not find that shadow banks have any notable impact on the qualitative transmission of LSAP exit on aggregate variables.

The main difference between the baseline and the ESP formulation is that, when exit is fast, the ESP causes the recovery to be slower as agents prefer limiting investment to avoid increasing the risk of a premature exit. The results are qualitatively robust to sensitivity analysis on the sensitivity parameter b (see Appendix C for details).

5.3 Forward Guidance

Figure 3 reveals that endogenizing the exit probability based on the inflation gap affects the recovery after a financial crisis when exit is fast. This experiment explores how the internalization of the endogenous switching probability affects the stochastic steady state during post-crisis hold. It answers the question: how does changing the exit speed affect the post-crisis-hold-specific steady state, and how does endogenizing the expected holding duration change these effects?

In this experiment, the economy stays in the post-crisis regime indefinitely: the

regime sequence is simply $(4, 4, \ldots)$. Agents, however, still integrate over all possible future regimes as determined by the transition matrix $\mathbb{T}$. This way, when comparing the baseline to the ESP calibration, I capture the effect of changing the expectations of agents about how long LSAP will remain in place, a type of forward guidance that works through the signaling channel of unconventional monetary policy.

For both the baseline and the ESP calibrations, I run simulations for the stochastic steady state across different exit speeds by varying the persistence parameters ρ_i for $i \in \{g, s, m\}$. For each exit speed, I simulate the model for 100 000 periods in five independent runs, and average outcomes to obtain a reasonable approximation of the corresponding stochastic steady state. Figure 4 displays the results, comparing outcomes to the regime-specific steady state of the baseline calibration. This experiment uses the second-order solution of the model.

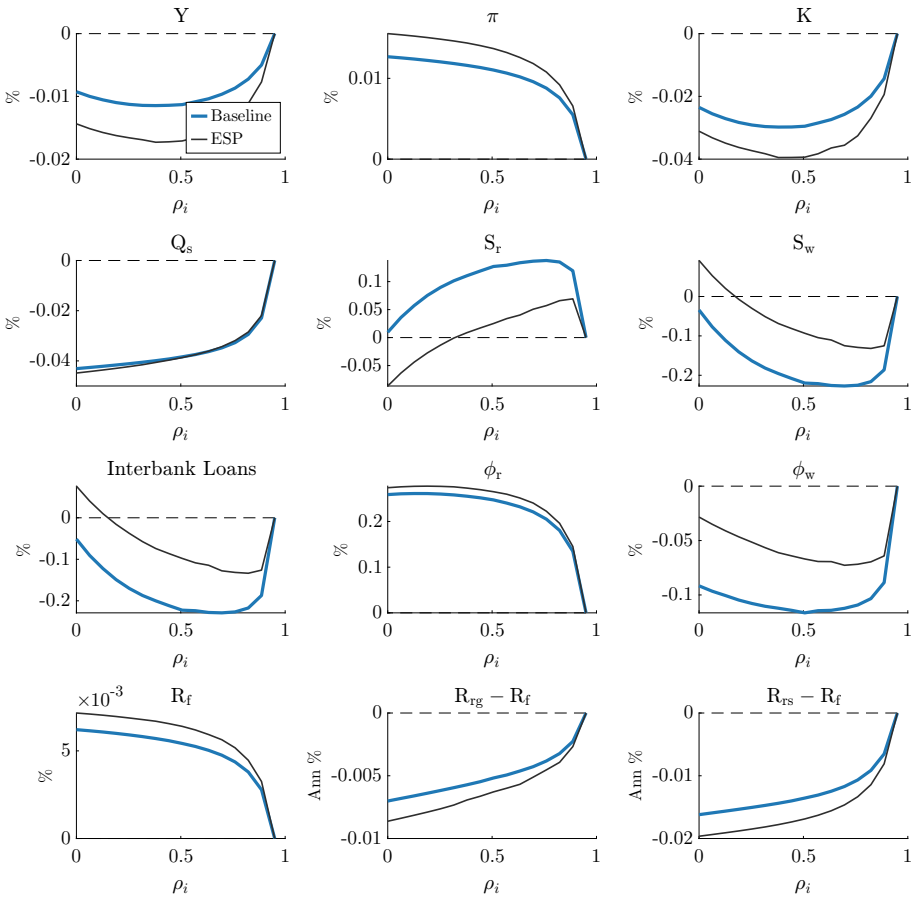

Figure 4: Forward Guidance: Post-Crisis Hold Stochastic Steady State Across Exit Speeds. Baseline vs ESP. Source: Own calculations.

First, consider the baseline calibration, where expected holding duration is fixed. Slower exit speeds, for both the baseline and ESP calibrations, have higher asset prices, investment and output in the stochastic steady state. For faster speeds,

as agents anticipate a larger shock once exit happens, they decrease lending preemptively in order to avoid losses in an exit, a precautionary disinvestment effect. The decrease in capital increases the marginal product of labor. Without a proportional decrease in the wage, this causes the marginal cost of intermediate goods to rise. While output is lower, this creates cost-push inflation, causing the central bank to increase the nominal interest rate. Faster exit speeds thus have a stagflationary effect in the post-crisis hold stochastic steady state.

I observe an interesting divergence between retail and shadow banks. Retail banks, with lower levels of leverage, increase their holdings of non-financial loans for faster exit speeds. Shadow banks, on the other hand, contract non-financial lending and instead increase their holdings of government bonds for faster exit speeds. Shadow banks' pivot towards more pledgeable assets loosens their incentive constraint. Thus, shadow bank leverage ϕ_w decreases in exit speed, while the opposite is true for retail bank leverage ϕ_r.

Forward guidance about exit timing nuances the effects described above. It weakens the increase in retail bank non-financial lending, which even turns negative at very high speeds. The ESP also mutes the precautionary disinvestment of shadow banks, yielding a smaller contraction in non-financial lending at higher exit speeds and a slight increase at very high speeds. Together, since retail banks account for a larger share of non-financial lending, the net effect of the ESP is that aggregate investment and capital are slightly lower compared to the baseline for faster exit speeds.

The effect of forward guidance on the post-crisis hold stochastic steady state is thus nuanced and varies across the two bank types. Primarily, the results show that forward guidance impacts outcomes through the signaling channel, even before exit occurs. Relative to the baseline, the ESP mechanism weakens the precautionary disinvestment effect caused by fast exit on shadow banks and strengthens it for retail banks. The results are qualitatively robust to sensitivity analysis on the sensitivity parameter b (see Appendix C for details).

