Empowering Central Bank Asset Purchases: The Role of Financial Policies *

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Abstract

This paper contributes to the debate on the macroeconomic effectiveness of expansionary non-standard monetary policy measures in a regulated banking environment. Based on an estimated DSGE model, we explore the interactions between central bank asset purchases and bank capital-based financial policies (be it regulatory, supervisory or macroprudential), through its influence on bank risk-shifting motives. We find that weakly capitalised banks display excessive risk-taking which reinforces the credit easing channel of central bank asset purchases, at the cost of higher bank default probability and lasting financial stability risks. In such a case, adequate bank capital demand through higher minimum capital requirements can curtail the excessive credit origination and restore a more efficient propagation of central bank asset purchases. Beyond the minimum capital requirements, supervisors can formulate further capital demands. Uncertainty about the supervisory oversight would provide a precautionary motive for banks to build extra capital buffer which might run against the non-standard monetary policy. Finally, with a well-capitalised banking system, macroprudential policy should look through the effects of central bank asset purchases on bank capital position as the costs in terms of macroeconomic stabilisation seem to outweigh the marginal financial stability benefits. On the contrary, in a weakly-capitalised banking system, a countercyclical macroprudential policy in conjunction with central bank asset purchases can mitigate banks risk-taking and dampen the excessive persistence of the non-standard monetary policy impulse on the real economy.

Keywords: DSGE models, regulatory uncertainty, non-standard measures, bank capital regulation, risk-taking.

JEL classification: E44, E52, F40.

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1 Introduction

After the financial crisis of 2008-2009, as short-term policy rates reached their effective lower bound (ELB), several central banks have embarked on various forms of non-standard measures, and notably asset purchase programmes. Some examples are the Large-Scale Asset Purchase programmes of the US Federal Reserve, the asset purchase facilities of the Bank of England and more recently the ECB's asset purchase programme (APP), which mainly includes the public sector purchase programme (PSPP). One consequence of such policies is the downward pressure on bank lending margins which might incentivise banks to undertake riskier investments (Borio and Zhu, 2012; Dell' Ariccia et al., 2016; Albertazzi et al., 2016). At the same time, the crisis led to a comprehensive overhaul of the regulatory and supervisory frameworks, reinforcing the risk prevention orientation of financial policies against the build-up of financial imbalances. Bank capital demands have been put in place to tame excessive leverage and unreasonable risk taking. At a given point in the cycle, such polices may run against the intended impact of non-standard monetary policy measures. Moreover, frequent changes in such bank capital demands based on micro and macroprudential considerations might increase the uncertainty about financial policies which in itself, could hamper the credit easing channel of non-standard monetary policy measures.

More precisely, in Europe, several financial policies formulate bank capital demands to banks. The EU Capital Requirements Regulation (CRR)[1] and the Directive (CRD IV)[2] lay down the minimum requirement of bank capital. As illustrated in Figure 1, the regulatory dimension applies to the constant minimum level of requirements, i.e. Pillar 1 (P1R). The overall capital demand also consists of Pillar 2 (P2R) supervisory requirements, which cover risks underestimated or not covered by Pillar 1, the capital conservation buffer (CCB) that focuses on the build up of capital buffers outside periods of stress, to be drawn down as losses are incurred, and the systemic risk buffer (SRB) that intends to increase the resilience of financial institutions with systemic relevance. The Supervisory Review and Evaluation Process (SREP)[3] of the ECB conducts yearly assessments of individual bank risks and recommends top-up capital demands through Pillar 2 guidance (P2G). Finally, the countercyclical capital buffer (CCyB)[4] is part of a set of macroprudential instruments which can be applied on systemically important financial institutions.

It is certainly beyond the scope of the present paper to build a macro-financial model which could encompass all the specific features of such bank capital-based financial policies. The salient aspects (or the stylised interpretation) of this policy apparatus which are relevant for the present analysis are threefold. First, the financial regulation sets minimum standards that are meant to be universal and stable trough time. This layer would be interpreted as a steady state feature of the structural model. Second, supervisory policy adds a layer which can vary significantly through the cross-section of the banking system but intends to be calibrated through-the-cycle. In our modelling framework, this layer could be introduced as a link between idiosyncratic bank risk and the supervisory capital demand. We will actually illustrate the need for supervisory policy not to generate uncertainty on its through-the-cycle calibration, notably in the context of central bank asset purchases. Third, some bank capital-based macroprudential instruments are expected to be implemented through a countercyclical rule. The relevant cyclical conditions for macroprudential policy might however differ

[1] EU (2013b)
[2] EU (2013a)
[3] EBA (2014)
[4] ESRB (2014) and more recent recommendations available in https://www.esrb.europa.eu/.

from the ones presiding upon monetary policy conduct.

This paper contributes to the debate on the macroeconomic effectiveness and strength of expansionary non-standard monetary policy measures in a regulated banking environment. The abovementioned layers of regulatory, supervisory and macroprudential bank capital demands, guide our analysis of the interaction with non-standard monetary policy measures. We explicitly study how incentives of banks to engage in risky projects affect the transmission of central bank asset purchases and evaluates the role of bank capital regulation. We shed some light on the hinderance that supervisory uncertainty might have on the effectiveness of non-standard monetary policy measures. And we assess in this context the potential benefits of countercyclical macroprudential policies.

We extend the dynamic stochastic general equilibrium (DSGE) model from Darracq Pariès and Kühl (2016) by introducing risk-taking motives of banks and bank capital policies. The model of Darracq Pariès and Kühl (2016) is estimated on euro area data and analyses the macroeconomic transmission of non-standard monetary measures through bank portfolio rebalancing frictions. We re-interpret such frictions and introduce a risk-taking behaviour of banks through limited liability under a deposit insurance scheme: bankers face idiosyncratic risks on their loan book return, and default when the return on asset is not sufficient to cover for the repayments due to deposits. In such a case, the deposit insurance agency serves the depositors and takes over the loan portfolio of the failed banker subject to resolution costs. Therefore, the bank has an incentive to take on risks beyond a socially optimal level. Banks engage in excessive leverage, providing a rationale for bank capital regulation which is implemented by imposing penalty costs if operating profits fall below the regulatory minimum.[5] The set of frictions also includes adjustment costs on bank government bond holdings which affect bank's portfolio decision between sovereign bonds and loan origination. The estimation model is meant to provide a realistic mapping of the euro area conditions and sufficient validity for the qualitative and quantitative implications of this analysis

This paper contributes to several strands in the literature. A broad literature looks at the channels of non-standard monetary policy through the banking sector (Chen et al., 2012; Darracq Pariès and Kühl, 2016; Darracq Pariès and Papadopoulou, 2018; Kühl, 2016). In this context, the portfolio rebalancing channel has been identified as one major transmission mechanism (Albertazzi et al., 2016; Bua and Dunne, 2017). The flattened yield curve stemming from central bank asset purchases, reduces the profitability of banks' maturity transformation activities. In their search for yield banks reallocate their investments from safe towards riskier assets that promise a higher return. Therefore, banks' tolerance for riskier assets raised the concerns about the possibility of the prolonged period of expansionary monetary policy to sow the seed for the next financial crisis (Stein, 2012; Woodford, 2012). The link between expansionary monetary policy, including non-standard measures, and bank risk-taking has been studied by a growing literature (Afanasyeva and Günter, 2015; Dell'Ariccia et al., 2014; Lambert and Ueda, 2014; Lamers et al., 2016). Most empirical contributions (Albertazzi et al., 2016; Dell' Ariccia et al., 2016; Lambert and Ueda, 2014) identify a negative relationship between the interest rate and bank risk-taking over the medium-term since lower returns from safe assets encourage banks to reshuffle their portfolios towards loans. Evidence also exists for a positive relationship when favorable economic conditions relaxes banks' incentives to seek higher non-risk adjusted returns (Altavilla et al., 2017). Overall, ample empirical evidence vindicates the presence

[5] This modelling approach exerts an occasionally binding capital constraint. Most contributions in the literature model a bank capital constraint which always binds. Karmakar (2016) provides another model approach where through a penalty function approach the capital constraint binds occasionally.

of a monetary policy risk-taking channel which the model in this paper intends to capture.

Another strand of literature has explored the structural foundations of bank risk-shifting motives. The agency problem associated with asymmetric information between banks and depositors can, in combination with limited liability for banks, exacerbate banks' risk-taking (Clerc et al., 2015; Cooper and Ross, 2002; Darracq Pariès et al., 2016; Gertler et al., 2012). As another essential determinant, low bank profitability resulting from lower net interest rate margins during expansionary monetary policy might drive banks to reduce the risk premium charged for loans. By doing so, banks tolerate extraordinary higher risk levels (Aikman et al., 2015; Kühl, 2016; Lamers et al., 2016). By extending more lending at lower borrowing costs, banks compensate lower margins with higher leverage, at the cost of higher probability of default. Moreover, the competition between banks which prompts banks to underbid each other's prices induces them to accept lower credit-worthiness of borrowers (Coimbra and Rey, 2017; Döttling, 2018). In general, weakly-capitalized banks or, put differently, banks with a high leverage ratios, are more responsive to take on risks as monetary policy turns accommodative (Borio and Zhu, 2012; Budrys et al., 2017; Dell'Ariccia et al., 2014).

Furthermore, bank capital regulation which aims at reducing the negative externality of excessive leverage and risk-taking of banks has been analysed extensively in the literature (Bianchi et al., 2016; Christiano and Ikeda, 2016; Clerc et al., 2015; Darracq Pariès et al., 2016; Korinek and Simsek, 2016). Stricter bank capital requirements impel banks to extend loans to borrowers with good quality collateral, whereby lending volumes decline during the transitory period. Moreover, banks' shareholders have an interest to increase banks' capital ratios by reducing risk-weighted assets instead of raising new capital, thereby contributing to financial stability (Admati et al., 2013). Based on the finding that risk-weighted bank capital ratios are procyclical, Benes and Kumhof (2015), Clancy and Merola (2017) and William and Zilberman (2016) find welfare gains from attenuating this distortion through countercyclical bank capital requirements.

Ultimately, an emerging stream of literature evaluates the interplay between bank capital regulation and monetary policy. Greater resilience of the banking sector stabilises credit supply, supporting the transmission of monetary policy actions. Along with the financial stability benefits, the bank lending channel in a well-capitalised financial sector is less sensitive to standard and non-standard monetary actions (Aghion and Kharroubi, 2014; Gambacorta and Mistrulli, 2004). Hence, well-capitalised banking system requires monetary policy to react more aggressively as its bank lending channel becomes less effective (Rubio and Carrasco-Gallego, 2016). Extended periods of low interest rates and tight bank capital regulation can be socially suboptimal when regulated banks involve in risk-taking by engaging in collusion (Tressel and Verdier, 2014). Moreover, the bound on interest rates are found to invert the stabilisation gains from bank capital regulation. As the bound prevents the bank from passing on the costs of capital to depositors, banks tend to take on higher risks (Döttling, 2018). *Ex ante* implemented macroprudential policy measures contain the aggregated demand externality of leverage which arises because high debt levels aggravate the situation of constrained monetary policy (Dogra, 2014; Farhi and Werning, 2016; Ferrero et al., 2017; Korinek and Simsek, 2016; Lewis and Villa, 2017).

This paper also contributes to the limited literature on financial and regulatory uncertainty. Empirical evidence suggests that banks facing higher uncertainty self-insure by holding higher capital positions. Thus, the pure uncertainty reinforces the pro-cyclicality of increasing the capital position relative to assets (Valencia, 2016). In contrast to these contributions, this paper looks explicitly at the interaction between capital constraints, the risk-taking channel and non-standard monetary policy.

The findings of this paper covers several dimensions. ***First***, we show that in a weakly-capitalised banking system, risk-taking motives caused by limited liability together with a deposit insurance scheme reinforces the credit easing effects of central bank asset purchases, thereby compounding the associated financial stability risks. In the model, central bank asset purchases compress government bonds yields and, through portfolio rebalancing, reduce banks credit intermediation margins. With low initial bank capital position, risk-shifting motives increase the strength of banks' portfolio rebalancing from government bonds towards loans. Excessive credit origination spurs sizable and protracted macroeconomic support to the real economy. However, this comes at the cost of higher bank default probability which can endanger financial stability.

In this case, higher capital requirements effectively can deter banks risk-shifting and restore a more efficient transmission mechanism of central bank asset purchases. Through the regulatory constraint, banks internalize the pecuniary externality associated with excessive bank leverage (Bianchi and Mendoza, 2013): extreme levels of bank leverage can indeed act as a financial accelerator and hence, intensify downturns. Starting from a weakly-capitalised banking system, we show that the economic stimulus of asset purchases is largely preserved with higher bank capital requirements, despite reduced lending. The financial stability risks of the non-standard monetary policy measure are then drastically reduced.

Second, while steady state minimum capital requirements should be set high enough to deter bank risk-shifting incentives, uncertainty about the cyclical conduct of the other financial policy layers could in itself hamper the intended transmission of non-standard monetary policy measures. Given the significant degree of discretion within supervisory reviews, we consider the case of an uncertainty shock on supervisory capital demand in conjunction with central bank asset purchases. The self-insurance motive of banks encourages them to accumulate costly bank equity. As a result banks are reluctant to pass on favorable financing conditions stemming from the monetary stimulus which weakens and delays the expansionary macroeconomic impact.

Third, during times of central bank asset purchases, countercyclical macroprudential rules can contain excessive risk-taking by banks but at a cost in terms of macroeconomic stabilization. We consider the macroprudential rule proposed by the ESRB by which capital demands react to the credit to annual GDP gap. The rule brings about tighter bank capital regulation and mutes the economic stimulus of central bank asset purchases. This is not accompanied by tangible improvement in financial stability when the banking system is well-capitalised to start with. Macroprudential policy should in this case look through the effects of the central bank asset purchases on bank balance sheets and adopt a general equilibrium perspective. Conversely, with fragile bank balance sheets, the combination of central bank asset purchases with macroprudential feedback provides strong safeguards against the potential financial stability risks of the non-standard measures. The macroprudential intervention actually substitutes for too lax minimum capital requirements and leans against excessive loan origination.

The remainder of this paper is organized as follows. Section 2 describes the model. Subsequently, Section 3 discusses the calibration and estimation of the model using Bayesian techniques. In Section 4, discusses the main simulation exercises by studying the macroeconomic impact of central bank asset purchases and bank capital regulation on risk-taking. The analysis also covers the influence of regulatory uncertainty and macroprudential policies. Subsequently, Section 5 summarizes and concludes.

2 The model economy

The model consists of following agents; households, intermediate labour union and labour packers, intermediate and final goods-producing firms, capital producers and non-financial firms (called entrepreneurs) investing into capital projects, banks, retail lending branches and loan officers who intermediate funds to the projects of non-financial firms, government and monetary authority. Both entrepreneurs and banks are exposed to endogenous borrowing constraints. Due to the fact that the loan market operates under imperfect competition, financial frictions and market power in the loan market create inefficiencies in borrowing conditions. The real sector is rather standard and features staggered prices and wages.

The model bases upon Smets and Wouters (2007) regarding the real sector and combines elements in the banking sector from Benes et al. (2014), Darracq Pariès et al. (2011), Darracq Pariès and Kühl (2016), and Kühl (2016). The modelling approach for bank capital regulation follows Jakab and Kumhof (2015). Furthermore banking sector features, like bank default and the institutionalization of deposit insurance, follow Clerc et al. (2015). The model economy evolves along a balanced-growth path driven by a positive trend, γ, in the technological progress of the intermediate goods-production and a positive steady state inflation rate, $\pi^{\star}$.[6]

2.1 Households

The economy is populated by a continuum of heterogenous infinitely-lived households, where each household is characterized by the quality of its labour services, $h \in [0, 1]$, and have access to financial markets.

The representative household enters period t with $D_{t-1}(h)$ units of deposits, with $R_{D,t-1}$ being the one period ahead nominal gross deposit rate and $B_{H,t-1}(h)$ units of government bonds with $R_{G,t-1}$ and $Q_{B,t}$ being the gross return and the price of government bonds, respectively.