5.4 Portfolio Balance

This experiment isolates the marginal contribution of each UMP component by setting $\kappa_i = 0$ for $i \in \{g, s, m\}$ while keeping other policies active. This enables the study of *the portfolio balance channel*: which policy causes the strongest contagion effects. Figure 5 displays the decomposition $\Delta_i(\mathcal{X}) = \mathcal{X} - \mathcal{X}_{\kappa_i=0}$ where $\Delta_i(\mathcal{X})$ represents the marginal effect of policy i. Exit speed follows the baseline $\rho_i = 0.95$ and the regime sequence is $(3, 3, 4^{18}, 1, \ldots)$. Since results are qualitatively similar across the baseline and ESP formulations, I only show the latter.

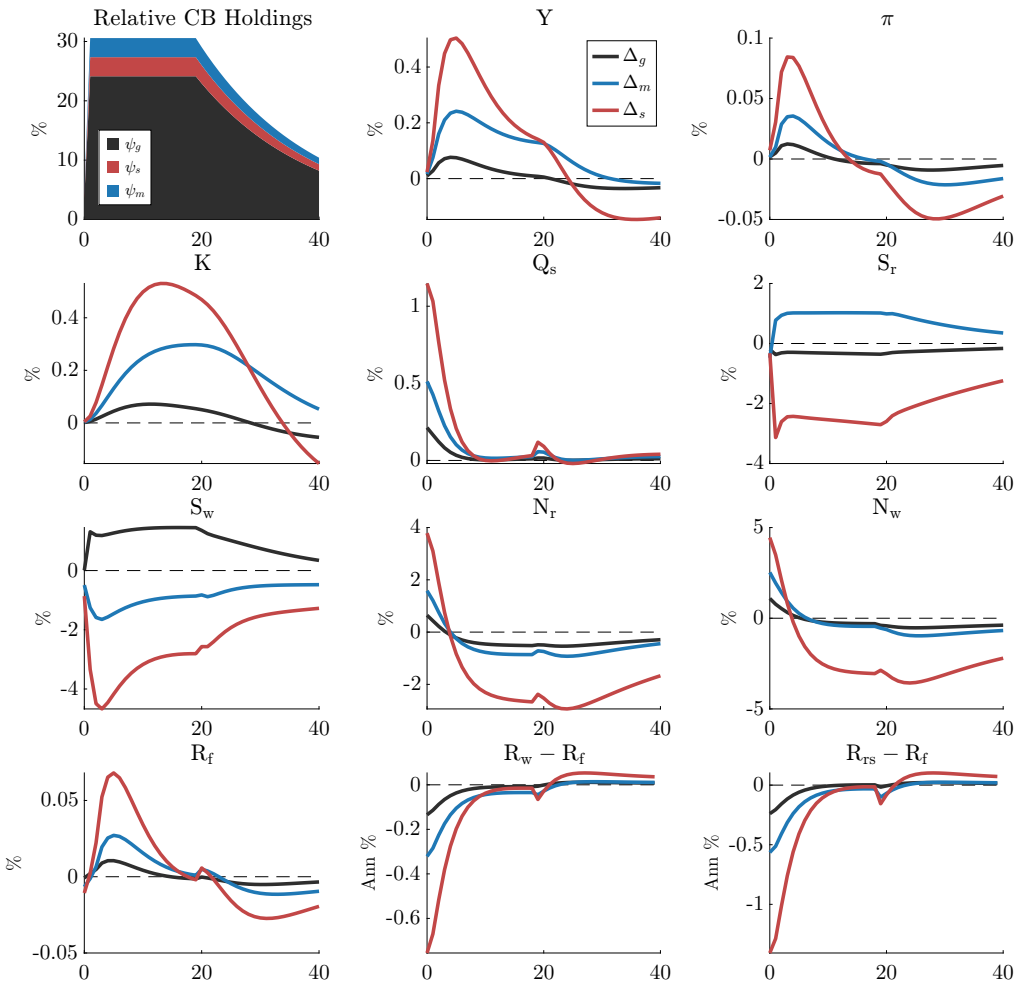

Figure 5: Portfolio Balance, Decomposition of Marginal Effects. Source: Own calculations.

Purchasing the least pledgeable asset, non-financial loans, yields the strongest stabilization of asset prices and output. By intervening "at the very source of economic disturbances" (Kirchner and Schwanebeck, 2017, p.27), these purchases directly stimulate investment by increasing Q_s. Government bond purchases have the weakest effect on output, despite the larger scale.

However, non-financial loan purchases also create the largest distortions on exit. After exit has begun, their contribution to capital and output eventually turns sharply negative. This policy also contributes the most to displacement of private lending, as the central bank directly crowds out the private sector in the non-financial loan market.

In the exit strategies experiment, we observe that shadow banks do not qualitatively affect the transmission of both LSAP and exit on aggregate variables beyond amplifying the financial accelerator mechanism. Here, the results show

that specific policies affect the portfolios of retail and shadow banks asymmetrically. The liquidity facility generates the largest marginal increase in retail bank lending, since it directly eases the retail bank incentive constraint. For shadow banks, government bond purchases generate the largest marginal effect on lending. This occurs through the "scarcity effect" of UMP (Arrata et al., 2020; D'Amico et al., 2018). As the central bank reduces the effective supply of government bonds (increasing their relative price), this causes shadow banks to rebalance towards non-financial loans.

While the contagion of non-financial loan purchases across the financial sector is generally stronger and a more effective tool for stabilizing the economy, it also creates larger distortions during exit and displaces private lending to a greater extent. What matters for credit intermediation before and during exit is not only the direct effect of asset purchases, but how they interact with the portfolio composition of different bank types. For shadow banks, this includes the scarcity effect on pledgeable assets.

6 Conclusion

This paper studies the interaction between shadow banks and LSAP exit, and the effects of different exit strategies used by the central bank. Using a Markov-switching DSGE model with a financial sector and an actively traded long-term government bond market, the analysis captures three channels of unconventional monetary policy: the premium channel, the portfolio balance channel, and the signaling channel through changing expectations about exit speed as well as forward guidance about exit timing.

This paper does not attempt to provide an analysis on the optimal design of LSAP exit strategies. Instead, the focus is on providing a descriptive analysis of how shadow banks affect the transmission of LSAP exit through different channels. The model ignores macroprudential regulation and does not explicitly model the process of securitization. I do not model or discuss the liquidity channel and exchange rate channel of UMP (see Casola (2021)), although studies have shown that both of these channels significantly affect transmission, especially for small open economies (see e.g., Erceg et al. (2024), D'Avernas et al. (2020), Kolasa et al. (2025)). Motivated by the focus on exit, this paper does not model the ZLB explicitly. For the same reason, I abstract from sovereign default risk in the government bond market.

The results suggest that shadow banks amplify the financial accelerator mechanism. Beyond this, they do not alter the transmission of LSAP exit on aggregate variables. Forward guidance about exit timing introduces a disciplinary effect when exit is fast that causes agents to be more conservative in their investment decisions to avoid inducing a premature exit. In the post-crisis stochastic steady state, forward guidance has heterogeneous effects across intermediary types, muting both the precautionary behavior of shadow banks and the expansion of retail bank private lending caused by faster exit speeds.

Through the portfolio balance channel, non-financial loan purchases yield the strongest stabilization but generate the largest exit distortions and displacement of private lending. The interaction between asset purchases and the portfolio composition of different bank types matters for credit intermediation both before and during exit. The liquidity facility has the strongest effect on retail bank lending, whereas government bond purchases most significantly impact shadow bank lending via a "scarcity effect", causing them to rebalance towards non-financial loans. The results suggest that exit duration and speed both matter for economic outcomes, and that shadow banks impact how these effects propagate throughout the financial sector.

A Derivations

A.1 Verification of value function, retail banks

Return to section. Start with

$$
\begin{aligned}
V_{r,t} &= \mathbb{E}_t \Lambda_{t,t+1} \left[(1-\sigma) n_{r,t+1} + \sigma V_{r,t+1} \right] \\
&= \mathbb{E}_t \Lambda_{t,t+1} \Bigg[(1-\sigma) \Big(\left(R_{rs,t+1} - R_{f,t+1} \right) \left(Q_{s,t} + f_t \right) s_{r,t} \\
&\quad + \left(R_{w,t+1} - R_{f,t+1} \right) b^w_{r,t} + \left(R_{rg,t+1} - R_{f,t+1} \right) \left(Q_{g,t} + f_{g,t}(b^g_{r,t}) \right) b^g_{r,t} \\
&\quad + R_{f,t+1} n_{r,t} - \left(R_{m,t+1} - R_{f,t+1} \right) m_t \Big) \\
&\quad + \sigma \Big(\mu_{rs,t+1} (Q_{s,t+1} + f_{t+1}) s_{r,t+1} + \mu_{rw,t+1} b^w_{r,t+1} \\
&\quad + \mu_{rg,t+1} (Q_{g,t+1} + f_{g,t+1}) b^g_{r,t+1} + \nu_{r,t+1} n_{r,t+1} - \mu_{m,t+1} m_{t+1} \Big) \Bigg] \\
&= \mathbb{E}_t \Lambda_{t,t+1} \Bigg[(1-\sigma) \Big(\left(R_{rs,t+1} - R_{f,t+1} \right) \left(Q_{s,t} + f_t \right) s_{r,t} \\
&\quad + \left(R_{w,t+1} - R_{f,t+1} \right) b^w_{r,t} + \left(R_{rg,t+1} - R_{f,t+1} \right) \left(Q_{g,t} + f_{g,t}(b^g_{r,t}) \right) b^g_{r,t} \\
&\quad + R_{f,t+1} n_{r,t} - \left(R_{m,t+1} - R_{f,t+1} \right) m_t \Big) \\
&\quad + \sigma \Big(\mu_{rs,t+1} (Q_{s,t+1} + f_{t+1}) s_{r,t+1} + \mu_{rw,t+1} b^w_{r,t+1} \\
&\quad + \mu_{rg,t+1} (Q_{g,t+1} + f_{g,t+1}) b^g_{r,t+1} - \mu_{m,t+1} m_{t+1} \\
&\quad + \nu_{r,t+1} \Big(\left(R_{rs,t+1} - R_{f,t+1} \right) \left(Q_{s,t} + f_t \right) s_{r,t} \\
&\quad + \left(R_{w,t+1} - R_{f,t+1} \right) b^w_{r,t} + \left(R_{rg,t+1} - R_{f,t+1} \right) \left(Q_{g,t} + f_{g,t}(b^g_{r,t}) \right) b^g_{r,t} \\
&\quad + R_{f,t+1} n_{r,t} - \left(R_{m,t+1} - R_{f,t+1} \right) m_t \Big) \Big) \Bigg] \\
&= \mathbb{E}_t \Lambda_{t,t+1} \Bigg[\left(1 - \sigma + \sigma \nu_{r,t+1} \right) \Big[(R_{rs,t+1} - R_{f,t+1}) (Q_{s,t} + f_{s,t}(s_{r,t})) s_{r,t} \\
&\quad + (R_{w,t+1} - R_{f,t+1}) b^w_{r,t} + (R_{rg,t+1} - R_{f,t+1}) (Q_{g,t} + f_{g,t}(b^g_{r,t})) b^g_{r,t} \\
&\quad + R_{f,t+1} n_{r,t} - (R_{m,t+1} - R_{f,t+1}) m_t \Big] \\
&\quad + \sigma \Big(\mu_{rs,t+1} (Q_{s,t+1} + f_{t+1}) s_{r,t+1} + \mu_{rw,t+1} b^w_{r,t+1} \\
&\quad + \mu_{rg,t+1} (Q_{g,t+1} + f_{g,t+1}) b^g_{r,t+1} - \mu_{m,t+1} m_{t+1} \Big) \Bigg]
\end{aligned}
$$

continuing:

$$
\begin{aligned}
V_{r,t} = \mathbb{E}_t \Lambda_{t,t+1} \Bigg[& \big(1-\sigma+\sigma\nu_{r,t+1}\big) \Big[(R_{rs,t+1} - R_{f,t+1})(Q_{s,t} + f_{s,t}(s_{r,t}))s_{r,t} \\
& + (R_{w,t+1} - R_{f,t+1}) b^w_{r,t} + (R_{rg,t+1} - R_{f,t+1})(Q_{g,t} + f_{g,t}(b^g_{r,t}))b^g_{r,t} \\
& + R_{f,t+1} n_{r,t} - (R_{m,t+1} - R_{f,t+1}) m_t \Big] \\
& + \sigma\mu_{rs,t+1} \Big[(Q_{s,t+1} + f_{t+1}) s_{r,t+1} + \gamma_t b^w_{r,t+1} \\
& + \iota_{t+1}(Q_{g,t+1} + f_{g,t+1}) b^g_{r,t+1} - \lambda m_{t+1} \Big] \Bigg] \\
= \mathbb{E}_t \Lambda_{t,t+1} \Bigg[& \big(1-\sigma+\sigma\nu_{r,t+1}\big) \Big[(R_{rs,t+1} - R_{f,t+1})(Q_{s,t} + f_{s,t}(s_{r,t}))s_{r,t} \\
& + (R_{w,t+1} - R_{f,t+1}) b^w_{r,t} + (R_{rg,t+1} - R_{f,t+1})(Q_{g,t} + f_{g,t}(b^g_{r,t}))b^g_{r,t} \\
& + R_{f,t+1} n_{r,t} - (R_{m,t+1} - R_{f,t+1}) m_t \Big] \\
& + \sigma\mu_{rs,t+1}\phi_{r,t+1} n_{r,t+1} \\
= \mathbb{E}_t \Lambda_{t,t+1} \Bigg[& \big(1-\sigma+\sigma\nu_{r,t+1}\big) \Big[(R_{rs,t+1} - R_{f,t+1})(Q_{s,t} + f_{s,t}(s_{r,t}))s_{r,t} \\
& + (R_{w,t+1} - R_{f,t+1}) b^w_{r,t} + (R_{rg,t+1} - R_{f,t+1})(Q_{g,t} + f_{g,t}(b^g_{r,t}))b^g_{r,t} \\
& + R_{f,t+1} n_{r,t} - (R_{m,t+1} - R_{f,t+1}) m_t \Big] \\
& + \sigma\mu_{rs,t+1}\phi_{r,t+1} \Big((R_{rs,t+1} - R_{f,t+1}) (Q_{s,t} + f_t) s_{r,t} \\
& + (R_{w,t+1} - R_{f,t+1}) b^w_{r,t} + (R_{rg,t+1} - R_{f,t+1}) (Q_{g,t} + f_{g,t}(b^g_{r,t}))b^g_{r,t} \\
& + R_{f,t+1} n_{r,t} - (R_{m,t+1} - R_{f,t+1}) m_t \Big) \\
= \mathbb{E}_t \Lambda_{t,t+1} & \big(1-\sigma+\sigma(\nu_{r,t+1} + \mu_{rs,t+1}\phi_{r,t+1})\big) \\
& \Big[(R_{rs,t+1} - R_{f,t+1})(Q_{s,t} + f_{s,t}(s_{r,t}))s_{r,t} \\
& + (R_{w,t+1} - R_{f,t+1}) b^w_{r,t} + (R_{rg,t+1} - R_{f,t+1})(Q_{g,t} + f_{g,t}(b^g_{r,t}))b^g_{r,t} \\
& + R_{f,t+1} n_{r,t} - (R_{m,t+1} - R_{f,t+1}) m_t \Big] \\
= \mathbb{E}_t \Omega_{r,t+1} & \Big[(R_{rs,t+1} - R_{f,t+1})(Q_{s,t} + f_{s,t}(s_{r,t}))s_{r,t} \\
& + (R_{w,t+1} - R_{f,t+1}) b^w_{r,t} + (R_{rg,t+1} - R_{f,t+1})(Q_{g,t} + f_{g,t}(b^g_{r,t}))b^g_{r,t} \\
& + R_{f,t+1} n_{r,t} - (R_{m,t+1} - R_{f,t+1}) m_t \Big]
\end{aligned}
$$

where

$$\Omega_{r,t+1} = \Lambda_{t,t+1} \left(1 - \sigma + \sigma(\nu_{r,t+1} + \mu_{rs,t+1}\phi_{r,t+1})\right)$$

A.2 Aggregation retail banks

Return to section.

$$
\begin{aligned}
N_{r,t} = \sigma \Big[& (R_{rs,t} - R_{f,t})(Q_{s,t-1} + f_{s,t-1}(S_{r,t-1}))S_{r,t-1} + (R_{w,t} - R_{f,t})S^w_{r,t-1} \\
& + (R_{rg,t} - R_{f,t})(Q_{g,t-1} \\
& + f_{g,t-1}(B^g_{r,t-1}))B^g_{r,t-1} + R_{f,t}N_{r,t-1} - (R_{m,t} - R_{f,t})M_{t-1} \Big] \\
& + \zeta_r \Big[R_{rs,t}(Q_{s,t-1} + f_{s,t-1}(S_{r,t-1}))S_{r,t-1} \\
& + R_{rg,t}(Q_{g,t-1} + f_{g,t-1}(B^g_{r,t-1}))B^g_{r,t-1} + R_{w,t}S^w_{r,t-1} \Big] \\
= & \Big[(\sigma + \zeta_r)R_{rs,t} - \sigma R_{f,t} \Big] (Q_{s,t-1} + f_{s,t-1}(S_{r,t-1}))S_{r,t-1} \\
& + \Big[(\sigma + \zeta_r)R_{w,t} - \sigma R_{f,t} \Big] S^w_{r,t-1} \\
& + \Big[(\sigma + \zeta_r)R_{rg,t} - \sigma R_{f,t} \Big] (Q_{g,t-1} + f_{g,t-1}(B^g_{r,t-1}))B^g_{r,t-1} \\
& + \sigma R_{f,t}N_{r,t-1} - \sigma(R_{m,t} - R_{f,t})M_{t-1} \\
= & \Big(\Big[(\sigma + \zeta_r)R_{rs,t} - \sigma R_{f,t} \Big] b^{*s}_{r,t-1} + \Big[(\sigma + \zeta_r)R_{w,t} - \sigma R_{f,t} \Big] b^{*w}_{r,t-1} \\
& + \Big[(\sigma + \zeta_r)R_{rg,t} - \sigma R_{f,t} \Big] b^{*g}_{r,t-1} \Big) A_{r,t-1} \\
& + \sigma R_{f,t}N_{r,t-1} - \sigma(R_{m,t} - R_{f,t})M_{t-1} \\
= & \Big[(\sigma + \zeta_r)R_{rs,t} - \sigma R_{f,t} \Big] \Big(b^{*s}_{r,t-1} + b^{*w}_{r,t-1} + b^{*g}_{r,t-1} \Big) A_{r,t-1} \\
& + (\sigma + \zeta_r)(R_{w,t} - R_{rs,t})b^{*w}_{r,t-1}A_{r,t-1} \\
& + (\sigma + \zeta_r)(R_{rg,t} - R_{rs,t})b^{*g}_{r,t-1}A_{r,t-1} \\
& + \sigma R_{f,t}N_{r,t-1} - \sigma(R_{m,t} - R_{f,t})M_{t-1} \\
= & \Big(\Big[(\sigma + \zeta_r)R_{rs,t} - \sigma R_{f,t} \Big] + (\sigma + \zeta_r)(R_{rg,t} - R_{rs,t})b^{*g}_{r,t-1} \\
& + (\sigma + \zeta_r)(R_{w,t} - R_{rs,t})b^{*w}_{r,t-1} \Big) A_{r,t-1} \\
& + \sigma R_{f,t}N_{r,t-1} - \sigma(R_{m,t} - R_{f,t})M_{t-1} \\
= & \Big(\Big[(\sigma + \zeta_r)R_{rs,t} - \sigma R_{f,t} \Big] - (\sigma + \zeta_r)(R_{rs,t} - R_{rg,t})b^{*g}_{r,t-1} \\
& - (\sigma + \zeta_r)(R_{rs,t} - R_{w,t})b^{*w}_{r,t-1} \Big) A_{r,t-1} \\
& + \sigma R_{f,t}N_{r,t-1} - \sigma(R_{m,t} - R_{f,t})M_{t-1}.
\end{aligned}
$$