During period t, households purchase $C_t(h)$ units of consumption, decide on the amount of units of deposit holdings to financial intermediaries $D_t(h)$ and on the amount of government bond holdings $B_{H,t}(h)$, with the latter being subject to quadratic portfolio adjustment costs that prevent them from frictionless arbitrage of their returns on securities, are defined as follows

$$\frac{1}{2}\chi_H \left(B_{H,t}(h) - \overline{B}_H\right)^2 \tag{1}$$

where $\overline{B}_H$ is the steady state level of government bonds holdings while χ_H denotes the portfolio adjustment cost parameter.

Furthermore, during period t, households supply $N_t^S(h)$ units of labor at the nominal wage W_t^h net of time-varying labor tax $\tau_{w,t}$.

At the end of period t, the household receives nominal transfers from the government at the amount $T_t(h)$ and a nominal stream of income $A_t(h)$ coming from state contingent securities arising

[6] In the description of the model, stock and flow variables are expressed in real and effective terms (except if mentioned otherwise). They are deflated by the price level and the technology-related balanced growth path trend.

from equating the marginal utility of consumption across households $h \in [0,1]$. Furthermore, it receives real profits $\Pi_t(h)$ net of transfers from the various productive and financial segments owned by the households. The household then faces the following budget constraint

$$
\begin{aligned}
& D_t(h) + Q_{B,t}\left[B_{H,t}(h) + \frac{1}{2}\chi_H\left(B_{H,t}(h) - \overline{B}_H\right)^2\right] + C_t(h) \\
= \; & \frac{R_{D,t-1}D_{t-1}(h) + R_{G,t}Q_{B,t-1}B_{H,t-1}(h)}{\gamma\pi_t} + \frac{(1-\tau_{w,t})\,W_t^h N_t^S(h) + A_t(h) + T_t(h)}{P_t} + \Pi_t(h)
\end{aligned} \tag{2}
$$

where P_t is an aggregate price index, $\pi_{t+1} = P_{t+1}/P_t$ is the one-period ahead inflation rate and W_t^h, $A_t(h)$ and $T_t(h)$ are expressed in effective terms.

The generic household h at time t obtains utility from consumption of an aggregate index $C_t(h)$, relative to internal habits depending on its past consumption, while receiving disutility from the supply of its homogenous labour $N_t^S(h)$. The instantaneous household utility $\mathcal{U}$ has the following functional form

$$
\mathcal{U}_t(h) \equiv \frac{\left(C_{t+j}(h) - \frac{\eta C_{t+j-1}(h)}{\gamma}\right)^{1-\sigma_c}}{1-\sigma_c}\exp\left(\widetilde{L}\frac{(\sigma_c-1)}{(1+\sigma_l)}N_{t+j}^S(h)^{1+\sigma_l}\right) \tag{3}
$$

where $\widetilde{L}$ is a positive scale parameter, σ_c is the intertemporal elasticity of substitution, η is the habit's parameter and σ_l is the inverse of the elasticity of work effort with respect to the real wage (Frisch elasticity).

The household, therefore, chooses $C_t(h)$, $N_t^S(h)$, $D_t(h)$ and $B_{H,t}(h)$ to maximise its intertemporal utility function defined as follows

$$
\mathcal{W}_t(h) = \max_{\{C_t(h),N_t^S(h),D_t(h),B_{H,t}(h)\}} \mathbb{E}_t\sum_{j=0}^{\infty}\left(\beta\gamma^{1-\sigma_c}\right)^j \varepsilon_{t+j}^b\,\mathcal{U}\left(C_{t+j}(h) - \frac{\eta C_{t+j-1}(h)}{\gamma}, N_{t+j}^S(h)\right) \tag{4}
$$

where β is the rate of time preference and ε_t^b is a consumption preference shock.

In equilibrium, households' choices in terms of consumption, hours, deposit and government bond holdings are identical and its first order conditions are as follows, respectively

$$
\varepsilon_t^b\frac{\exp\left(\widetilde{L}\frac{(\sigma_c-1)}{(1+\sigma_l)}(N_t^S)^{1+\sigma_l}\right)}{1-\sigma_c} = \beta\eta\gamma^{-\sigma_c}\mathbb{E}_t\left[\varepsilon_{t+1}^b\frac{\exp\left(\widetilde{L}\frac{(\sigma_c-1)}{(1+\sigma_l)}(N_{t+1}^S)^{1+\sigma_l}\right)}{1-\sigma_c}\right] + \Lambda_t \tag{5}
$$

$$
\varepsilon_t^b\widetilde{L}(\sigma_c-1)(N_t^S)^{\sigma_l}\mathcal{U}_t = \Lambda_t\frac{(1-\tau_{w,t})\,W_t^h}{P_t} \tag{6}
$$

$$
\mathbb{E}_t\left[\Xi_{t,t+1}\frac{R_{D,t}}{\pi_{t+1}}\right] = 1 \tag{7}
$$

$$
\mathbb{E}_t\left[\Xi_{t,t+1}\frac{R_{G,t+1}}{\pi_{t+1}}\right] = 1 + \chi_H\left(B_{H,t} - \overline{B}_H\right) \tag{8}
$$

where Λ_t is the lagrange multiplier associated with the budget constraint and $\Xi_{t,t+1} = \beta\gamma^{-\sigma_c}\frac{\Lambda_{t+1}}{\Lambda_t}$ is the period t stochastic discount factor of the households for nominal income streams at period $t+1$.

2.2 Banks

The banking sector is owned by the households and is segmented in various parts. Bankers collect household deposits and provide funds to the retail lending branches. In doing so, they face capital requirements which are sensitive to the riskiness of the loan contract, forcing them to hoard a sufficient level of equity and benefiting from limited liability under a deposit insurance scheme. Furthermore, by introducing capital requirements that are sensitive to the state of the economy, the inherent cyclicality in banks' lending behaviour is likely to be reinforced, as shown in Darracq Pariès et al. (2011). *Ceteris paribus*, a risk-sensitive capital requirements regime (i.e. the Basel II or Basel III capital adequacy framework; see BIS (2004)) is expected to have pro-cyclical effects. Bankers devote endogenously their funds to government bonds and loans to the retail branch of the bank. Thereby, banks are constrained by adjustment costs on banks' bond holdings. Furthermore, banks may also default when their return on assets is not sufficient to cover their deposit repayments. Retail lending branches receive funding from the bankers and allocate it to the loan officers. In the retail segment, a second wedge results from banks operating under monopolistic competition by facing nominal rigidity in their interest rate setting. Last, loan officers extent loan contracts to entrepreneurs as explained previously, which implies a third financing cost wedge related to credit risk compensation.

2.2.1 Bankers

Every period a fraction $(1-f)$ of household's members are workers, a fraction fe are entrepreneurs while the remaining mass $f(1-e)$ are bankers. Bankers face a probability ζ_b of staying banker over next period and probability $(1-\zeta_b)$ of becoming a worker again. When a banker exit, accumulated earnings are transferred to the respective household while newly entering bankers receive initial funds from their household. Overall, households transfer a real amount $\Psi_{B,t}$ to new bankers for each period t.[7]

Bankers operate in competitive markets providing loans to retail lending branches, $L_{BE,t}$. They can also purchase government securities, $B_{B,t}$, at price $Q_{B,t}$. To finance their lending activity, bankers receive deposits, D_t, from households, with a gross interest rate $R_{D,t}$ and accumulate net worth, $NW_{B,t}$. Their balance identity, in real terms, reads as follows

$$L_{BE,t} + Q_{B,t}B_{B,t} = D_t + NW_{B,t}. \tag{9}$$

Bankers' assets are subject to idiosyncratic shocks, $\omega_{b,t}$, independent and identically distributed across time and across bankers. $\omega_{b,t}$ follows a lognormal cumulative distribution function (CDF) $F_b(\omega_{b,t})$, with mean 1 and variance σ_b.

Alike for households, purchasing and selling of government bonds poses quadratic costs to the banker of

$$\varrho_t NW_{B,t} = \frac{1}{2}\chi_B \left(\frac{Q_{B,t}B_{B,t}}{NW_{B,t}} - \frac{\overline{Q}_B \overline{B}_H}{\overline{NW}_B} \right)^2 NW_{B,t}. \tag{10}$$

The implementation of portfolio costs for banks and households assure that limits to arbitrage exist across the short-term and long-term bond market, which implies that the long rate is not the expected

[7] As shown later in this section, bankers' decisions are identical so the decision problem is exposed for a representative banker.

average of short rates, therefore creating a term premium. As a consequence, the Wallace Irrelevance proposition of full arbitrage between asset classes does not hold (Chen et al., 2012; Eggertsson and Woodford, 2003). With this friction, public asset purchases are effective in influencing the relative price of both asset classes that are imperfect substitutes.

The operating profit of a banker for period $t+1$, OP^b_{t+1}, results from the gross interest received from the loans to the retail lending bank, the return on sovereign bond holding, the lump-sum share of profits (and losses) coming from retail lending branches and loan officers activity, $\Pi^R_{B,t}$, pro-rated according to each banker's net worth, minus the gross interest paid on deposits, defined as follows

$$OP^b_{t+1}\left(\omega_{b,t+1}\right) \equiv \omega_{b,t+1} R_{BLE,t} L_{BE,t} + R_{G,t+1} Q_{B,t} B_{B,t} - \varrho_t NW_{B,t} - R_{D,t} D_{B,t} + \Pi^R_{B,t+1} \tag{11}$$

where $R_{BLE,t}$ is the banker's financing rate. As every bank holds a diversified portfolio such that its share in loans managed by the retail branches is equal to its share in aggregate loans, it also holds a proportional share of loan losses.

The first key assumption in the decision problem of bankers relates to *limited liability*, resulting in payoffs that are always positive, i.e. bankers default when their return on asset is not sufficient to cover the repayments due to deposits. Therefore, the corresponding constraint is

$$OP^b_{t+1} \geq 0 \tag{12}$$

and is not holding for draws of $\omega_{b,t+1}$ that fall below the threshold $\overline{\omega}_{b,t+1}$ given by

$$\overline{\omega}_{b,t+1} \equiv \frac{R_{D,t} D_t - R_{G,t+1} Q_{B,t} B_{B,t} + \varrho_t NW_{B,t} - \Pi^R_{B,t+1}}{R_{BLE,t} L_{BE,t}}. \tag{13}$$

Denoting the leverage ratios for loans and government bonds as $\kappa^l_{B,t} = \frac{L_{BE,t}}{NW_{B,t}}$ and $\kappa^g_{B,t} = \frac{Q_{B,t} B_{B,t}}{NW_{B,t}}$, respectively, the default cutoff point can be expressed as follows

$$\overline{\omega}_{b,t+1} \equiv \frac{R_{D,t}\left(\kappa^l_{B,t} + \kappa^g_{B,t} - 1\right) - R_{G,t+1}\kappa^g_{B,t} - \frac{\Pi^R_{B,t+1}}{NW_{B,t}} + \varrho_t}{\kappa^l_{B,t} R_{BLE,t}}. \tag{14}$$

Deposit insurance takes over banks' default risk. When bankers default occurs, the deposit insurance agency serves the depositors and takes over the loan portfolio of the failed banker subject to resolution costs, μ_b, expressed as a fraction of the banker's assets and defined as follows

$$\Omega_{b,t} \equiv \left[\overline{\omega}_{b,t} - \Gamma_b\left(\overline{\omega}_{b,t}\right) + \mu_b \int_0^{\overline{\omega}_{b,t+1}} \omega \mathrm{d}F_b\left(\omega\right)\right] R_{BLE,t} L_{BE,t}. \tag{15}$$

If bankers do not default, the second key assumption in the decision problem of bankers relates to a regulatory *penalty*

$$\chi_b\left(L_{BE,t} + Q_{B,t} B_{B,t}\right)$$

which is imposed if operating profit is less than a fraction of each risk weighted asset class. Thereby, ν_b denotes the bank capital requirement for loans and ν_g the minimum fraction for government bonds, respectively. Therefore, the corresponding non-binding constraint is

$$OP^b_{t+1} > \nu_b \left(\omega_{b,t+1} R_{BLE,t} L_{BE,t}\right) + \nu_g \left(R_{G,t+1} Q_{B,t} B_{B,t}\right) \tag{16}$$

where χ_b is the regulatory penalty and both constraints are exogenously taken into the bankers' decision. In order to minimise the risk of violating bank capital requirements, bankers decide on holding excess capital. The bank capital buffer as well as the bank balance sheet composition is endogenously determined by each bank.

Therefore, the penalty will be paid for realisations of $\omega_{b,t+1}$ which imply that bankers operating profits fall below the certain fraction of risk-weighted assets specified above. In this respect, the second threshold $\overline{\omega}^{\nu}_{b,t+1} > \overline{\omega}_{b,t+1}$ is given by

$$\overline{\omega}^{\nu}_{b,t+1} \equiv \frac{R_{D,t}\left(\kappa^l_{B,t} + \kappa^g_{B,t} - 1\right) - \left(1-\nu_g\right) R_{G,t+1}\kappa^g_{B,t} - \frac{\Pi^R_{B,t+1}}{NW_{B,t}} + \frac{1}{2}\chi_B\left(\kappa^g_{B,t} - \overline{\kappa}^g_B\right)^2}{\left(1-\nu_b\right)\kappa^l_{B,t} R_{BLE,t}}. \tag{17}$$

Based on the above two key assumptions, the expected return on net worth from period t to $t+1$ can be expressed as follows

$$\mathbb{E}_t \left\{ \begin{array}{c} \widetilde{E}\left[OP^b_{t+1}\left(\omega_{b,t+1}\right) \mid \omega_{b,t+1} \geq \overline{\omega}_{b,t+1}\right] \\ -\widetilde{E}\left[\chi_b\left(L_{BE,t} + Q_{B,t}B_{B,t}\right) \mid \overline{\omega}_{b,t+1} \leq \omega_{b,t+1} \leq \overline{\omega}^{\nu}_{b,t+1}\right] \end{array} \right\} \tag{18}$$

where $\widetilde{E}$ is the conditional expectation operator for the cross-section distribution of idiosyncratic banker returns on private loans. After some manipulations, the one-period return on bank's net worth, $R^B_{N,t+1}$, can be formulated as

$$R^B_{N,t+1} \equiv R_{BLE,t}\kappa^l_{B,t}\left[1 - \Gamma_b\left(\overline{\omega}_{b,t+1}\right)\right] - \chi_b\left(\kappa^l_{B,t} + \kappa^g_{B,t}\right)\left(F\left(\overline{\omega}^{\nu}_{b,t+1}\right) - F\left(\overline{\omega}_{b,t+1}\right)\right) \tag{19}$$

where $\Gamma_b(\overline{\omega})$ is defined as follows

$$\Gamma_b(\overline{\omega}) \equiv (1 - F_b\left(\overline{\omega}\right))\overline{\omega} + \int_0^{\overline{\omega}} \omega \mathrm{d}F_b\left(\omega\right). \tag{20}$$

Given bankers' myopic view, each banker maximizes its expected next period return to net worth summarized by equation (18) for the exposures to private sector loans $\kappa^l_{b,t}$ and government securities $\kappa^g_{b,t}$, specified as follows

$$\max_{\{\kappa^l_{b,t},\kappa^g_{b,t}\}} \mathbb{E}_t\left[\Xi_{t,t+1}\frac{R^B_{N,t+1}NW_{B,t}}{\gamma\pi_{t+1}}\right] \tag{21}$$

subject to the banks' idiosyncratic cutoff values given by equations (14) and (17).[8]

[8] The stream of transfers $\Pi^R_{B,t+1}$ are considered exogenous by bankers in their decision problem which implies that $\frac{\partial \Pi^R_{B,t+1+s}}{\partial \kappa^*_{B,t}} = 0$.

The first order conditions for this problem can then be formulated as follows

$$\mathbb{E}_t \left[\Xi_{t,t+1} \frac{\partial R^B_{N,t+1}}{\partial \kappa^l_{B,t}} \diagup \pi_{t+1} \gamma \right] = 0 \tag{22}$$

$$\mathbb{E}_t \left[\Xi_{t,t+1} \frac{\partial R^B_{N,t+1}}{\partial \kappa^g_{B,t}} \diagup \pi_{t+1} \gamma \right] = 0 \tag{23}$$

The partial derivatives of bankers net return on net worth with respect to $\kappa^l_{B,t}$ and $\kappa^g_{B,t}$, after some manipulations, are expressed as follows

$$\begin{aligned} \frac{\partial R^B_{N,t+1}}{\partial \kappa^l_{B,t}} &= R_{BLE,t} \left(1 - \int_0^{\overline{\omega}_{b,t+1}} \omega \mathrm{d}F_b(\omega) \right) - R_{D,t} \left(1 - F_b\left(\overline{\omega}_{b,t+1}\right)\right) \\ &-\chi_b \left[\begin{array}{c} \left(F\left(\overline{\omega}^{\nu}_{b,t+1}\right) - F\left(\overline{\omega}_{b,t+1}\right)\right) \\ +\mathcal{K}_t \frac{\mathrm{d}F_b\left(\overline{\omega}^{\nu}_{b,t+1}\right)}{(1-\nu_b)} \left(R_{D,t} - (1-\nu_b)\,\overline{\omega}^{\nu}_{b,t+1} R_{BLE,t}\right) \\ -\mathcal{K}_t \mathrm{d}F_b\left(\overline{\omega}_{b,t+1}\right)\left(R_{D,t} - \overline{\omega}_{b,t+1} R_{BLE,t}\right) \end{array} \right] \end{aligned} \tag{24}$$

and

$$\begin{aligned} \frac{\partial R^B_{N,t+1}}{\partial \kappa^g_{B,t}} &= \left(R_{G,t+1} - R_{D,t} - \chi_B\left(\kappa^g_{B,t} - \overline{\kappa}^g_B\right)\right)\left(1 - F_b\left(\overline{\omega}_{b,t+1}\right)\right) \\ &-\chi_b \left[\begin{array}{c} \left(F\left(\overline{\omega}^{\nu}_{b,t+1}\right) - F\left(\overline{\omega}_{b,t+1}\right)\right) \\ +\mathcal{K}_t \frac{\mathrm{d}F_b\left(\overline{\omega}^{\nu}_{b,t+1}\right)}{(1-\nu_b)} \left(R_{D,t} - (1-\nu_g)\,R_{G,t+1} + \chi_B\left(\kappa^g_{B,t} - \overline{\kappa}^g_B\right)\right) \\ -\mathcal{K}_t \mathrm{d}F_b\left(\overline{\omega}_{b,t+1}\right)\left(R_{D,t} - R_{G,t+1} + \chi_B\left(\kappa^g_{B,t} - \overline{\kappa}^g_B\right)\right) \end{array} \right] \end{aligned} \tag{25}$$

where $\mathcal{K}_t$ is it defined as follows

$$\mathcal{K}_t \equiv \frac{\kappa^l_{B,t} + \kappa^g_{B,t}}{R_{BLE,t}\kappa^l_{B,t}}.$$

Next, we disentangle how the three main frictions, namely bank capital regulation, portfolio adjustment costs and limited liability shape the transmission channels of the banking sector. ***First***, regarding bank capital regulation the return from loans and bonds are equal to the banks' funding costs plus a premium that depends on the penalty costs from breaching the bank capital requirement. The bank internalizes the probability weighted penalty payments that would arise in case of violation of the constraint. Accordingly, the banks' endogenous choice of the leverage ratios balances the costs of excess bank capital against the regulatory charges from high intermediation activity. As mentioned before, the bank optimally holds a buffer on top of the regulatory capital constraint. It is important to note that the friction diminishes the return on net worth or said differently, detracts the interest rate margin with adverse impact on bank lending.

Second, the direct effect of portfolio adjustment cost results in the compression of the government bond margin. As central bank asset purchases diminish the excess return on long-term bonds, it renders other asset classes more preferable in terms of yield which incentivices the bank to re-shuffle their portfolio towards loans. This happens due to the fact that decreasing term premiums, that arise when market fragmentation across maturities, cause deviations from the expectation hypothesis.

Third, the deposit insurance prevents individual bankruptcy risks of banks' loan book to materialise while inducing moral hazard which both optimality conditions reflect.[9] Consequently, banks are motivated to misprice risks by offering lower financing costs for loans, as shown in equation (24). With this distortion the risk contingent expected return from loans elevates supporting credit issuance to the bank. In turn the friction lowers the expected return of government holdings relative to loans. This reflects weaker limits to arbitrage from the safe assets while driving the propagation of the portfolio rebalancing channel. Therefore, the term associated with bank capital requirements compensates partly the idiosyncratic risk distortion. This specific feature of the model underlines the importance of tight bank capital regulation to ascertain sustained bank leverage.

Finally, aggregating across bankers, a fraction ζ_b continues operating into the next period while the rest exits from the industry. The new bankers are endowed with starting net worth, $\Psi_{B,t}$, proportional to the assets of the old bankers. Accordingly, the aggregate dynamics of bankers' net worth is given by

$$NW_{B,t} = \zeta_b R^B_{N,t} \frac{NW_{B,t-1}}{\gamma \pi_t} + \Psi_B. \tag{26}$$

The aggregation across bankers allows us to define the average capital buffer across banks in terms of total asset, $A_t = L_{BE,t} + Q_{B,t} B_{B,t}$, as follows

$$K_{B,t+1} = \frac{(R_{BLE,t} L_{BE,t} + R_{G,t+1} Q_{B,t} B_{B,t} - R_{D,t} D_t) - \nu_b (R_{BLE,t} L_{BE,t}) - \nu_g (R_{G,t+1} Q_{B,t} B_{B,t})}{R_{A,t+1} A_t} \tag{27}$$

where

$$R_{A,t+1} A_t = R_{BLE,t} L_{BE,t} + R_{G,t+1} Q_{B,t} B_{B,t} \tag{28}$$

summarizes the representative bank's balance sheet asset side gross of *ex post* return.

With the definition of the return on bank equity, equation (18), we can reformulate the average bank capital ratio $\tilde{\nu}_t$ across banks as

$$\tilde{\nu}_{t+1} = \frac{R_{BLE,t} L_{BE,t} + R_{G,t+1} Q_{B,t} B_{B,t} - R_{D,t} D_t}{R_{A,t+1} A_t}. \tag{29}$$

2.2.2 Retail lending branches and loan officers

A continuum of retail lending branches indexed by j provide differentiated loans to loan officers. The total financing needs of loan officers follow a CES aggregation of differentiated loans which are imperfect substitutes with elasticity of substitution $\frac{\mu^R_E}{\mu^R_E - 1} > 1$ and defined as follows

$$L_{E,t} = \left[\int_0^1 L_{E,t}(j)^{\frac{1}{\mu^R_E}} \mathrm{d}j \right]^{\mu^R_E} \tag{30}$$

while the corresponding average return on loans is defined as follows

$$R_{LE} = \left[\int_0^1 R_{LE}(j)^{\frac{1}{1-\mu^R_E}} \mathrm{d}j \right]^{1-\mu^R_E}. \tag{31}$$

Retail lending branches are monopolistic competitors which levy funds from the *bankers* and set gross nominal interest rates on a staggered basis *à la* Calvo (1983), facing each period a constant

[9] Limited liability provides incentives for the individual banks to take on risk in the form of as much leverage with only bank capital regulation as a limiting factor. Higher leverage is associated with higher excess return on loans.

probability $1 - \xi_E^R$ of being able to re-optimize. This staggered lending rate setting acts in the model as maturity transformation in banking activity and leads to imperfect pass-through of market interest rates on bank lending rates. If a retail lending branch cannot re-optimize its interest rate, then the interest rate is left at its previous period level

$$R_{LE,t}(j) = R_{LE,t-1}(j). \tag{32}$$

Therefore, the retail lending branch j chooses $\hat{R}_{LE,t}(j)$ to maximize its intertemporal profits

$$\max_{\{\hat{R}_{LE,t}(j)\}} \mathbb{E}_t \left[\sum_{k=0}^{\infty} \left(\beta\gamma^{-\sigma_c}\xi_E^R\right)^k \frac{\Lambda_{t+k}}{\Lambda_t} \left(\hat{R}_{LE,t}(j)L_{E,t+k}(j) - R_{BLE,t+k}(j)L_{E,t+k}(j)\right)\right] \tag{33}$$

where the demand from the loan officers is given by

$$L_{E,t+k}(j) = \left(\frac{\hat{R}_{LE,t}(j)}{R_{LE,t}}\right)^{-\frac{\mu_E^R}{\mu_E^R-1}} \left(\frac{R_{LE,t}}{R_{LE,t+k}}\right)^{-\frac{\mu_E^R}{\mu_E^R-1}} L_{LE,t+k}. \tag{34}$$

Finally, loan officers, that operate in perfect competition, receive one-period loans from the retail lending branches, which cost an aggregate gross nominal interest rate $R_{LE,t}$ that is set at the beginning of period t and extend loan contracts to entrepreneurs which pay a state-contingent return $\widetilde{R}_{LE,t+1}$. Loan officers have no other source of funds so that the volume of the loans they provide to the entrepreneurs equals the volume of funding they receive. Therefore, they seek to maximise its discounted intertemporal flow of income so that the first order condition of its decision problem gives

$$\mathbb{E}_t \left[\Xi_{t,t+1} \frac{\left(\widetilde{R}_{LE,t+1} - R_{LE,t}\right)}{\pi_{t+1}} \right] = 0. \tag{35}$$

In the end, profits and losses made by retail branches and loan officers are transferred back to the bankers.

2.3 Entrepreneurs

As explained before, every period a fraction fe of the representative household's members are entrepreneurs. Like bankers, each entrepreneur faces a probability ζ_e of staying entrepreneurs over next period and a probability $(1 - \zeta_e)$ of becoming a worker again. To keep the share of entrepreneurs constant, it is assumed that a similar number of workers randomly becomes entrepreneur. When an entrepreneur exits, their accumulated earnings are transferred to the respective household. At the same time, newly entering entrepreneurs receive initial funds from their household. Overall, households transfer a real amount $\Psi_{E,t}$ to the entrepreneurs for each period t. Finally, as it will become clear later, entrepreneurs decisions for leverage and lending rate are independent from their net worth and therefore identical.[10]

At the end of period t entrepreneurs buy the capital stock K_t from the capital producers at real price Q_t (expressed in terms of consumption goods). They transform the capital stock into an

[10] Accordingly, the decision problem is exposed for a representative entrepreneur.

effective capital stock $u_{t+1}K_t$ by choosing the utilisation rate u_{t+1} subject to adjustment costs. This adjustment cost on the capacity utilization rate are defined per unit of capital stock $\Gamma_u(u_{t+1})$.[11]

The effective capital stock can then be rented out to intermediate goods producers at a nominal rental rate of $r_{K,t+1}$. Finally, by the end of period $t+1$, entrepreneurs sell back the depreciated capital stock $(1-\delta)K_t$ to capital producer at price Q_{t+1}.

The gross nominal rate of return on capital from period t to $t+1$ is therefore given by

$$R_{KK,t+1} \equiv \pi_{t+1} \frac{r_{K,t+1}u_{t+1} - \Gamma_u(u_{t+1}) + (1-\delta)Q_{t+1}}{Q_t}. \tag{36}$$

Each entrepreneur's return on capital is subject to a multiplicative idiosyncratic shock ω_e. These shocks are independent and identically distributed across time and across entrepreneurs. $\omega_{e,t}$ follows a lognormal CDF $F_e(\omega_e)$, with mean 1 and variance σ_e. For the estimation, we assume the variance σ_e is attached to a multiplicative shock $\varepsilon_t^{\sigma_e}$.

By the law of large number, the average across entrepreneurs (denoted with the operator $\widetilde{E}$) for expected return on capital is given by

$$\widetilde{E}\left[\mathbb{E}_t\left(\omega_{e,t+1}R_{KK,t+1}\right)\right] = \mathbb{E}_t\left(\int_0^\infty \omega_{e,t+1}\mathrm{d}F_{e,t}(\omega)\, R_{KK,t+1}\right) = \mathbb{E}_t\left(R_{KK,t+1}\right). \tag{37}$$

Entrepreneur's choice over capacity utilization is independent from the idiosyncratic shock and implies that

$$r_{K,t} = \Gamma_u'(u_t). \tag{38}$$

Entrepreneurs finance their purchase of capital stock with their net worth $NW_{E,t}$ and a one-period loan $L_{E,t}$ (expressed in real terms and deflated by the consumer price index) from the commercial lending branches. Therefore their balance identity in real terms reads as follows

$$Q_tK_t = NW_{E,t} + L_{E,t}. \tag{39}$$

In the tradition of costly state verification frameworks, lenders cannot observe the realisation of the idiosyncratic shock unless they pay a monitoring cost μ_e per unit of assets that can be transferred to the bank in case of default. The set of lending contracts available to entrepreneurs is constraint, since they can only use debt contracts in which the lending rate $R_{LLE,t}$ is pre-determined at the previous time period.

Default occurs when the entrepreneurial income that can be seized by the lender falls short of the agreed repayment of the loan. At period $t+1$, once aggregate shocks are realised, this will happen for draws of the idiosyncratic shock below a certain threshold $\overline{\omega}_{e,t}$, given by

$$\overline{\omega}_{e,t+1}\chi_e R_{KK,t+1}\kappa_{e,t} = (R_{LLE,t}+1)(\kappa_{e,t}-1) \tag{40}$$

where $R_{LLE,t}$ is the nominal lending rate determined at period t, χ_e represents the share of the

[11] The cost (or benefit) Γ_u is an increasing function of capacity utilization and is zero at steady state, $\Gamma_u(u^\star) = 0$. The functional forms used for the adjustment costs on capacity utilization is given by

$$\Gamma_u(X) = \frac{\overline{\overline{r_K}}}{\varphi}\left(\exp\left[\varphi(X-1)\right]-1\right).$$

entrepreneur's assets (gross of capital return) that banks can recover in case of default and $\kappa_{e,t}$ is the corporate leverage defined as follows

$$\kappa_{e,t} = \frac{Q_t K_t}{NW_{E,t}}. \tag{41}$$

It is also assumed that when banks take over the entrepreneur's assets, they have to pay the monitoring costs.