A.3 Verification of value function, shadow banks

Return to section. Start with

$$
\begin{aligned}
V_{w,t} &= \mathbb{E}_t \Lambda_{t,t+1} \left[(1-\sigma) n_{w,t+1} + \sigma V_{w,t+1} \right] \\
&= \mathbb{E}_t \Lambda_{t,t+1} \Bigg[(1-\sigma) \Big(\left(R_{ws,t+1} - R_{w,t+1} \right) Q_{s,t} s_{w,t} \\
&\quad + \left(R_{wg,t+1} - R_{w,t+1} \right) Q_{g,t} b^g_{w,t} + R_{w,t+1} n_{w,t} \Big) \\
&\quad + \sigma \Big(\mu_{ws,t+1} Q_{s,t+1} s_{w,t+1} + \mu_{wg,t+1} Q_{g,t+1} b^g_{w,t+1} \\
&\quad + \nu_{w,t+1} n_{w,t+1} \Big) \Bigg] \\
&= \mathbb{E}_t \Lambda_{t,t+1} \Bigg[(1-\sigma) \Big(\left(R_{ws,t+1} - R_{w,t+1} \right) Q_{s,t} s_{w,t} \\
&\quad + \left(R_{wg,t+1} - R_{w,t+1} \right) Q_{g,t} b^g_{w,t} + R_{w,t+1} n_{w,t} \Big) \\
&\quad + \sigma \Big(\mu_{ws,t+1} Q_{s,t+1} s_{w,t+1} + \mu_{wg,t+1} Q_{g,t+1} b^g_{w,t+1} \\
&\quad + \nu_{w,t+1} \Big(\left(R_{ws,t+1} - R_{w,t+1} \right) Q_{s,t} s_{w,t} \\
&\quad + \left(R_{wg,t+1} - R_{w,t+1} \right) Q_{g,t} b^g_{w,t} + R_{w,t+1} n_{w,t} \Big) \Big) \Bigg] \\
&= \mathbb{E}_t \Lambda_{t,t+1} \Bigg[\left(1 - \sigma + \sigma \nu_{w,t+1} \right) \Big[(R_{ws,t+1} - R_{w,t+1}) Q_{s,t} s_{w,t} \\
&\quad + (R_{wg,t+1} - R_{w,t+1}) Q_{g,t} b^g_{w,t} + R_{w,t+1} n_{w,t} \Big] \\
&\quad + \sigma \Big(\mu_{ws,t+1} Q_{s,t+1} s_{w,t+1} + \iota_t \mu_{ws,t+1} Q_{g,t+1} b^g_{w,t+1} \Big) \Bigg] \\
&= \mathbb{E}_t \Lambda_{t,t+1} \Bigg[\left(1 - \sigma + \sigma \nu_{w,t+1} \right) \Big[(R_{ws,t+1} - R_{w,t+1}) Q_{s,t} s_{w,t} \\
&\quad + (R_{wg,t+1} - R_{w,t+1}) Q_{g,t} b^g_{w,t} + R_{w,t+1} n_{w,t} \Big] \\
&\quad + \sigma \mu_{ws,t+1} \phi_{t+1} n_{w,t+1} \Bigg]
\end{aligned}
$$

continuing:

$$
\begin{aligned}
V_{w,t} = \mathbb{E}_t \Lambda_{t,t+1} \Bigg[& \big(1 - \sigma + \sigma \nu_{w,t+1}\big) \Big[(R_{ws,t+1} - R_{w,t+1}) Q_{s,t} s_{w,t} \\
& + (R_{wg,t+1} - R_{w,t+1}) Q_{g,t} b^g_{w,t} + R_{w,t+1} n_{w,t} \Big] \\
& + \sigma \mu_{ws,t+1} \phi_{t+1} \Bigg(\left(R_{ws,t+1} - R_{w,t+1}\right) Q_{s,t} s_{w,t} \\
& + \left(R_{wg,t+1} - R_{w,t+1}\right) Q_{g,t} b^g_{w,t} + R_{w,t+1} n_{w,t} \Bigg) \Bigg] \\
= \mathbb{E}_t \Lambda_{t,t+1} & \big(1 - \sigma + \sigma(\nu_{w,t+1} + \mu_{ws,t+1} \phi_{t+1})\big) \\
& \Big[(R_{ws,t+1} - R_{w,t+1}) Q_{s,t} s_{w,t} \\
& + (R_{wg,t+1} - R_{w,t+1}) Q_{g,t} b^g_{w,t} + R_{w,t+1} n_{w,t} \Big] \\
= \mathbb{E}_t \Omega_{w,t+1} & \Big[(R_{ws,t+1} - R_{w,t+1}) Q_{s,t} s_{w,t} \\
& + (R_{wg,t+1} - R_{w,t+1}) Q_{g,t} b^g_{w,t} + R_{w,t+1} n_{w,t} \Big]
\end{aligned}
$$

where

$$
\Omega_{w,t+1} = \mathbb{E}_t \Lambda_{t,t+1} \left(1 - \sigma + \sigma(\nu_{w,t+1} + \mu_{ws,t+1} \phi_{t+1})\right)
$$

A.4 Aggregation shadow banks

Return to section.

$$
\begin{aligned}
N_{w,t} = \sigma \Bigg[& (R_{ws,t} - R_{w,t}) Q_{s,t-1} S_{w,t-1} \\
& + (R_{wg,t} - R_{w,t}) Q_{g,t-1} B^{g}_{w,t-1} + R_{w,t} N_{w,t-1} \Bigg] \\
& + \zeta_w \Bigg[R_{ws,t} Q_{s,t-1} S_{w,t-1} + R_{wg,t} Q_{g,t-1} B^{g}_{w,t-1} \Bigg] \\
= & \Bigg[\sigma (R_{ws,t} - R_{w,t}) + \zeta_w R_{ws,t} \Bigg] Q_{s,t-1} S_{w,t-1} \\
& + \Bigg[\sigma (R_{wg,t} - R_{w,t}) + \zeta_w R_{wg,t} \Bigg] Q_{g,t-1} B^{g}_{w,t-1} \\
& + \sigma R_{w,t} N_{w,t-1} \\
= & \Bigg[(\sigma + \zeta_w) R_{ws,t} - \sigma R_{w,t} \Bigg] Q_{s,t-1} S_{w,t-1} \\
& + \Bigg[(\sigma + \zeta_w) R_{wg,t} - \sigma R_{w,t} \Bigg] Q_{g,t-1} B^{g}_{w,t-1} \\
& + \sigma R_{w,t} N_{w,t-1} \\
= & \Bigg(\Bigg[(\sigma + \zeta_w) R_{ws,t} - \sigma R_{w,t} \Bigg] b^{*s}_{w,t-1} \\
& + \Bigg[(\sigma + \zeta_w) R_{wg,t} - \sigma R_{w,t} \Bigg] b^{*g}_{w,t-1} \Bigg) A_{w,t-1} \\
& + \sigma R_{w,t} N_{w,t-1} \\
= & \Bigg[(\sigma + \zeta_w) R_{ws,t} - \sigma R_{w,t} \Bigg] \left(b^{*s}_{w,t-1} + b^{*g}_{w,t-1} \right) A_{w,t-1} \\
& + (\sigma + \zeta_w)(R_{wg,t} - R_{ws,t}) b^{*g}_{w,t-1} A_{w,t-1} \\
& + \sigma R_{w,t} N_{w,t-1} \\
= & \Bigg(\Bigg[(\sigma + \zeta_w) R_{ws,t} - \sigma R_{w,t} \Bigg] + (\sigma + \zeta_w)(R_{wg,t} - R_{ws,t}) b^{*g}_{w,t-1} \Bigg) A_{w,t-1} \\
& + \sigma R_{w,t} N_{w,t-1} \\
= & \Bigg(\Bigg[(\sigma + \zeta_w) R_{ws,t} - \sigma R_{w,t} \Bigg] - (\sigma + \zeta_w)(R_{ws,t} - R_{wg,t}) b^{*g}_{w,t-1} \Bigg) A_{w,t-1} \\
& + \sigma R_{w,t} N_{w,t-1}.
\end{aligned}
$$

B Main equation list

Return to section.

$$U_{C,t}W_t = \chi N_t^{\phi} \tag{1}$$

$$1 = \Lambda_{t,t+1}R_{f,t+1} \tag{2}$$

$$U_{C,t} = (C_t - hC_{t-1})^{-1} - \beta h\mathbb{E}_t\left(C_{t+1} - hC_t\right)^{-1} \tag{3}$$

$$\Lambda_{t,t+1} = \beta\frac{\mathbb{E}_t U_{C,t+1}}{U_{C,t}} \tag{4}$$

$$Y_{m,t} = A_t(\psi_t(s_t)K_{t-1})^{\alpha}(N_t^d)^{1-\alpha} \tag{5}$$

$$\log A_t = \rho_A \log A_{t-1} + \sigma_A\varepsilon_{A,t} \tag{6}$$

$$W_t = P_{m,t}(1-\alpha)\frac{Y_{m,t}}{N_t^d} \tag{7}$$

$$Z_t = P_{m,t}\alpha\frac{Y_{m,t}}{\psi_t(s_t)K_{t-1}} \tag{8}$$

$$\log\psi_t(s_t) = (1-\rho_\psi(s_t))\log\psi_{mean}(s_t) \tag{9}$$

$$+\rho_\psi(s_t)\log(\psi_{t-1})(s_{t-1}) + \sigma_{\psi,t}\varepsilon_{\psi,t} \tag{10}$$

$$K_t = S_t \tag{11}$$

$$K_t = (1-\delta)\psi_t(s_t)K_{t-1} + I_t \tag{12}$$

$$Q_{s,t} = 1 + F\left(\frac{I_t}{I_{t+1}}\right) + F'\left(\frac{I_t}{I_{t-1}}\right)\left(\frac{I_t}{I_{t-1}}\right) \tag{13}$$

$$-\mathbb{E}_t\Lambda_{t,t+1}F'\left(\frac{I_{t+1}}{I_t}\right)\left(\frac{I_{t+1}}{I_t}\right)^2 \tag{14}$$

$$\mathbb{E}_t\sum_{j=0}^{\infty}\zeta^j\Lambda_{t,t+j}\left[\frac{P_t^*}{P_{t+j}}\prod_{k=1}^{j}\pi_{t+k-1}^{\zeta_p} - \frac{\varepsilon}{\varepsilon-1}P_{m,t+j}\right]Y_{i,t+j} = 0 \tag{15}$$

$$P_t = \left[(1-\zeta)(P_t^*)^{1-\varepsilon} + \zeta(\pi_{t-1}^{\zeta_p}P_{t-1})^{1-\varepsilon}\right]^{\frac{1}{1-\varepsilon}} \tag{16}$$

$$R_{rs,t+1} = \frac{Z_{t+1} + (1-\delta)\psi_{t+1}(s_{t+1})Q_{s,t+1}}{Q_{s,t} + f_{s,t}(s_{r,t})} \tag{17}$$

$$R_{ws,t+1} = \frac{Z_{t+1} + (1-\delta)\psi_{t+1}(s_{t+1})Q_{s,t+1}}{Q_{s,t}} \tag{18}$$

$$R_{rg,t+1} = \frac{\eta + (1-\eta)(c + Q_{g,t+1})}{Q_{g,t} + f_{g,t}(B_{r,t}^g)} \tag{19}$$

$$R_{wg,t+1} = \frac{\eta + (1-\eta)(c + Q_{g,t+1})}{Q_{g,t}} \tag{20}$$

$$\mu_{rs,t} = \frac{1}{\gamma_t}\mu_{rw,t} \tag{21}$$

$$\mu_{rs,t} = \frac{1}{\iota_t}\mu_{rg,t} \tag{22}$$

$$\mu_{rs,t} = \frac{1}{\lambda}\mu_{m,t} \tag{23}$$

$$\phi_{r,t} = \frac{\nu_{r,t}}{\theta_t - \mu_{rs,t}} + \frac{\lambda M_t}{N_{r,t}} \tag{24}$$

$$\mu_{rs,t} = \mathbb{E}_t \Omega_{r,t+1} \left(R_{rs,t+1} - R_{f,t+1} \right) \tag{25}$$

$$\mu_{rw,t} = \mathbb{E}_t \Omega_{r,t+1} \left(R_{w,t+1} - R_{f,t+1} \right) \tag{26}$$

$$\mu_{rg,t} = \mathbb{E}_t \Omega_{r,t+1} \left(R_{rg,t+1} - R_{f,t+1} \right) \tag{27}$$

$$\mu_{m,t} = \mathbb{E}_t \Omega_{r,t+1} \left(R_{m,t+1} - R_{f,t+1} \right) \tag{28}$$

$$\nu_{r,t} = \mathbb{E}_t \Omega_{r,t+1} R_{f,t+1} \tag{29}$$

$$\Omega_{r,t+1} = \Lambda_{t,t+1} \left(1 - \sigma + \sigma(\nu_{r,t+1} + \mu_{rs,t+1} \phi_{r,t+1}) \right) \tag{30}$$