The *ex post* return to the lender on the loan contract, denoted $\widetilde{R}_{LE,t}$, can then be expressed as

$$\widetilde{R}_{LE,t} = G(\overline{\omega}_{e,t})\chi_e R_{KK,t}\frac{\kappa_{e,t-1}}{\kappa_{e,t-1}-1} \tag{42}$$

where is defined as follows

$$G_e(\overline{\omega}) = (1 - F_e(\overline{\omega}))\overline{\omega} + (1-\mu_e)\int_0^{\overline{\omega}} \omega \mathrm{d}F_e(\omega). \tag{43}$$

Furthermore, it is assumed that entrepreneurs are myopic and the end-of-period t contracting problem for entrepreneurs consists in maximising the next period return on net worth for the lending rate and leverage subject to the participation constraint of the lender in equation (35) and the default threshold $\overline{\omega}_{e,t+1}$ in equation (40)

$$\max_{\{R_{LLE,t},\kappa_{e,t}\}} \mathbb{E}_t\left[\left(1-\chi_e\Gamma_e(\overline{\omega}_{e,t+1})\right)R_{KK,t+1}\kappa_{e,t}\right] \tag{44}$$

where $\Gamma_e(\overline{\omega})$ is defined as follows

$$\Gamma_e(\overline{\omega}) = (1 - F_e(\overline{\omega}))\overline{\omega} + \int_0^{\overline{\omega}} \omega \mathrm{d}F_e(\omega). \tag{45}$$

Following some manipulations, the first order conditions for the lending rate and the leverage lead to the following

$$\mathbb{E}_t\left[\left(1-\chi_e\Gamma_e(\overline{\omega}_{e,t+1})\right)R_{KK,t+1}\kappa_{e,t}\right] = \frac{\mathbb{E}_t\left[\chi_e\Gamma'_e(\overline{\omega}_{e,t+1})\right]}{\mathbb{E}_t\left[\Xi_{t,t+1}G'_e(\overline{\omega}_{e,t+1})\right]}\mathbb{E}_t\left[\Xi_{t,t+1}\right]R_{LE,t} \tag{46}$$

where $\Gamma'_e(\overline{\omega})$ is defined as follows

$$\Gamma'_e(\overline{\omega}) = (1 - F_e(\overline{\omega})) \text{ and } G'_e(\overline{\omega}) = (1 - F_e(\overline{\omega})) - \mu_e\overline{\omega}\mathrm{d}F_e(\overline{\omega}). \tag{47}$$

As anticipated at the beginning of the section, the solution to the problem shows that all entrepreneurs choose the same leverage and lending rate. Moreover, the features of the contracting problem imply that the *ex post* return to the lender $\widetilde{R}_{LE,t}$ will differ from the *ex ante* return $R_{LE,t-1}$.[12]

Finally, aggregating across entrepreneurs, a fraction ζ_e continues operating into the next period while the rest exits from the industry. The new entrepreneurs are endowed with starting net worth, proportional to the assets of the old entrepreneurs. Accordingly, the aggregate dynamics of

[12] Log-linearising equation (46) and the participation constraint in equation (35), one can show that innovations in the *ex post* return are notably driven by innovations in $R_{KK,t}$.

entrepreneurs' net worth is given by

$$NW_{E,t} = \zeta_e \left(1 - \chi_e \Gamma_e(\overline{\omega}_{e,t})\right) \frac{R_{KK,t}}{\pi_{t-1}} \kappa_{e,t-1} NW_{E,t-1} \big/ \gamma + \Psi_{E,t}. \tag{48}$$

2.4 Capital producers

Using investment goods, a segment of perfectly competitive firms, owned by households, produce a stock of fixed capital. At the beginning of period t, those firms buy back the depreciated capital stocks $(1-\delta)K_{t-1}$ at real prices (in terms of consumption goods) Q_t. Then they augment the various stocks using distributed goods and face adjustment costs. The augmented stocks are sold back to entrepreneurs at the end of the period for the same prices. The decision problem of capital stock producers is given by

$$\max_{\{K_t, I_t\}} \mathbb{E}_t \sum_{k=0}^{\infty} \Xi_{t,t+k} \left\{ \; Q_{t+k}(K_{t+k} - (1-\delta)K_{t+k-1} \big/ \gamma) - I_{t+k} \; \right\} \tag{49}$$

subject to the constraint

$$K_t = (1-\delta)K_{t-1} \big/ \gamma + \left[1 - S\left(\gamma \frac{I_t \varepsilon_t^I}{I_{t-1}}\right)\right] I_t \tag{50}$$

where S is a non-negative adjustment cost function formulated in terms of the gross rate of change in investment while investment are denoted by I_t.[13] Furthermore, ε_t^I is an efficiency shock to the technology of fixed capital accumulation.

2.5 Goods-producing firms

There are two types of firms in the model, the intermediate and the final goods-producing firms, with the former being monopolistic competitors while the latter operating in a competitive environment.

2.5.1 Intermediate goods-producing firms

In the intermediate goods-producing sector, firms $z \in [0,1]$ are monopolistic competitors and produce differentiated products by using a common Cobb-Douglas technology defined as follows

$$Y_t(z) = \varepsilon_t^a \left(u_t K_{t-1}(z) \big/ \gamma\right)^{\alpha} \left[N^D(z)\right]^{1-\alpha} - \Omega_{a,t} \tag{51}$$

where ε_t^a is an exogenous productivity shock and $\Omega_{a,t} > 0$ is a fixed cost. A firm z hires capital $\widetilde{K}_t(z)$ defined as

$$\widetilde{K}_t(z) = u_t K_{t-1}(z) \tag{52}$$

and labor $N_t^D(z)$ on a competitive market by minimizing its production cost. Due to our assumptions on the labor market and the rental rate of capital, the real marginal cost is identical across producers. The model also introduces a time varying tax on firm's revenue which is affected by an independent

[13] The functional form adopted is $S(x) = \phi/2 \; (x-\gamma)^2$.

and identically distributed shock, ε_t^p, defined by

$$\varepsilon_t^p = \frac{1-\tau_{p,t}}{1-\tau_p^\star}. \tag{53}$$

In each period, a firm z faces a constant (across time and firms) probability, $1-\alpha_p$, of being able to re-optimize its nominal price, say $P_t^*(z)$. If a firm cannot re-optimize its price, the nominal price evolves according to the rule

$$P_t(z) = \pi_{t-1}^{\xi_p} \left[\pi^\star\right]^{(1-\xi_p)} P_{t-1}(z) \tag{54}$$

with ξ_p representing the price indexation, *i.e.* the nominal price is indexed on past inflation and steady state inflation. In the model, all firms that can re-optimize their price at time t choose the same level, denoted p_t^* in real terms.

2.5.2 Final goods-producing firms

Final producers operate in a competitive environment produce an aggregate final good Y_t, expressed in effective terms, that may be used for consumption and investment. This production is obtained using a continuum of differentiated intermediate goods $Y_t(z)$, where each firm $z \in [0,1]$ (also expressed in effective terms) with the Kimball (1995) technology. The Kimball aggregator is defined by

$$\int_0^1 G\left(\frac{Y_t(z)}{Y_t}; \theta_p, \psi\right) \mathrm{d}z = 1 \tag{55}$$

with its functional form as follows

$$\begin{aligned} G\left(\frac{Y_t(z)}{Y_t}\right) &= \frac{\theta_p}{(\theta_p(1+\psi)-1)} \left[(1+\psi)\,\frac{Y_t(z)}{Y_t} - \psi\right]^{\frac{\theta_p(1+\psi)-1}{\theta_p(1+\psi)}} \\ &\quad - \left[\frac{\theta_p}{(\theta_p(1+\psi)-1)} - 1\right], \end{aligned} \tag{56}$$

while θ_p and ψ represent the elasticity of substitution between goods and the curvature of the Kimball aggregator in the goods market, respectively. μ_p is the Lagrange multiplier on the constraint determining the price mark-up. The representative final good producer maximizes profits $P_t Y_t - \int_0^1 P_t(z) Y_t(z) \mathrm{d}z$ subject to the production function, taking as given the final good price P_t and the prices of all intermediate goods.

2.6 Intermediate labour unions and labour packers

The differentiated labor services are produced by a continuum of unions which transform the homogeneous household labor supply, sets wages subject to a Calvo scheme and offers those labour services to intermediate labour packers.

Intermediate goods-producers make use of a labor input N_t^D produced by a segment of labor packers. Those labor packers operate in a competitive environment and aggregate a continuum of differentiated labor services $N_t(i)$, $i \in [0,1]$ using a Kimball (1995) technology where the Kimball aggregator is defined as follows

$$\int_0^1 H\left(\frac{N_t(i)}{N_t^D}; \theta_w, \psi_w\right) \mathrm{d}i = 1 \tag{57}$$

and its functional form as follows

$$\begin{aligned} H\left(\frac{N_t(i)}{N_t^D}\right) &= \frac{\theta_w}{(\theta_w(1+\psi_w)-1)}\left[(1+\psi_w)\frac{N_t(i)}{N_t^D} - \psi_w\right]^{\frac{\theta_w(1+\psi_w)-1}{\theta_w(1+\psi_w)}} \\ &\quad - \left[\frac{\theta_w}{(\theta_w(1+\psi_w)-1)} - 1\right] \end{aligned} \tag{58}$$

where the parameter θ_w and ψ_w determine the elasticity of substitution between labour inputs and the curvature of the demand curve in the wage market, respectively. μ_w is the Lagrange multiplier on the constraint representing the wage mark-up.[14]

Each labour union is a monopoly supplier of a differentiated labour service and sets its wage on a staggered basis, paying households the nominal wage rate W_t^h. Every period all unions face a constant probability $1-\alpha_w$ of optimally adjusting its nominal wage, say $W_t^*(i)$, which will be the same for all suppliers of differentiated labor services.

The aggregate real wage, expressed in effective terms, that intermediate producers pay for the labor input provided by the labor packers, thereafter is denoted by W_t, while W_t^* denotes the effective real wage claimed by re-optimizing unions. Taking into account that unions might not be able to choose their nominal wage optimally in a near future, $W_t^*(i)$ is chosen to maximize their intertemporal profit under the labor demand from labor packers. In the case that unions cannot re-optimize, wages are indexed on past inflation and steady state inflation according to the following indexation rule

$$W_t(i) = \gamma\left[\pi_{t-1}\right]^{\xi_w}\left[\pi^\star\right]^{1-\xi_w} W_{t-1}(i) \tag{59}$$

with the degree of wage indexation ξ_w. Furthermore, unions are subject to a time-varying tax rate $\tau_{w,t}$ which is affected by an independent and identically distributed shock, ε_t^w defined by

$$\varepsilon_t^w = \frac{1-\tau_{w,t}}{1-\tau_w^\star}. \tag{60}$$

2.7 Government sector

Public expenditures $G^\star$, expressed in effective terms, are subject to random shocks ε_t^g. The government covers the financing costs for the deposit insurance agency $\Omega_{b,t}$ as defined in equation (15) and finances its public spending with labour tax, product tax and lump-sum transfers so that the government debt $Q_{B,t}B_G$, expressed in real effective terms, accumulates according to

$$Q_{B,t}B_{G,t} = \frac{R_{G,t}}{\pi_t} Q_{B,t-1}B_{G,t-1}/\gamma + G^\star\varepsilon_t^g - \tau_{w,t}w_tL_t - \tau_{p,t}Y_t - T_t + \Omega_{b,t}. \tag{61}$$

[14]This function has the advantage that under the restriction $\psi_w = 0$ it reduces to the standard expression of the Dixit Stiglitz world.

In the following, we neglect the dynamics of public debt and assume that lump-sum taxes T_t are adjusted to ensure that government debt remains constant:

$$\forall t > 0 \quad B_{G,t} = \overline{B_G}. \tag{62}$$

Long-term sovereign debt is introduced by assuming that government securities are perpetuities which pay geometrically-decaying coupons where c_g is the coupon rate and τ_g is the decaying factor.[15] The nominal return on sovereign bond holding from period t to period $t+1$ is therefore

$$R_{G,t+1} = \varepsilon_{t+1}^{R_G} \frac{c_g + (1-\tau_g) Q_{G,t+1}}{Q_{G,t}}. \tag{63}$$

For the purpose of the empirical analysis, we introduced an *ad hoc* government bond valuation shock, $\varepsilon_t^{R_G}$. This "reduced-form" shock is meant to capture time-variation in the excess bond return not captured by our bank-centric formulation of the term premium.

2.8 Monetary and supervisory authority

The monetary and supervisory authority can engage in several type of policies, these being standard (conventional) and non-standard (unconventional) monetary policies, regulatory, supervisory and macroprudential policies.

Standard monetary policy assumes that the central bank aims at steering the deposit rate $R_{D,t}$, while non-standard monetary policy focuses only on central bank government bond purchases.[16]

Regulatory, supervisory and macroprudential policies aim to ensure the resilience of individual banks through bank capital provision, with the main instrument being the setting of the capital requirement ratio.[17] In order to disentangle the three layers of policies, as illustrated in Figure 1, it is assumed in the model that the total capital requirements is the summation of three components, as specified below

$$\nu_b = \nu_{b,r} + \nu_{b,s,t} + \nu_{b,m,t} \tag{64}$$

where

1. $\nu_{b,r}$ denotes the regulatory requirement which aims to mitigate extreme risk exposure of the bank by equipping it with sufficient loss absorbing capacity,

2. $\nu_{b,s,t}$ denotes the supervisory requirement which intends to capture potential capital needs of banks in response to detected bank specific risks in individual banks during supervisory assessments, and

3. $\nu_{b,m,t}$ denotes the macroprudential capital ratio that stands for the countercyclical bank capital buffer implemented to safeguard the soundness of the whole financial system.

[15] In other words, the bond pays c_g the first period, $(1-\tau_g)c_g$ the second one, $(1-\tau_g)^2 c_g$ the third one, etc..

[16] For the sake of simplicity the analysis of the central bank balance sheet is beyond the scope of this paper and we leave it for future research.

[17] Although, prudential policies are categorised into three broad areas, namely capital-based, asset-based and liquidity-based, and can be operationalised either or both as a micro- and macroprudential tool, this paper focuses only on capital-based micro- and macroprudential policies.

The transmission of above policies through the different agents that interplay in the model and the respective sectors in the economy where they operate on are illustrated in Figure 2 in a schematic representation.

2.8.1 Standard monetary policy

Similar to Smets and Wouters (2007), it is assumed that standard monetary policy follows an interest rate rule, of Taylor-type, defined as follows

$$\hat{R}_{D,t} = max\left(\underline{\hat{R}_D}, \hat{R}^*_{D,t}\right) \tag{65}$$

$$\hat{R}^*_{D,t} = \rho\hat{R}_{D,t-1} + (1-\rho)\left[r_\pi\hat{\pi}_t + r_{\Delta y}\Delta y_t\right] + r_{\Delta\pi}\Delta\pi_t + \ln\left(\varepsilon^r_t\right) \tag{66}$$

specified in terms of the deviations of inflation from its steady state value, output growth and inflation changes. Written in deviation from the steady state, ρ stands for the interest rate inertia (smoothing) while and r_π, $r_{\Delta y}$ and $r_{\Delta\pi}$ capture the interest rate sensitivities to inflation, output growth and inflation changes, respectively.[18] The ε^r_t captures the non-systemic component, namely monetary policy shock. In the case that the deposit interest rate is constraint at its effective lower bound, then the outcome of the interest rate rule is the lower bound $\underline{\hat{R}_D}$ as specified by the monetary authority.

2.8.2 Non-standard monetary policy

Non-standard monetary policy can be operationalised via direct purchases of government bonds of the amount $B_{CB,t}$ by the monetary authority. In order to account for the design and announcement strategy of purchase programmes, we adopt the approach by Darracq Pariès and Kühl (2016) which assumes that purchases evolve according to the following stochastic process

$$B_{CB,t} = \rho_{B1}B_{CB,t-1} + \gamma_0\varepsilon_{CB,t} + \gamma_1\varepsilon_{CB,t-1} + \gamma_2\varepsilon_{CB,t-2} + ... + \gamma_n\varepsilon_{CB,t-n} \tag{67}$$

where $\varepsilon_{CB,t-i}$ from $i = 0, ..., n$ represent the evolution of purchases which are carried out in the build-up phase and are assumed to be communicated and known in period $t-n$. Once all purchases are carried out and $B_{CB,t}$ reaches its peak, holdings of government bonds start decaying following an AR(1) process where ρ_{B1} is calibrated to match the redemption schedule of 10-year bonds.

2.8.3 Regulatory policies

In line with the reform packages, CRR and CRD IV, the regulatory dimension is attributed to the constant minimum level of requirements. The measure is consistent by Pillar 1 (P1R) and Pillar 2 (P2R) requirements, with the latter concentrating on risks underestimated or not covered by Pillar 1, capital conservation buffer (CCB) that focuses on the build up of capital buffers outside periods of stress which can be drawn down as losses are incurred and systemic risk buffer (SRB) that intends to increase the resilience of the financial sector to non-cyclical risks that could have a serious negative impact on the national financial system or the real economy. Although P1R and P2R are microprudential policies and SRB is a macroprudential policy, CCB can be operationalised both as a micro- and macroprudential tool.