$$\begin{aligned} N_{r,t} = & \Bigg(\Bigg[(\sigma + \zeta_r) R_{rs,t} - \sigma R_{f,t} \Bigg] \\ & - (\sigma + \zeta_r)(R_{rs,t} - R_{rg,t}) b^{*g}_{r,t-1} \\ & - (\sigma + \zeta_r)(R_{rs,t} - R_{w,t}) b^{*w}_{r,t-1} \Bigg) A_{r,t-1} \end{aligned} \tag{31}$$

$$+ \sigma R_{f,t} N_{r,t-1} - \sigma (R_{m,t} - R_{f,t}) M_{t-1} \tag{32}$$

$$\mu_{ws,t} = \frac{1}{\iota_t} \mu_{wg,t} \tag{33}$$

$$\phi_{w,t} = \frac{\nu_{w,t}}{(\theta_t - \mu_{ws,t})} + \frac{\theta_t (1 - \omega) B^w_{w,t}}{(\theta_t - \mu_{ws,t}) N_{w,t}} \tag{34}$$

$$\mu_{ws,t} = \mathbb{E}_t \Omega_{w,t+1} \left(R_{ws,t+1} - R_{w,t+1} \right) \tag{35}$$

$$\mu_{wg,t} = \mathbb{E}_t \Omega_{w,t+1} \left(R_{wg,t+1} - R_{w,t+1} \right) \tag{36}$$

$$\nu_{w,t} = \mathbb{E}_t \Omega_{w,t+1} R_{w,t+1} \tag{37}$$

$$\Omega_{w,t+1} = \mathbb{E}_t \Lambda_{t,t+1} \left(1 - \sigma + \sigma(\nu_{w,t+1} + \mu_{ws,t+1} \phi_{t+1}) \right) \tag{38}$$

$$\begin{aligned} N_{w,t} = & \Bigg(\Bigg[(\sigma + \zeta_w) R_{ws,t} - \sigma R_{w,t} \Bigg] \\ & - (\sigma + \zeta_w)(R_{ws,t} - R_{wg,t}) b^{*g}_{w,t-1} \Bigg) A_{w,t-1} \end{aligned} \tag{39}$$

$$+ \sigma R_{w,t} N_{w,t-1} \tag{40}$$

$$T_t = T + \varsigma B^g_t \tag{41}$$

$$\begin{aligned} & Q_{g,t}(B^g_t - (1 - \eta) B^g_{t-1}) + (R_{m,t} - R_{f,t}) M_{t-1} \\ & \quad + (R_{rs,t} - R_{f,t}) \psi_{s,t-1} Q_{s,t-1} S_{t-1} \end{aligned} \tag{42}$$

$$= (G_t - T_t) + (\eta + (1 - \eta) c) B^g_{t-1} + \Xi_t(\psi_{g,t} Q_{g,t} B^g_t, \psi_{s,t} Q_{s,t} S_t, M_t) \tag{43}$$

$$i_t = (i + \kappa_\pi \pi_t + \kappa_y \widehat{y}_t) + \sigma_i \varepsilon_{i,t} \tag{44}$$

$$i_t = R_{f,t+1} \mathbb{E}_t \pi_{t+1} \tag{45}$$

$$\psi_{g,t} = \kappa_{g,t}(s_t) \mathbb{E}_t \Big[(R_{rg,t+1} - R_{f,t+1}) - (R_{rg} - R_f) \Big] + \rho_g(s_t) \psi_{g,t-1} \tag{46}$$

$$\psi_{s,t} = \kappa_{s,t}(s_t) \mathbb{E}_t \Big[(R_{rs,t+1} - R_{f,t+1}) - (R_{rs} - R_f) \Big] + \rho_s(s_t) \psi_{s,t-1} \tag{47}$$

$$\psi_{m,t} = \kappa_{m,t}(s_t) \mathbb{E}_t \Big[(R_{rs,t+1} - R_{f,t+1}) - (R_{rs} - R_f) \Big] + \rho_m(s_t) \psi_{m,t-1} \tag{48}$$

$$N_t^d = N_t \tag{49}$$

$$(1-\psi_{g,t})B_t^g = B_{r,t}^g + B_{w,t}^g \tag{50}$$

$$(1-\psi_{s,t})S_t = S_{r,t} + S_{w,t} \tag{51}$$

$$\psi_{m,t} = \frac{M_t}{Q_s S_t} \tag{52}$$

$$B_{w,t}^w = B_{r,t}^w \tag{53}$$

$$\begin{aligned} Y_t = C_t + \left[1 + F\left(\frac{I_t}{I_{t-1}}\right)\right] I_t + G_t \\ + F_{s,t}(S_{r,t}) + F_{g,t}(B_{r,t}^g) \end{aligned} \tag{54}$$

$$+ \Xi_t(\psi_{g,t} Q_{g,t} B_t^g, \psi_{s,t} Q_{s,t} S_t, M_t) \tag{55}$$

C Sensitivity Analysis ESP

This section presents the sensitivity analysis for the ESP formulation of the model with respect to the parameter b. The main experiments are repeated while varying b between 1 and 5. Figure 6 presents the results of the main exit experiment. The setup is identical to that in subsection 5.2. Differences between each b value and the baseline $b = 3$ are plotted.

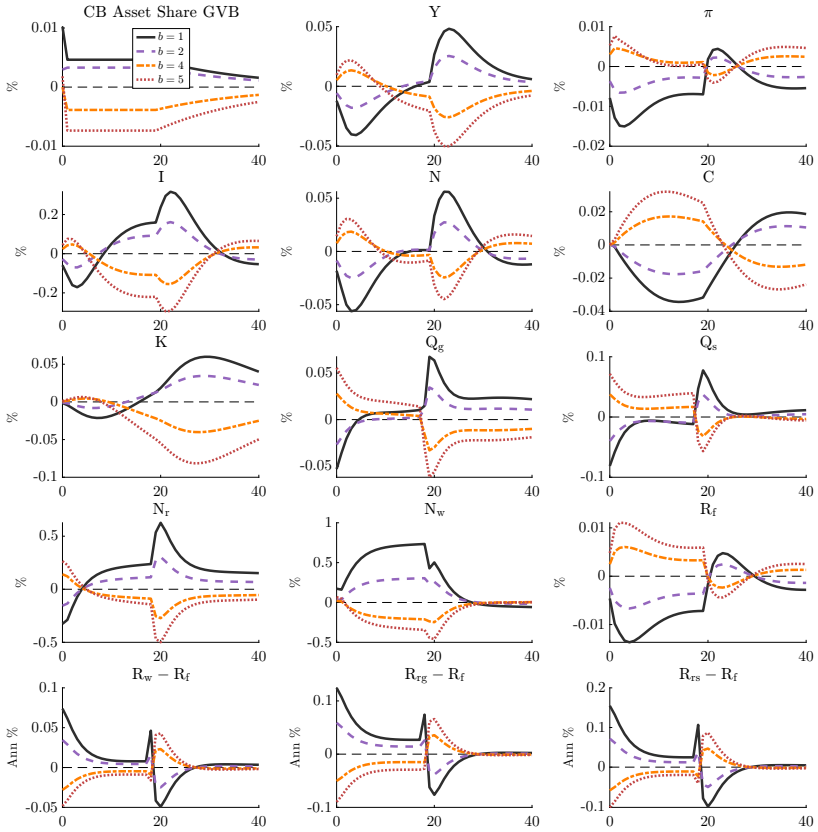

Figure 6: Exit Strategies, Sensitivity Analysis w.r.t. b. Plots show differences between different values of b and the baseline $b = 3$. Source: Own calculations.