[18] $\hat{x_t} = ln(x_t/\overline{x})$ denotes the log-deviation of a generic variable x from its deterministic steady-state level $\overline{x}$.

The mechanism behind these policies is based on the requirement that bank equity must cover a fraction of $\nu_{b,r}$ of loans gross return and a fraction ν_g of government bond gross return. Due to its safe asset characteristics the bond capital requirement ν_g serves as a proxy for other types of liquidity constraints which are beyond the focus if this study. *Ex ante* the continuum of banks differ only in their scale of operation (and hence their level of net worth). *Ex post*, each period a time-varying fraction of banks violates the capital ratio depending on the performance of the banks' loan book. These banks pay pecuniary costs of χ_b of bank assets to the government which deteriorates the banks' capital position even further. While the representative bank incorporates the probability of regulatory penalty and the idiosyncratic risk on the return on bank loans into their decision problem, the aggregate losses in the retail lending branches due to loan default can additionally worsen the capital position of the bank.

2.8.4 Supervisory policies

With regard to supervisory policies, we focus particularly on the uncertainty surrounding the yearly SREP policy process that can bring about additional bank capital standards for banks. SREP, conducts regular assessments through the discretionary power of the ECB with the aim to identify individual risks of banks, therefore guiding banks to hold additional capital. These supervisory measure captures this top-up on minimum requirements through Pillar 2 guidance (P2G) and are categorised as a microprudential tool.

In the model, banks' decisions take into account future adjustments of the regulatory instrument which are capture by transitory changes in the level of the bank capital requirement through $\tilde{\nu}_{b,s,t}$. In this sense, the capital ratio $\tilde{\nu}_{b,s,t}$ follows an autoregressive process specified as follows

$$\log\left(\nu_{b,s,t}\right) = \rho_\nu \log\left(\nu_{b,s,t-1}\right) + \varepsilon_{\sigma_\nu,t}\epsilon_t^\nu \tag{68}$$

where $\epsilon_t^\nu \sim \mathcal{N}(0, \sigma_\nu)$ follows a normal distribution with mean 0 and variance σ_ν. $\varepsilon_{\sigma_\nu,t}$ acts as a shifter of the variance of $\nu_{b,s,t}$ and it is assumed to follow an autoregressive process

$$\log\left(\varepsilon_{\sigma_\nu,t}\right) = \rho_{\sigma_\nu} \log\left(\varepsilon_{\sigma_\nu,t-1}\right) + \epsilon_t^{\sigma_\nu} \tag{69}$$

where $\epsilon_t^{\sigma_\nu} \sim \mathcal{N}(0, \sigma_{\sigma_\nu})$ follows a normal distribution with mean 0 and variance σ_{σ_ν}. By allowing the variance of the regulatory capital shock to rise, the probability of events that are distant from the mean regulatory adjustment increases. With an increase in the regulatory uncertainty through $\varepsilon_{\sigma_\nu,t}$, economic agents and in particular banks are likely to modify their behaviour even though the mean outcome remains unchanged.

2.8.5 Macroprudential policies

Capital-based macroprudential policies operate through a countercyclical rule on the regulatory capital requirement ν_b which addresses the pecuniary externality associated with the pro-cyclicality of capital requirements. The countercyclical capital buffer (CCyB) is part of a set of macroprudential instruments that the European Systemic Risk Board (ESRB) may apply on systemically important financial institutions. Therefore, countercyclical capital buffer is another source for variation of the bank capital requirement which is based on the discretion of national authorities to require additional buffers subject to their appraisal of the economic conditions.

In line with the ESRB proposed rule, the capital adequacy ratio is set endogenously as follows

$$\nu_{b,m,t} = \rho_{\nu_b}\nu_{b,m} + (1-\rho_{\nu_b})\left(\phi_{\nu_b}\left(X_t - X\right) + \nu_{b,m,t-1}\right) \tag{70}$$

where ϕ_{ν_b} determines its cyclical adjustment linked to the dynamics of X_t. Replicating the proposition for the countercyclical capital buffer of the ESRB, the rule reacts to the credit to annual GDP ratio defined as follows

$$X_t = \frac{L_{BE,t}}{\sum_{j=0}^{3} Y_{t-j}}. \tag{71}$$

The parameter ϕ_{ν_b} is chosen by a welfare maximization procedure.

2.9 Market clearing conditions on debt markets

In what follows, we provide details of the market clearing conditions that comprise the goods, the labour and financial markets.

2.9.1 Goods markets

The market clearing condition on goods market is given by

$$Y_t = C_t + I_t + G^\star \varepsilon_t^g + \Psi\left(u_t\right) K_{t-1}/\gamma + \mu_e \int_0^{\overline{\omega}} \omega \mathrm{d}F_e\left(\omega\right) K_{t-1}/\gamma. \tag{72}$$

2.9.2 Labour markets

Equilibrium in the labor market implies that

$$\Delta_{wk,t} N_t^D = N_t^S \tag{73}$$

with $N_t^D = \int_0^1 N_t^D(z)dz$, $N_t^S = \int_0^1 N_t^S(h)dh$. and $\Delta_{wk,t}$ being the wage dispersion index.

$$\Delta_{pk,t} Y_t = \varepsilon_t^a \left(u_t K_{t-1}/\gamma\right)^\alpha \left(N_t^D\right)^{1-\alpha} - \Omega \tag{74}$$

with $\Delta_{pk,t}$ being the price dispersion index.

2.9.3 Debt markets

On the private credit market, due to nominal rigidity in the setting of interest rate by retail banking branches, the following conditions holds

$$L_{BE,t} = \Delta_{E,t}^R L_{E,t} \tag{75}$$

where $\Delta_{E,t}^R = \int_0^1 \left(\frac{R_{E,t}(j)}{R_{E,t}}\right)^{-\frac{\mu_E^R}{\mu_E^R - 1}} \mathrm{d}j$ is the dispersion index among retail bank interest rates.

Moreover, in equilibrium the lump-sum transfer to bankers per unit of net worth from retail lending and loan officer profits and losses is given by

$$\frac{\Pi^{R}_{B,t+1}}{NW_{b,t}} = \left(\widetilde{R}_{LE,t+1} - R_{BLE,t}\right)\kappa^{l}_{B,t}. \tag{76}$$

We can now rewrite the banks' *ex ante* net worth

$$NW_{B,t} = \zeta_b \mathbb{E}_t\left[\left(\tilde{R}_{LE,t} - R_{D,t-1}\right)\kappa^{l}_{B,t-1} + \left(R_{G,t} - R_{D,t-1}\right)\kappa^{g}_{B,t-1} + R_{D,t-1}\right]\frac{NW_{B,t-1}}{\pi_t \gamma} + \Psi_B. \tag{77}$$

Finally, on the government bond market, the fixed supply is distributed across holdings by households, bankers and the central bank

$$B_{H,t} + B_{B,t} + B_{CB,t} = \overline{B_G}. \tag{78}$$

where $\overline{B_G}$ is the steady state value of government bonds.

3 Calibration, Data and Estimation

The main purpose of the empirical exercise is not to conduct an exhaustive review of the structural determinants of the euro area business cycle, or to evaluate the statistical performance of the model. Instead, the aim is to obtain a satisfactory level of data consistency in order to proceed with the policy evaluations.

3.1 Calibration

Like in Smets and Wouters (2007), as described below and shown in Table 1, some parameters are treated as fixed in the estimation.

The steady state level of the lending rate spreads $\frac{R_{LLE}-R_D}{\pi}$ is decomposed in three financial wedges as follows

1. the *bank capital spread* which results from the decision problems of bankers and requires in equilibrium a higher return on private sector intermediation than on deposits, $r_B = 100\frac{R_{BLE}-R_D}{\pi}$,

2. the *monopolistic margin* which is applied in the retail banking segment and leads to a markup on financing rate provided by the bankers, $r_\mu = 100\frac{R_{LE}-R_{BLE}}{\pi}$, and

3. the *credit risk compensation* which corresponds to the spread between the lending rate applied by loan officers and the return on the overall loan portfolio for the retail bankers, $r_{risk} = 100\frac{R_{LLE}-R_{LE}}{\pi}$.

With respect to the bankers, we calibrate the standard deviation of the idiosyncratic shock σ_b so that the annual percentage of banks violating the minimum capital adequacy ratio is approximately equal to 12%, corresponding to a 3% per quarter as in Benes and Kumhof (2015). The bank resolution cost, μ_b, is calibrated to 0.3. The minimum capital requirements, ν_b, is set to 9% while the steady-state capital ratio of bankers is set approximately to 13%. A symmetric capital buffer of around 4-4.5% is consistent with available empirical evidence over the post-crisis period. Furthermore, we calibrate regulatory penalty, χ_b, such that in the steady state, the bank capital wedge which is the spread over and above the funding cost is equal to 150 basis points (in annual terms).

The continuation probability of bankers, ζ_b, ensures that in the steady state the return on equity is 20% (gross of operating costs and other costs which are not accounted for in our model but represent at least half of the net operating income in the euro area). The transfers to new bankers, Ψ_B, clear the net worth accumulation equation for given spreads and capital ratio and are set to 0.1% of bank assets. This calibration leads to a negligible steady-state probability of bankers defaulting. In this context, the limited liability distortions become almost irrelevant.

The competitive margin r_μ is calibrated to 60 bps (in annual terms).

As concerns the entrepreneurs, we target a default frequency for firms at 0.3% and a credit risk compensation on corporate loans, r_{risk} of 50 bps (in annual terms) which broadly corresponds to one third of the sample mean of the lending spreads. The external finance premium $100\left(\frac{R_{KK}}{R_{LE}}-1\right)$ is set at 200 bps (in annual terms). We also aim at a matching a credit-to-GDP ratio consistent with the loan data under consideration. In order to match those endogenous steady state variables, four parameters are adjusted: the monitoring costs μ_e, the standard deviation of the idiosyncratic shock σ_e, the limited seizability parameter χ_e and the entrepreneurs survival probability ζ_e. We assume that the additional transfers to new entrepreneurs, Ψ_E, are null.

The steady state level of sovereign spread, $(R_G - R_D)$, is jointly determined with r_B through the bankers first order conditions for bond holdings and loan origination. In the baseline calibration, the sovereign spread is at 120 basis points (in annual terms). We set the geometric-decay of the perpetual coupons on sovereign bond τ_g so that the duration of the securities is 10 years. The initial coupon level is adjusted to ensure that the steady state sovereign bond price Q_B equals 1. For the household first order condition on sovereign bond holdings to be consistent with the steady state sovereign spread and the share of bank holding of sovereign bonds, we let $\overline{B}_H$ clear the steady state relationship associated with this equation. The ratio of banks' holdings of government bonds to their loan book, $\alpha_B = \frac{\kappa_B^g}{\kappa_B^l}$, is set to 12%, in line with aggregate BSI statistics from the ECB. The total outstanding amount of sovereign debt in the steady state is assumed to be 60% of annual GDP.

Regarding the adjustment cost parameters on the holding of sovereign securities for both households, χ_H, and bankers, χ_B, we set them so that, at the prior mode for the other parameters, the transmission of a central bank asset purchase programme like the ECB's January 2015 announcement displays the relevant stylised features found in the literature. In particular, we aim at the lowest degree of adjustment costs which generates a compression of sovereign yields of around 50 basis points and a pass-through to lending rate spreads close to 1 after two years.

Last, the depreciation rate of the capital stock δ is set to 0.025 and the share of government spending in output to 18%. The steady state labor market markup is fixed at 1.5 and the curvature parameter of the Kimball aggregators is set to 10.

3.2 Data and Estimation

Following the above calibration, the remaining parameters are estimated with euro area data using Bayesian likelihood methods. We consider 9 key macroeconomic quarterly time series from 1995q1 to 2014q2, output, consumption, fixed investment, hours worked, real wages, GDP deflator inflation rate, three-month short-term interest rate, bank lending spreads and (weighted) 10-year euro area sovereign spread. The data are not filtered prior to the estimation. The end of the sample is set so that the estimation period does not include binding lower bound occurrences.

Data for GDP, consumption, investment, employment, wages and consumption-deflator are based on Fagan et al. (2001) and Eurostat. Employment numbers replace hours. Consequently, as in Smets and Wouters (2005), hours are linked to the number of people employed e_t^* with the following dynamics

$$e_t^* = \beta \mathbb{E}_t e_{t+1}^* + \frac{(1-\beta\lambda_e)(1-\lambda_e)}{\lambda_e}(l_t^* - e_t^*) \tag{79}$$

The three-month money market rate is the three-month Euribor taken from the ECB website and we use backdated series for the period prior to 1999 based on national data sources. Data on retail bank lending rates to non-financial corporations are based on official ECB statistics from January 2003 onwards and on ECB internal estimates based on national sources in the period before. The lending rates refer to new business rates. For the period prior to January 2003 the euro area aggregate series have been weighted using corresponding loan volumes (outstanding amounts) by country.

The quarterly growth rate of GDP, consumption, investment and loans, are all expressed in real terms and divided by working age population. The employment variable is also divided by working age population. Real wages are measured with respect to the consumption deflator. Interest rates and spreads are measured quarterly. With the exception of loan growth and employment rate for which specific trend developments are not pinned down by the model, transformed data are not demeaned as the model features non-zero steady state values for such variables. A set of parameters are therefore estimated to ensure enough degrees of freedom to account for the mean values of the observed variables. Trend productivity growth γ captures the common mean of GDP, consumption, investment and real wage growth. $\overline{L}$ is a level shift that we allow between the observed detrended employment rate and the model-consistent one. $\overline{\pi}$ is the steady state inflation rate which controls for the CPI inflation rate mean. Furthermore, the preference rate $r_\beta = 100(1/\beta - 1)$ which, combined with $\overline{\pi}$ and γ, pins down the mean of the nominal interest rate.

The exogenous shocks of the model are divided in four categories[19] as follows

1. the efficient shocks which constitute the AR(1) shocks on technology ϵ_t^a, investment ϵ_t^I, public expenditures ϵ_t^g and consumption preferences ϵ_t^b,

2. the inefficient shocks which constitute the ARMA(1,1) shocks on price markups ϵ_t^p, and AR(1) on wage markups ϵ_t^w,

3. the financial shocks which constitute the AR(1) shock on entrepreneurs idiosyncratic risk $\epsilon_t^{\sigma_e}$, and on the valuation of sovereign bonds $\epsilon_t^{R_G}$, and

4. the policy shocks which constitute the AR(1) shock on short-term interest rates ϵ_t^r.

As it is standard the number of shocks are limited to be equal to the number of the observed variables. Furthermore, as in Smets and Wouters (2007), the government spending and the productivity shocks are correlated, $\rho_{a,g}$.

The prior distributions of the other structural parameters are reported in Table 2. They are chosen in line with Smets and Wouters (2007) and previous literature. The main differences relate

[19] All the AR(1) processes are written as: $\log(\varepsilon_t^x) = \rho_x \log(\varepsilon_{t-1}^x) + \epsilon_t^x$ where $\epsilon_t^x \sim \mathcal{N}(0, \sigma_{\varepsilon^x})$. ARMA(1,1) are of the form $\log(\varepsilon_t^x) = \rho_x \log(\varepsilon_{t-1}^x) - \eta_x \epsilon_{t-1}^x + \epsilon_t^x$. All shock processes ε_t^x are equal to one in the steady state.

to the choice of uniform priors for the standard deviations of the exogenous shocks. It's worth mentioning that we choose a relatively uninformative prior distribution for the Calvo lottery parameter related to retail lending rate setting, ξ_E^R.