Qualitatively, the results are similar across different values of b. Quantitatively, there are minor differences. Changing b affects Y by less than $|0.05|\%$ at its peak deviation from the $b = 3$ case and inflation by around $|0.015|\%$ at most. When the exit probability is more sensitive to changes in the inflation gap (higher b), the effects described in the main text become slightly amplified.

For higher b, direct impacts become slightly attenuated since the initial drop in inflation increases the expected holding duration to be longer. Agents internalize that deviations of inflation from target will have a larger impact on the exit probability. As inflation recovers, and agents become more concerned about the central bank exiting, they withhold investment for longer, slowing down the recovery of output while in the post-crisis regime. Conversely, agents are

also aware that the exit probability is more sensitive to the changing economic conditions, yielding some support to asset prices.

Table 4 presents maximum absolute deviations across different values of b for selected variables of the two other main experiments. The results mirror the discussion above, with no qualitative differences and only minor quantitative differences across different values of b.

Table 4: Sensitivity Analysis b

Var (%)	$b=1$			$b=2$			$b=3$			$b=4$			$b=5$		
Forward Guidance															
Exit Speed	0.00	0.50	0.95	0.00	0.50	0.95	0.00	0.50	0.95	0.00	0.50	0.95	0.00	0.50	0.95
Y	-0.006	-0.008	0.005	-0.011	-0.013	0.002	-0.014	-0.017	0.000	-0.017	-0.020	-0.001	-0.019	-0.021	-0.003
π	0.010	0.009	-0.003	0.013	0.011	-0.001	0.016	0.014	0.000	0.018	0.016	0.001	0.019	0.017	0.002
K	-0.013	-0.020	0.012	-0.024	-0.031	0.005	-0.031	-0.040	0.000	-0.037	-0.045	-0.004	-0.040	-0.047	-0.006
I	-0.014	-0.020	0.013	-0.025	-0.032	0.005	-0.032	-0.041	0.000	-0.038	-0.046	-0.004	-0.041	-0.048	-0.007
Q_g	-0.043	-0.042	0.020	-0.057	-0.057	0.008	-0.067	-0.068	0.000	-0.076	-0.076	-0.006	-0.080	-0.081	-0.012
Q_s	-0.031	-0.026	0.012	-0.038	-0.033	0.005	-0.045	-0.039	0.000	-0.050	-0.044	-0.004	-0.055	-0.048	-0.006
N_r	-0.261	-0.202	0.072	-0.319	-0.261	0.033	-0.365	-0.311	0.000	-0.400	-0.352	-0.028	-0.426	-0.386	-0.052
N_w	0.282	0.054	0.156	0.201	-0.019	0.048	0.156	-0.048	0.000	0.123	-0.050	-0.018	0.085	-0.044	-0.014
R_f	0.005	0.004	-0.002	0.006	0.005	-0.001	0.007	0.006	0.000	0.008	0.007	0.001	0.008	0.008	0.001
$R_w - R_f$	-0.011	-0.009	0.004	-0.014	-0.012	0.002	-0.015	-0.014	0.000	-0.017	-0.015	-0.001	-0.018	-0.017	-0.002
$R_{rg} - R_f$	-0.006	-0.004	0.001	-0.008	-0.006	0.001	-0.009	-0.006	0.000	-0.009	-0.007	-0.000	-0.010	-0.008	-0.001
$R_{rs} - R_f$	-0.014	-0.011	0.004	-0.017	-0.014	0.002	-0.020	-0.017	0.000	-0.022	-0.019	-0.001	-0.023	-0.021	-0.003
Portfolio Balance															
	Δ_g	Δ_m	Δ_s	Δ_g	Δ_m	Δ_s	Δ_g	Δ_m	Δ_s	Δ_g	Δ_m	Δ_s	Δ_g	Δ_m	Δ_s
Y	0.073	0.232	0.486	0.075	0.238	0.497	0.076	0.242	0.504	0.077	0.244	0.508	0.077	0.245	0.509
π	0.011	0.031	0.077	0.012	0.034	0.081	0.012	0.036	0.084	0.013	0.037	0.086	0.013	0.037	0.087
K	0.070	0.301	0.530	0.071	0.301	0.533	0.071	0.298	0.531	0.071	0.292	0.525	0.070	0.284	0.516
I	0.424	1.334	2.870	0.433	1.357	2.914	0.437	1.367	2.938	0.437	1.366	2.943	0.435	1.356	2.932
Q_g	0.156	0.367	0.802	0.156	0.370	0.813	0.157	0.373	0.824	0.158	0.377	0.836	0.159	0.381	0.848
Q_s	0.208	0.494	1.100	0.210	0.503	1.125	0.213	0.512	1.148	0.215	0.520	1.167	0.216	0.527	1.184
N_r	0.615	1.495	3.626	0.632	1.543	3.711	0.644	1.582	3.786	0.654	1.615	3.851	0.662	1.640	3.905
N_w	1.171	2.661	4.368	1.121	2.574	4.397	1.090	2.527	4.445	1.072	2.503	4.496	1.059	2.489	4.541
R_f	0.009	0.023	0.061	0.010	0.025	0.065	0.011	0.027	0.068	0.011	0.029	0.071	0.011	0.030	0.073
$R_w - R_f$	0.134	0.320	1.517	0.132	0.312	1.508	0.135	0.321	1.497	0.137	0.328	1.488	0.138	0.333	1.480
$R_{rg} - R_f$	0.296	0.846	2.185	0.284	0.820	2.167	0.276	0.801	2.151	0.270	0.785	2.138	0.265	0.774	2.127
$R_{rs} - R_f$	0.370	1.050	2.963	0.361	1.033	2.950	0.354	1.020	2.938	0.349	1.009	2.927	0.345	1.001	2.919

Portfolio Balance: max absolute percentage deviation from baseline ESP with all policies turned on. Forward Guidance: deviation from steady state at $b = 3$, $\rho_i = 0.95$, $i \in \{g, s, m\}$. Non-spread variables in percentage deviations, spreads in annual percentage point deviations from steady state. Source: Own calculations.

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