The posterior distributions are characterised by the mode, mean and the 80% highest density intervals which are also displayed in the Table 2. Most of the estimates match with values in the literature. As known for the euro area, price stickiness exceeds wage stickiness, $\alpha_p > \alpha_w$, while the mean of the price markup, μ_p is only slightly above the calibration value for wages. The estimates indicate a relatively moderate degree of price and wage indexation, ξ_p and ξ_w, respectively. The estimated capital share α is close to the well-known figure in the literature, while the investment adjustment costs ϕ are rather low compared with the range reported in the literature. The value for capital utilization adjustment cost ψ implies a standard degree of rigidity in capital adjustment. The outcome of the estimation predicts an annual steady state inflation rate $\bar{\pi}$ of 2% which is consistent with the ECB target and the average inflation for the period. Turning to the parameters for household preferences, the estimation shows a considerable level of habit formation η with a value of 0.772. With an value below one, the mean of the Frisch elasticity σ_l is reasonable. The inverse of the intertemporal elasticity of substitution σ is also well identified by the model. The estimated time preference rate r_β translates into discount factor of β equal to 0.999. Moreover, the data indicates a modest trend growth productivity. The Calvo lottery parameter for lending rates ξ_E^R implies a moderate rigidity of lending rate adjustment. The posterior means of the parameters governing the monetary policy rule are in line with the literature. Accordingly, the monetary policy response to inflation deviations from steady state is broadly standard, while the reaction to deviations of inflation is almost insignificant. The reaction to output deviations is rather low. The interest rate smoothing parameter ρ points to high inertia in the monetary policy conduct.

4 The transmission of central bank asset purchases and bank-capital based financial policies

The focus of this paper is on the interactions between non-standard monetary policy and financial policies within a DSGE framework with a rich banking sector. In doing so, we first investigate the distinctive transmission mechanism of standard and non-standard monetary policy measures under the assumption of a well-capitalized banks, whereby banks risk-shifting motives are muted. The non-standard measure that we refer to, consists in the purchase of government bonds by the central bank.

Standard and non-standard monetary policy interventions can be shown to display stark differences in their propagation channel, notably through the banking system. Central bank asset purchases penalise bank net interest income, thereby raising concerns about the financial stability risks of such measures, in particular if financial policy bodies fail to internalise the general equilibrium effects of the monetary policy interventions.

This section also sheds light on the scope for minimum capital requirements to effectively tame the potential side-effects of central bank asset purchases. Limited liability of banks together with deposit insurance would in itself justify a tighter stance of bank capital regulation. This argument turns out to be reinforced by the objective of mitigating the bank risk-taking channel of central bank asset purchases in weakly-capitalised jurisdictions.

The section then elaborates further on the interactions between other dimensions of bank capital-based financial policies and central bank asset purchases. In particular, the case for limiting the uncertainty on supervisory oversight is analysed. We also advocate for macroprudential policy to look through the temporary effects of non-standard monetary policy on bank balance sheets, and pledge their interventions on identified excessive risk-shifting from the banking system.

4.1 The transmission of standard and non-standard monetary policy in a well-capitalised banking system

In what follows, we compare the transmission of standard and non-standard monetary policies through the banking sector, providing a rationale for the vigilance of financial policies as regards non-standard monetary policy interventions. In most instances, central bank asset purchases are introduced as an additional policy tool when the short-term interest rate reached its ELB and thus the room for further easing of the monetary stance through standard measures has been exhausted. To analyse such a policy configuration, we allow for an occasionally binding constraint on the policy rate in some scenarios. Since our model has satisfactory data consistency, we use a well-founded and realistic composition of shocks to simulate the lower bound scenario.

Figure 3 contrasts the impulse response functions from an accommodative monetary policy shock (see red dashed lines) and from the announcement of a central bank asset purchase programme. In the simulation of the government bond purchase programme, the short-term policy rate is constrained by the ELB (see the blue dotted lines) or free to react in line with the estimated Taylor rule (see the blue dashed lines). Our non-standard monetary policy experiment mimics the January 2015 ECB's PSPP announcement of euro area long-term government bonds purchases by 60 billion per month from March 2015 until September 2016. The stock of central bank asset holdings was expected to peak at approximately 9.6% of annual GDP. As stated above the announced monthly flow of purchases is introduced through news shocks in the model. After the purchases, the portfolio holdings start decaying following an AR(1) process consistent with the assumption that the bonds are 10-year equivalent and would be held to maturity. For those simulations, we use the benchmark model calibration of the banking sector: the capital position of the banks as well as the riskiness of banks loan portfolio imply negligible probability of default so that risk-shifting motives are not quantitatively relevant. The next section will precisely relax those assumptions.

In normal times, policy rate cuts are favourable to banking sector profitability both through higher net interest income as well as general equilibrium effects. Temporarily lower short-term interest rates steepen the term structure and directly support the profitability of maturity transformation activities of the banking system. In the model, lending conditions respond sluggishly to money market rates due to staggered lending rate setting so the monetary policy easing supports bankers net interest income. Besides, the decline in short-term interest rates leads to higher price of sovereign bonds which provides some mild holding gains for the banks. Finally, improving economic conditions and increasing asset prices are beneficial to firms creditworthiness, with receding delinquency rates. Such favourable developments in credit quality allow loan officers to scale down their credit risk compensation, which could be interpreted as lower provisioning needs for the banking sector. Turning to the macroeconomic stimulus of the measures, output increases by 0.4 p.p. at the peak while annual inflation ends up 0.6 p.p. higher. Standard monetary policy interventions entail powerful transmission channels beyond the banking system, on the real side through the intertemporal substitution of spending decisions, and on the financial side, through the discount factor of asset pricing decisions. Therefore, the credit multiplier is relatively low with real loans increasing by 0.2 p.p. at the peak while corporate lending rate display a short-lived decline by around 25 basis points, normalising rapidly thereafter.

By contrast, the APP entails a strong portfolio rebalancing channel, incentivising banks to ease credit conditions, foregoing profit margins on loans and originating more credit exposures. In the model, two key frictions are providing leeway for central bank asset purchases to affect government bond yields, credit conditions and ultimately the economy at large. First, we introduced adjustment cost on the holding of sovereign bonds for household and banks: together with a frictionless intermediation sector, this friction still enables asset purchases to compress sovereign bond yields, but with no impact on the real and nominal allocation. The second key friction relates to the bankers decision problem. Through the limited liability and regulatory constraint, an exogenous shock on the return of government bonds is transmitted to credit conditions through a bank capital channel. It also creates portfolio rebalancing frictions as in the partial equilibrium context for bankers, one marginal extra unit of capital buffer would not leave the asset composition unchanged.

Consequently, the modelled frictions in bankers' capital structure decisions embed a constrained portfolio allocation between securities and loans. In this context, central bank asset purchases do have an impact on government bond yields and compress the excess return on this asset class. Banks therefore benefit from sizeable holding gains on their securities portfolio, by around 3% of their net worth. The lower expected return on government bond portfolio urge banks to shed sovereign bonds and increase loan exposures. This rebalancing mechanism leads in equilibrium to narrower excess return on loan books by intermediaries. Credit expansion through lower borrowing cost is a key propagation mechanism of the central asset purchases in the model, compared with standard monetary policy easing. The narrowing of net interest income is due to a sizeable and protracted decline in lending rates. As with the standard monetary policy shock, credit quality improves alongside with economic activity and asset prices. All in all, the model-based propagation of asset purchases might appear as more harmful than standard policy on bankers profitability, to the extent that the focus is on net interest income and ignores the general equilibrium effects of the non-standard measure on credit quality and valuation gains on securities held.

Turning to the macroeconomic stimulus of the measures, the asset purchase programme generates an increase in output by 0.5 p.p. at the peak while annual inflation ends up 0.2 p.p. higher. The impact on the real side turns out relatively similar of the one of the standard monetary policy shock but the associated inflationary impact is much weaker. This is mainly due to a more pronounced and longer lasting decrease in the rental rate of capital, which affects the marginal costs of intermediate producers. Indeed, central bank asset purchases mainly operate in the model through the financial intermediation wedge. This wedge entails a cost channel which runs against the inflationary effects of the real side adjustment. Regarding credit conditions, the impact on credit origination is much stronger than in the standard monetary policy case, with real loans peaking at around 0.8%, together with a much more pronounced decrease in lending rate by almost 40 bps at the peak. The expansionary effects of the non-standard monetary policy measure lead to a tightening of the standard monetary policy instrument through the estimated Taylor rule. The short-term policy rate peaks at 25 bps after one year. This also illustrates the strategic complementarities between the two instruments.

For the ELB scenario, we assume a realistic composition of shocks that pushes the policy rate to its lower bound. To do so, we use the Kalman filter to retrieve the smoothed shocks from the sample 1995q1-to-2020q4 which covers the ultra low interest rate period and official ECB macroeconomic projections of March 2018. We set the lower bound on the policy rate such that the policy rate starts to be binding in Q3 2014, consistent with the official ECB communication on its main key interest rates reaching the lower bound at that time. The interest rate on the main refinancing operations was set at for first time of 5 bps in September 2014. By applying the Occbin toolbox the period at the ELB is subsequently an endogenous outcome of the model.

Assuming that the policy rate is constrained at its ELB for 4 quarters, the macroeconomic impact of central bank asset purchases on output and inflation is significantly amplified. The stronger multipliers turn out to be weakly related to the credit channel of the measures. Indeed, the bank capital position and asset dynamics are not strongly affected by the ELB constraint. At the margin, it brings a bank funding benefits as the policy rate is not increased over the first quarters. This induces the bank to extend more loans for a lower return augmenting the impact of non-standard monetary policy measures. Actually, the strengthening of the macroeconomic is stemming for the signalling channel of the ELB constraint which mainly operates outside the banking sector.

Concluding from above, loan origination through portfolio rebalancing is a key propagation channel of central bank asset purchases. The pronounced credit expansion might come with side effects as foregoing profit margins could raise the default probability of a weakly capitalised banking sector and spur financial stability risks. This would open the case for financial policies to limit bank leveraging tendency on riskier assets. Such interactions between regulatory and non-standard monetary policies are explored in greater details through the next sections.

4.2 Regulatory requirements and the financial stability risks of central bank asset purchases

The previous simulations have been conducted using the benchmark calibration for the banking sector (see section 3). In this case, the default probability for bankers is very low so that the limited liability distortion becomes almost ineffective. We consider now a calibration with lower regulatory capital ratio in order to portray a weakly-capitalised banking system. Setting ν_b at 4%, the default probability for Bankers reaches 3% annually in the steady state and limited liability plays an active role in the risk-taking behaviour of intermediaries. Figure 7 actually shows the steady state allocation as a function of ν_b. As tighter bank capital regulation forces banks to hoard a higher fraction of relatively more expensive equity financing, banks end up charging higher lending rates and restrict loan supply in the steady state. Bankers shrink their balance sheet size but along with the improvements in bank risk (i.e. lower probability of default), tighter requirements are cushioned through lower capital buffers.

In order to analyse the interactions between risk-taking and capital requirements, we intend to contrast two different model specifications with respect to their steady state implications (see Figure 7) as well as their influence on the transmission of asset purchases (see Figure 4): in the first specification, banks do not benefit from limited liability, bearing the full impact of asset return realisations on their profit and loss (see black dashed line), while in the second one, banks are subject to limited liability under a deposit insurance scheme (see blue dotted line). In the latter case, banks may default when their return on asset is not sufficient to cover the repayments due to deposits. Then the deposit insurance agency serves the depositors and takes over the loan portfolio of the failed banker subject to resolution costs. Limited liability together with deposit insurance introduces an implicit subsidy for bankers, since their financing instrument, e.g. deposits, is not priced according to the default risk it bears. This actually generates misaligned perceptions on expected loan return and excess risk-taking. Steady state results of Figure 7, indeed show that for low levels of capitalisation, the equilibrium return on loans with limited liability is lower than in the model without limited liability. In addition, the steady state probability of bank default is higher as are loan origination and leverage.

Turning to the propagation of central bank asset purchases in a weakly-capitalised banking system, Figure 4 shows the responses of selected macroeconomic variables, distinguishing the cases with and without limited liability. As the central bank acquires government bonds from financial intermediaries and the yield on this asset class diminishes, banks with limited liability have an incentive to issue more loans and charge a lower risk premium to compensate for weaker profitability. Loan origination expansion is twice stronger with limited liability, relative to the case of fully liable bankers, and significantly more protracted. The moral hazard problem strengthens the portfolio rebalancing channel of asset purchases as banks are more eager to substitute government bonds for risky private debt in order to exploit the implicit subsidy of limited liability. Turning to the bond market, the higher willingness to sell government bonds under limited liability, dampens the drop in yields and leads to weaker capital gains from bond holdings. Altogether, banks' net worth deteriorates much more over the medium-term and bankers probability of default increases sharply. Excessive leverage and bank fragility reveal that bankers with limited liability are less reluctant to breach any low level of capital ratio.

Regarding the macroeconomic impact of the central bank asset purchases, the increase in activity and investment is almost twice bigger under limited liability, with peak effects reached later. The transmission is also more persistent: output remains significantly above the steady state after 20 quarters which it already converges back in the absence of limited liability. Similarly, the inflationary pressure from the non-standard measure is higher by 0.1 p.p. all through the simulation horizon, under limited liability, which leads to a tighter stance of the rule-based standard monetary policy.

The model dynamics substantiate the risk-taking channel of non- and standard monetary policy (Adrian and Shin, 2010; Borio and Zhu, 2012). When net interest rate income from maturity transformation is low, weakly-capitalized banks are encouraged to invest in riskier lending reflected in excessively loose financing conditions.[20] The sensitivity of the yield curve to banks' risk-taking, more precisely the weaker response government yields, indicates that the risk-taking channel partly compensates the direct pass-through of central bank asset purchases on the bond market. Therefore, the stronger the risk-taking channel, the larger the amplification of credit and macro variables − an observation in line with Borio and Zhu (2012); De Groot (2014).[21]

Two striking implications result from this simulation exercise which emphasize the need to impose bank capital regulation. First, under limited liability, the credit easing channel of central bank asset purchases could entail strong inefficiencies which can be addressed by capital regulation. Sec-

[20] Notably, the restrictive interest rate response could countervail risk incentives, but is clearly offset by the powerful portfolio re-balancing channel of asset purchases.

[21] Leverage and the risk appetite are perfectly correlated which explains why well-capitalized banks do not suffer from augmented bank default. From this follows that leverage is the representative banks' choice. Comparably, in the model of Gertler et al. (2012) and De Groot (2014) banks adjust endogenously their balance sheet composition between outside and inside equity.

ond, the limited liability distortion reinforces a much more protracted impact of the non-standard policy intervention. Such a policy persistence, however, may complicate the use of the non-standard instrument for macroeconomic stabilisation purposes or require very active central bank portfolio management to deliver the intended temporary stimulus: capital regulation might also tame the persistence of the macroeconomic impact, alongside with the financial stability risks.

Against this background, we illustrate the implications of higher bank capital regulation on the transmission mechanism of central bank asset purchases. Figure 5 compares the effects for banks with limited liability, which are either well-capitalized (as in the benchmark calibration and in Figure 3) or weakly-capitalized (as in Figure 4). It shows that well-capitalised banks due to stricter regulation originate less loans in response to central bank asset purchases. Higher regulatory capital mutes banks' risk-taking incentive as stronger capital base improves bankers solvency risk. Lower bank default probabilities mitigate the implicit subsidy stemming from limited liability. Consequently, the credit easing effect of central bank asset purchases becomes significantly less persistent. Tighter capital requirements induce bankers to internalize its pecuniary externality associated with high leverage. Another remarkable observation is that higher capital requirements mitigate banks' willingness to sell government bonds. Consequently, the response of long-term yields resembles the one obtained for weakly-capitalized banks without limited liability.

Turning to macroeconomic outcomes, the real effects of outright government bond purchases with tight regulation are qualitatively similar to the ones with weakly-capitalized banks over the first year. But the expansion of key macroeconomic variables is more short-lived, reverting back to baseline as fast as in the simulation without limited liability of Figure 4. One aspect worth mentioning is that regulatory pressures not only deter risk-shifting behaviour but also pull back the peak transmission of non-standard monetary policy. Capital requirements by correcting the limited liability distortion eliminate bank defaults and thereby reduce excess credit. This is achieved though without curtailing the magnitude of the output multiplier.

Our results are robust to the situation when the policy rate is constrained. In Figure 6 we assume as before that a composition of shocks pushes the policy rate to the ELB. Banks are either well-, medium- or weakly-capitalised which corresponds to capital requirements of 9%, 7% and 5% respectively. The lower the level of bank capitalisation and hence the higher the risk-taking incentives, the stronger the amplification of the ELB on real i.e. output, investment) and nominal impact of asset purchases. Also borrowers' creditworthiness improves considerably more when banks are weakly capitalised. In contrast, financial variables are hardly affected by the ELB constraint relative to the scenario with an active monetary policy rule and divergent regulatory capital ratios. In sum, bank risk-shifting and constrained standard monetary appear as two self-reinforcing factors amplifying the macroeconomic impact of central bank asset purchases. On explanation could come from the high persistence of non-standard measure effect with weakly-capitalised banks. In the unconstrained scenario, the policy rate increase via the Taylor rule implies a more protracted deviation from the steady state than in the case of well-capitalised banks. Consequently, the easing signal from the ELB constraint is more pronounced, with powerful transmission outside of the banking sector. Besides, the risk-taking motive of banks alters not only the macroeconomic impact of central bank asset purchases but also the length of the ELB period in the underlying scenario (i.e. the ELB scenario on which the central bank asset purchase shocks are introduced): with weakly-capitalised banks the policy rate remains one more quarter at the ELB, indicating that the implicit constraint on the standard policy instrument is stronger.

4.3 Supervisory discretion and policy uncertainty

The focus of this section turns now to supervisory oversight, its interventions across the banking system and the risk for policy uncertainty to interfere with the intended transmission of central bank asset purchases. In order to motivate our exercise, let us recall that the supervisory framework in the euro area has undertaken drastic changes since 2014. Moreover, the annual review of supervisory capital demands allows for a high degree of discretion and has been subject to substantial framework changes (notably concerning the distinction between Pillar 2 guidance and requirements for example). Consequently, while supervisory actions are effectively targeting cross-sectional heterogeneity in bank risk profiles (which can not be meaningfully mapped into our model), we want to contemplate the possibility that banks still perceive some degree of supervisory policy uncertainty.

The supervisory capital demand volatility given by equation (68) is calibrated in order to be in line with evidence from the recent rounds of SREP evaluation. In this regard, the standard deviation, σ_ν, is set such that it reflects around 1 p.p. change of the existing capital ratio.[22] Given the end of the year announcement of additional capital requirements with a phasing-in period of one year, the autoregressive parameter, $\tilde{\nu}_{b,s,t}$, is set to 0.98 in order to capture the persistent impact of the intervention. For our experiment, we introduce the uncertainty shock by doubling the standard deviation σ_{σ_ν} of the volatility shifter $\varepsilon_{\sigma_\nu,t}$, from 1 to 2. Increasing the variation of the bank capital demand shock intends to illustrate the increased uncertainty on supervisors' discretionary adjustments. For the persistence parameter of the uncertainty shock, ρ_{σ_ν}, we opt for a value of 0.5.

Previous simulations are based on a linear first-order approximation of the model around the non-stochastic steady state of the model which is a sufficient strategy as long as certainty equivalence is not restricting the scope of the analysis. For second (and higher) moments to matter in the decision rule of the representative agent, a third order approximation to the policy function is necessary. To avoid explosive behaviour of the simulated data which can result from higher order perturbated policy functions, we apply the pruning method by Kim et al. (2008) when calculating the policy function with Dynare.

As discussed in Fernàndez-Villaverde et al. (2011), with higher order approximations the simulated paths of the model's endogenous variables depart from their deterministic steady-state values, i.e. the expected value of endogenous variables depend also on the variance of the shocks in the economy. Therefore, the state at which the impulse response functions are started, i.e. the past history of shocks, matters for the computation of the impulse response functions. The literature suggests two possible states of the ergodic mean as starting points: (i) The fixed-point that the model converges to in the absence of shocks applied by Fernàndez-Villaverde et al. (2011); Basu and Bundick (2017) which we refer to as stochastic steady state and (ii) the state where, simply speaking, the model settles if it is continuously hit by shocks. The later approach proposed by Koop et al. (1996) requires the computation of generalized impulse response function which are constructed for the $n = 1, 2, 3...$ periods after the shock according to:

$$GIRF_n(\epsilon_t, \Upsilon_{t-1}) = \mathbb{E}_t \left[Y_{t+n} \epsilon_t, \Upsilon_{t-1} \right] - \mathbb{E}_t \left[Y_{t+n} \Upsilon_{t-1} \right] \tag{80}$$

[22] Based on this assumption, we allow the capital ratio in a linear environment to fluctuate between $[8.1\%, 9.9\%]$.

while the ϵ_t is the one standard deviation shock that hits the economy in period t and Υ_t encompasses the history of shocks. Instead, following the first method, we center our impulse response functions around the the ergodic mean in the absence of past and future shocks:

$$IRF_n(\epsilon_t, \Upsilon_{t-1}) = \mathbb{E}_t\left[Y_{t+n}|\epsilon_t, \Upsilon_{t-1} = \{0\}, \Upsilon_{t+1} = \{0\}\right] - \mathbb{E}_t\left[Y_{t+n}|\Upsilon_{t-1} = \{0\}, \Upsilon_{t+1} = \{0\}\right] \quad (81)$$

We decide for this approach as our focus is to evaluate the impact of higher regulatory uncertainty in isolation without any change in the actual volatility size of the simulation period.[23] In general, Basu and Bundick (2017) show that both approaches lead to similar results. More precisely, for this simulation exercise, we construct impulse response functions as follows:[24]

1. We retrieve the third-order policy function from Dynare that accounts for the volatility from the capital requirement shock. We set the exogenous shocks to zero and iterate the third-order policy function forward for 5020 periods starting from the non-stochastic steady state.

2. We disregard the first 5000 periods as burn-in. Each point after the burn-in represents the stochastic steady-state.

3. Starting from the stochastic steady state, we assume the economy is hit by a one standard deviation uncertainty shock. We then compute the impulse responses as percentage deviation between the equilibrium responses and the pre-shock stochastic steady state in line with according to the 81.

Against this background, we analyse how uncertainty around bank capital adequacy ratios alter banks' business behaviour when a central bank purchasing programme provides economic stimulus. Figure 8 displays impulse response functions to non-standard measures, with the benchmark calibration, and accompanied by a one standard deviation shock to the regulatory uncertainty shock.

First, increased regulatory uncertainty in the economy is perceived as tightening of ν_b by banks because the uncertainty increases the penalty costs in the optimisation constraints of the banks. Through precautionary motives, banks accumulate more net worth. With these additional capital buffers and hence a falling leverage ratio, they intend to safeguard their business from potential regulatory costs. As more funds are used to build up a capital buffer, banks cut back on loans by raising borrowing costs in the short-run. Outside of the banking sector, households increase their precautionary savings and decide to consume less. In the production sector, the slow adjustment of prices and higher external finance premium spur firms to cut their demand for labour and capital curtailing investment. Overall the regulatory uncertainty shock shows that the precautionary effects in banks, households and firms decisions depresses economic activity and prices. The propagation shares some similarities with an actual tightening of supervisory capital demand, albeit with a more pronounced effect on consumption and inflation.[25]

We turn now to the combined impact of the non-standard measures and regulatory uncertainty shocks. Higher uncertainty about ν_b dampens the transmission of a one-off impulse on asset pur-

[23] Moreover, a more practical reason is that the computation of generalized impulse response functions is very time-consuming.

[24] Previous impulse response functions have been calculated as the deviation of the variables paths from their deterministic steady state.

[25] We find the reactions, in particular in the production sector, to be consistent with the literature on macroeconomic uncertainty Basu and Bundick (2017); Fernàndez-Villaverde et al. (2011) and Cesa-Bianchi and Fernandez-Corugedo (2016) even though the shock works through a different channel.

chases. The effect on consumer prices, consumption and output growth is more delayed since banks are reluctant to originate loans despite the PSPP incentives. Because the bank extends its equity position to buffer against regulatory uncertainty, banks leverage falls considerably more compared to the single impact of PSPP. Associated with the reduced willingness of banks to extend loans, the creditworthiness of borrowers deteriorates for a short period of time which reinforces downward pressure on economic activity. The results show that discretionary scope of supervisors to shift the adequacy ratio can hamper the macroeconomic stimulus of non-standard monetary policy.

Our results relate to Cesa-Bianchi and Fernandez-Corugedo (2016) who find that credit frictions boost the impact of macroeconomic uncertainty. The empirical findings of Valencia (2016) and Nodari (2014) on the relevance of financial regulatory policy uncertainty for business cycle fluctuations are also consistent with our results.

4.4 Counter-cyclical Macroprudential rule

Introducing a macroprudential policy rule in the model allows us to address the third layer of bank capital-based financial policy and analyze its interaction with asset purchases. The macroprudential rule reacts to the Credit-to-GDP ratio, in line with ESRB recommendations.

In order to study the performance of the rule within the model (equation (70)), we conduct a welfare analysis to optimally set the reaction parameter ϕ_{ν_b} given the stochastic environment and well-capitalised banks. In that sense "optimal" refers to the parameter value that maximizes the households' life time utility function. Using a second order approximation of the model (Schmitt-Grohe and Uribe, 2004) the search procedure seeks for parameter values in a grid from $[0, 10]$. The welfare objective function is given by

$$\mathcal{W}_t = \epsilon_t^b \mathcal{U}_t + \mathbb{E}_t \left(\beta \gamma^{1-\sigma}\right) \mathcal{W}_{t+1}. \tag{82}$$

Similarly to Lozej et al. (2017), we abstract from any persistence in the rule, setting ρ_{ν_b} to zero. As Figure 9 plots the welfare as a function of ϕ_{ν_b}. The maximum is found for ϕ_{ν_b} at 0.32332.

Figure 10 displays the reactions to non-standard measures for well-capitalised banks. Since central bank outright transactions lead to an increase in the credit-to-GDP gap, the macroprudential rule imposes on banks 10% percent higher regulatory capital ratio. To avoid penalty costs from the heightened capital requirements, banks attempt to build-up capital buffers. Over the medium-term, bank's net worth declines by less with the active macroprudential rule. Moreover, the presence of the rule deters risk-taking incentives as banks anticipate that any marginal increase in loan origination might trigger a tightening of macroprudential capital demands. The credit easing effect of central bank asset purchase is therefore muted, leading to smaller multipliers on investment and output. Furthermore, the subdued inflation impact shows that the rule interferes with price stability objectives of non-standard monetary policy measures. As banks' sufficient capitalisation keeps default probability very low, the macroprudential feedback does not deliver visible benefits for a resilient banking system. However it dampens significantly the accommodative monetary policy impulse. Therefore, without tangible impact on financial stability, the macroprudential authority should preferably look through the temporary credit easing effects of central bank asset purchases.

When monetary and financial authorities operate within a fragile banking system, the case for active coordination of the policy interventions might become clearer. Figure 11 replicates the previous experiments assuming weakly-capitalized banks. In this case, as mentioned in the previous sections, the non-standard monetary policy measure induces a wider opening of the credit-to-GDP gap since low capital requirements enables banks to engage in excessive credit extension. The macroprudential capital demand becomes 3 times larger than in the case of well-capitalised banking system. This prevents banks from easing excessively lending conditions. Loan dynamics ultimately resembles the one obtained by combining macroprudential policy and central bank asset purchases with well-capitalized banks. The rule achieves sizeable benefits in terms of financial stability by limiting the increase in bank default probability. Turning to macroeconomic outcomes, the countercyclical capital provision mutes the economic stimulus of central bank asset purchases on output and inflation to levels that are again comparable to the prior case of well-capitalised banks. Summing up, financial policy can effectively limit "unhealthy" credit growth and hence extensive risk-taking behaviour of banks in response to asset purchases, within insufficiently capitalised banking jurisdiction. However, such a role for macroprudential intervention might be seen as a second best compared with setting higher capital requirements. This remains a conjecture for the present analysis, leaving such a normative assessment for further research.

William and Zilberman (2016) and Rubio and Carrasco-Gallego (2016) suggest to complement countercyclical bank capital regulation with a more aggressive monetary policy stance on inflation for a socially optimal outcome. Our results relate nonetheless to these findings.

5 Conclusion

This paper examines the impact of financial policies on the transmission of central bank asset purchases. More precisely, it evaluates the scope for regulatory, supervisory and macroprudential bank capital demands to contain the potential side effects of accommodative non-standard monetary policy. The estimated model accounts for risk-taking motives of banks and is capable of reproducing the banks' portfolio rebalancing channel of asset purchases. The findings suggest that minimum bank capital requirements should ensure an adequate capitalisation of the banking system in order to prevent the central bank asset purchases from sizeably increasing banks solvency risk. Otherwise, weak bank capitalisation leads to a strong risk-taking channel of the non-standard measure, generating highly persistent macroeconomic stimulus and a protracted expansion of credit. Due to bank precautionary motives, uncertainty about financial policies acts as a quasi tightening of standard which might delay or hamper the intended transmission of the central bank asset purchases. Risk shifting of banks reinforces the dampening effect of monetary stimulus. Finally countercyclical macroprudential policy can deter risk-shifting motives of weakly-capitalised banks but also reduces the output multiplier of central bank asset purchases. In a well-capitalised banking environment with low bank default probability, the macroprudential rule impedes on the transmission of asset purchases and should preferably refrain from counteracting the non-standard monetary policy impulse.

A normative analysis of these conclusions would imply an evaluation the optimal mix between financial and non-standard monetary policies which is beyond the scope of this paper and is left for future research.

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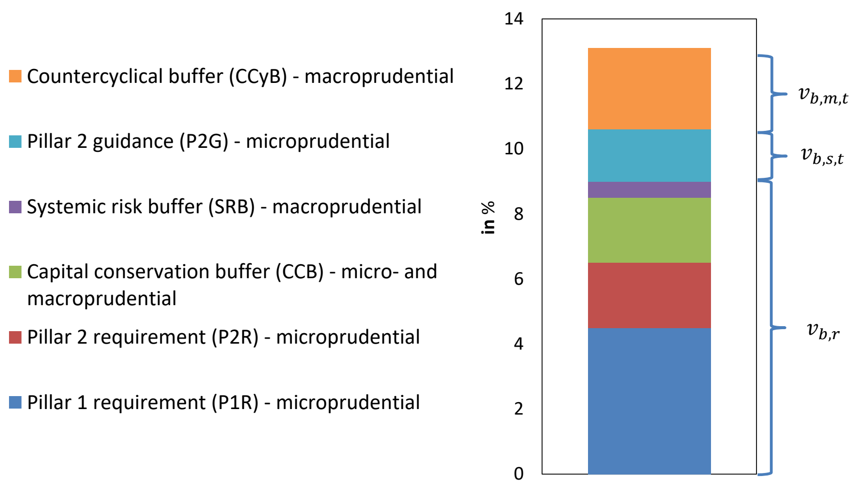
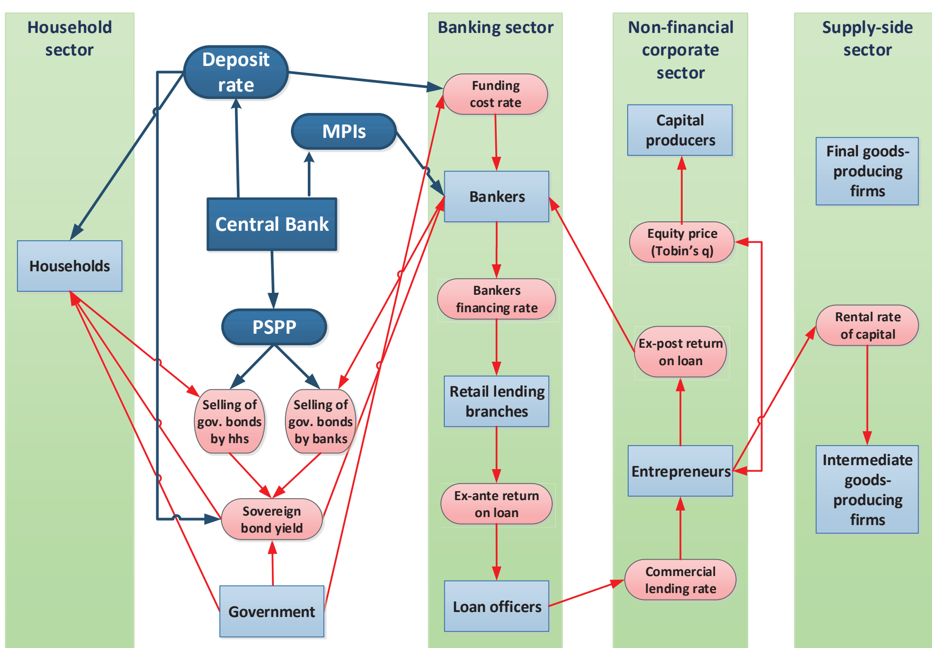
Figure 1: SREP 2017 outcome: Bank capital (CET 1) demand for 2018.



Source: ECB.

Notes: $\nu_{b,r}$ and $\tilde{\nu}_{b,s,t}$ denote the regulatory and supervisory requirements, while $\nu_{b,m,t}$ the macroprudential countercyclical capital buffer. The values corresponding to the SREP 2017 outcome for 2018 are as follows: P1R=4.5%; P2R=2%; CCB=2%; SRB=0.5%; P2G=1.6%; CCyB=2.5%; $\nu_{b,r} + \tilde{\nu}_{b,s,t} + \nu_{b,m,t} = 13.1\%$.

Figure 2: Schematic representation of the model and transmission of policies



Source: ECB.

Notes: PSPP = Public Sector Purchase Programme. MPIs = All regulatory, supervisory and macroprudential policies.

Table 1: Calibrated parameters

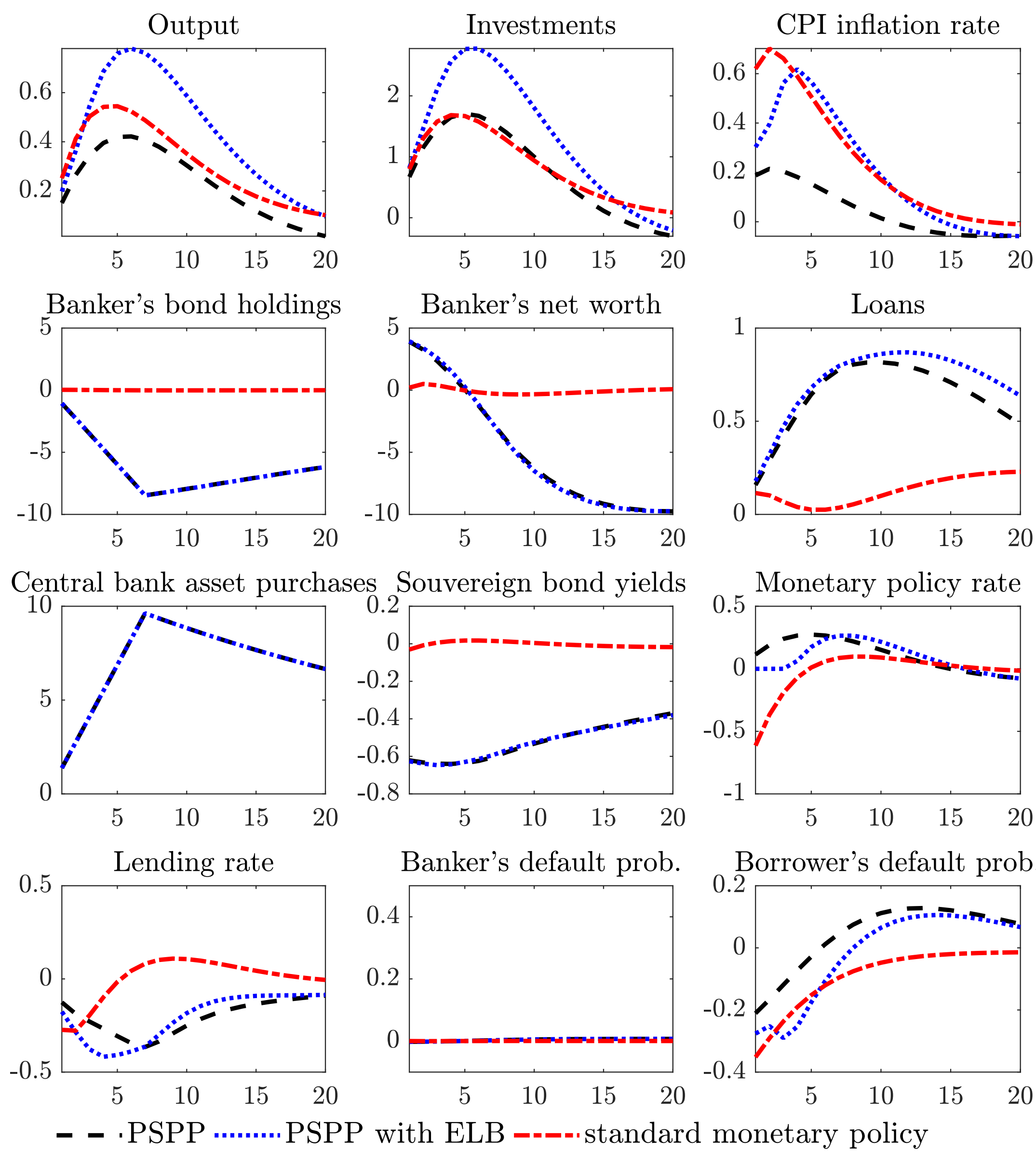
Parameters		Value
Price and wage setting		
μ_w	Wage markup	1.50
ψ	Kimball goods aggregator parameter	10
ψ_w	Kimball labour aggregator parameter	10
Technology		
δ	Fixed capital stock depreciation rate	0.025
Entrepreneurs		
μ_e	Monitoring costs	0.10
σ_e	std idiosyncratic entrepreneur risk	0.30
χ_e	Seizability rate	0.50
ζ_e	Survival probability for entrepreneurs	0.99
Ψ_E	Tranfers to new entrepreneurs (percentage of assets)	0
Banks		
$\mu_E^R - 1$	Lending rate monopolistic margin in basis points	15.00
ζ_b	Survival probability for bankers	0.95
σ_b	std idiosyncratic bank risk	0.03
χ_b	Regulatory penalty	0.40
ν_b	Regulatory bank capital requirement	0.09
ν_g	Regulatory constraint on gov. bonds	0.09
Ψ_B	Transfers to new bankers (percentage of assets)	0.10
μ_b	Resolution costs for bank default	0.30
Government sector and debt market		
$G^\star/Y$	Share of gov. expenditures to output	0.18
$B_G/4Y$	Share of outstanding gov. bonds to output (annual)	0.60
κ_B^g/κ_B^l	Share of bank holdings of gov. bond to loans	0.12
$\overline{B_H}/4Y$	Households target gov. bond holdings	0.27
τ_g	Geometric decay factor for coupons	0.02
c_g	Coupon rate	0.04
$\chi_H/100$	Portfolio adj. cost for households	5.50
$\chi_B/100$	Portfolio adj. cost for bankers	0.50

Table 2: Estimated parameters

Parameters		A priori beliefs			A posteriori beliefs			
		Dist.	Mean	Std.	Mode	Mean	$\mathcal{I}_1$	$\mathcal{I}_2$
σ_c	Intertemp. elasticity of subst.	gamm	1.5	0.2	1.673	1.747	1.433	2.059
η	Habit formation	norm	0.7	0.1	0.788	0.772	0.702	0.840
σ_l	Labor disutility	gamm	2	0.75	0.683	0.888	0.348	1.401
ϕ	Investment adj. cost	norm	4	1.5	3.914	4.440	2.772	6.097
φ	Cap. utilization adj. cost	beta	0.5	0.15	0.667	0.623	0.404	0.849
α_p	Calvo lottery, price setting	beta	0.5	0.1	0.643	0.649	0.554	0.746
ξ_p	Indexation, price setting	beta	0.5	0.15	0.188	0.188	0.071	0.298
α_w	Calvo lottery, wage setting	beta	0.5	0.1	0.428	0.454	0.346	0.562
ξ_w	Indexation, wage setting	beta	0.5	0.15	0.205	0.247	0.090	0.405
ξ_E^R	Calvo lottery, lending rate	beta	0.5	0.2	0.461	0.446	0.320	0.574
α	Capital share	norm	0.3	0.05	0.326	0.333	0.282	0.384
μ_p	Price markup	norm	1.25	0.12	1.484	1.508	1.335	1.673
r_β	Time-preference rate	gamm	0.25	0.1	0.093	0.115	0.045	0.182
γ	Trend productivity	gamm	0.3	0.1	0.141	0.126	0.063	0.187
$\overline{L}$	Employment shift	norm	0	5	-0.338	-0.048	-2.922	2.719
$\overline{\pi}$	SS inflation rate	gamm	0.5	0.05	0.513	0.514	0.433	0.594
ρ	Interest rate smoothing	beta	0.75	0.15	0.905	0.907	0.885	0.929
r_π	Taylor rule coef. on inflation	norm	1.5	0.25	1.681	1.700	1.374	2.017
$r_{\Delta Y}$	Taylor rule coef. on d(output)	norm	0.12	0.05	0.111	0.111	0.088	0.134
$r_{\Delta\pi}$	Taylor rule coef. on d(inflation)	gamm	0.3	0.1	0.083	0.091	0.049	0.132
λ_e	Employment adj. cost	beta	0.5	0.3	0.877	0.868	0.840	0.898
$\rho_{a,g}$	Corr(Tech.,Gov. Spend.)	unif	4.5	3.2	0.648	0.754	0.083	1.424
ρ_a	AR(1) Technology	beta	0.5	0.3	0.898	0.896	0.843	0.948
ρ_b	AR(1) Preference	beta	0.5	0.3	0.017	0.129	0.000	0.267
ρ_g	AR(1) Gov. spending	beta	0.5	0.2	0.989	0.988	0.979	0.997
ρ_I	AR(1) Inv. Technology	beta	0.5	0.2	0.803	0.737	0.562	0.893
ρ_p	AR(1) Price markup	beta	0.5	0.2	0.984	0.930	0.832	0.999
η_p	MA(1) Price markup	beta	0.5	0.2	0.862	0.742	0.563	0.918
ρ_w	AR(1) Wage markup	beta	0.5	0.2	0.954	0.945	0.914	0.974
ρ_{σ_e}	AR(1) entrepr. risk	beta	0.9	0.1	0.917	0.916	0.902	0.930
ρ_{R_G}	AR(1) bond valuation	beta	0.5	0.3	0.981	0.964	0.927	0.999
Standard deviations								
ϵ_t^a	Technology	unif	5	2.9	0.789	0.785	0.513	1.059
ϵ_t^b	Preference	unif	5	2.9	2.105	2.254	1.505	2.948
ϵ_t^g	Gov. spending	unif	5	2.9	1.752	1.793	1.539	2.036
ϵ_t^I	Inv. Technology	unif	10	5.8	3.658	4.302	2.777	5.735
ϵ_t^p	Price markup	unif	0.25	0.1	0.133	0.125	0.090	0.158
ϵ_t^w	Wage markup	unif	0.25	0.1	0.130	0.132	0.090	0.172
ϵ_t^r	Policy rate	unif	0.25	0.1	0.090	0.095	0.080	0.110
$\epsilon_t^{\sigma_e}$	Entrepreneurs risk	unif	5	2.9	4.259	4.596	3.785	5.402
$\epsilon_t^{R_G}$	Gov. bond valuation	unif	5	2.9	1.109	1.506	0.740	2.323
$P_\lambda(\mathcal{Y})$		53.446						

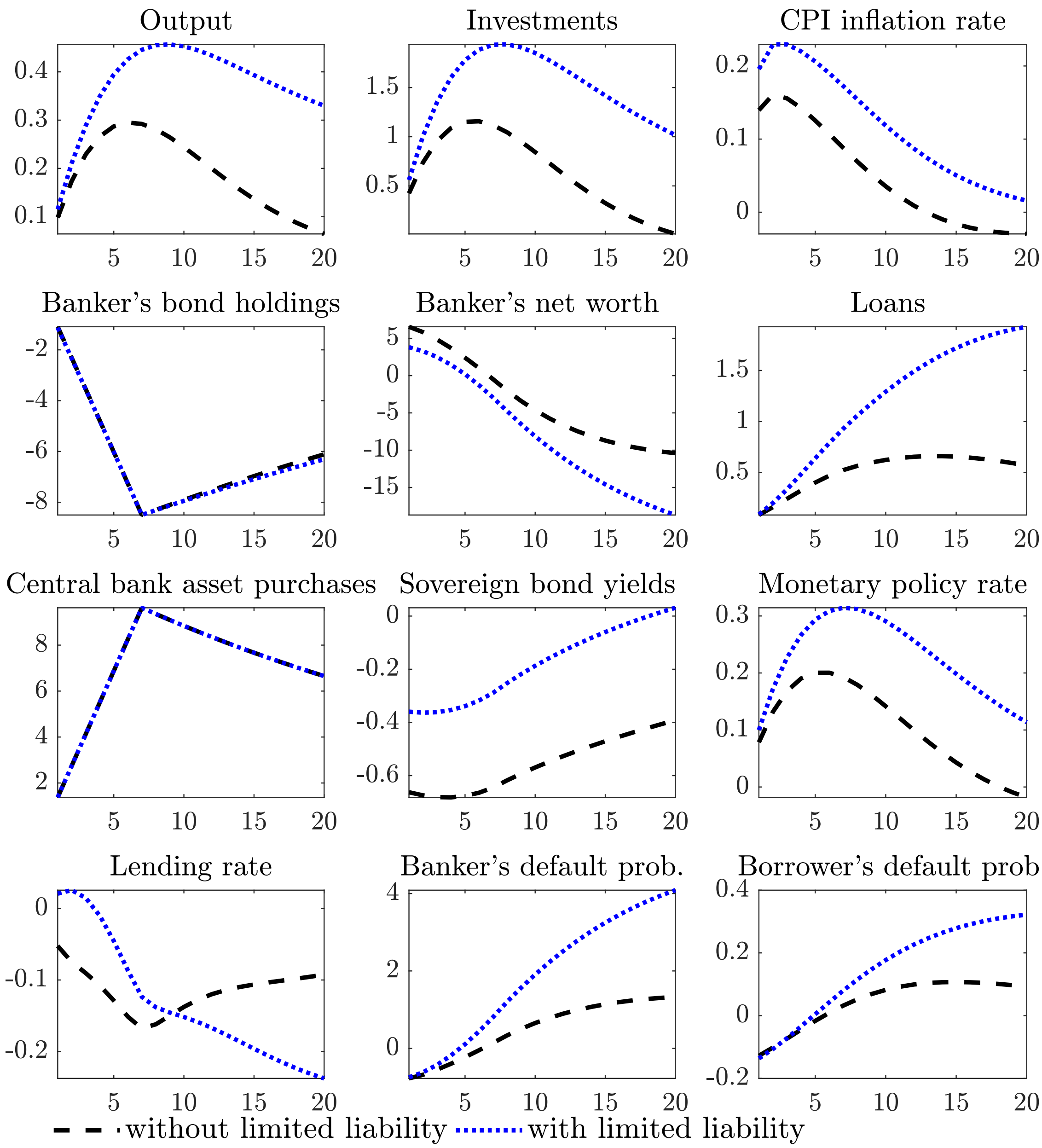
Notes: $[\mathcal{I}_1, \mathcal{I}_2]$ is the shortest interval covering eighty percent of the posterior distribution.

Figure 3: Standard and non-standard monetary policy with and without effective lower bound: benchmark calibration



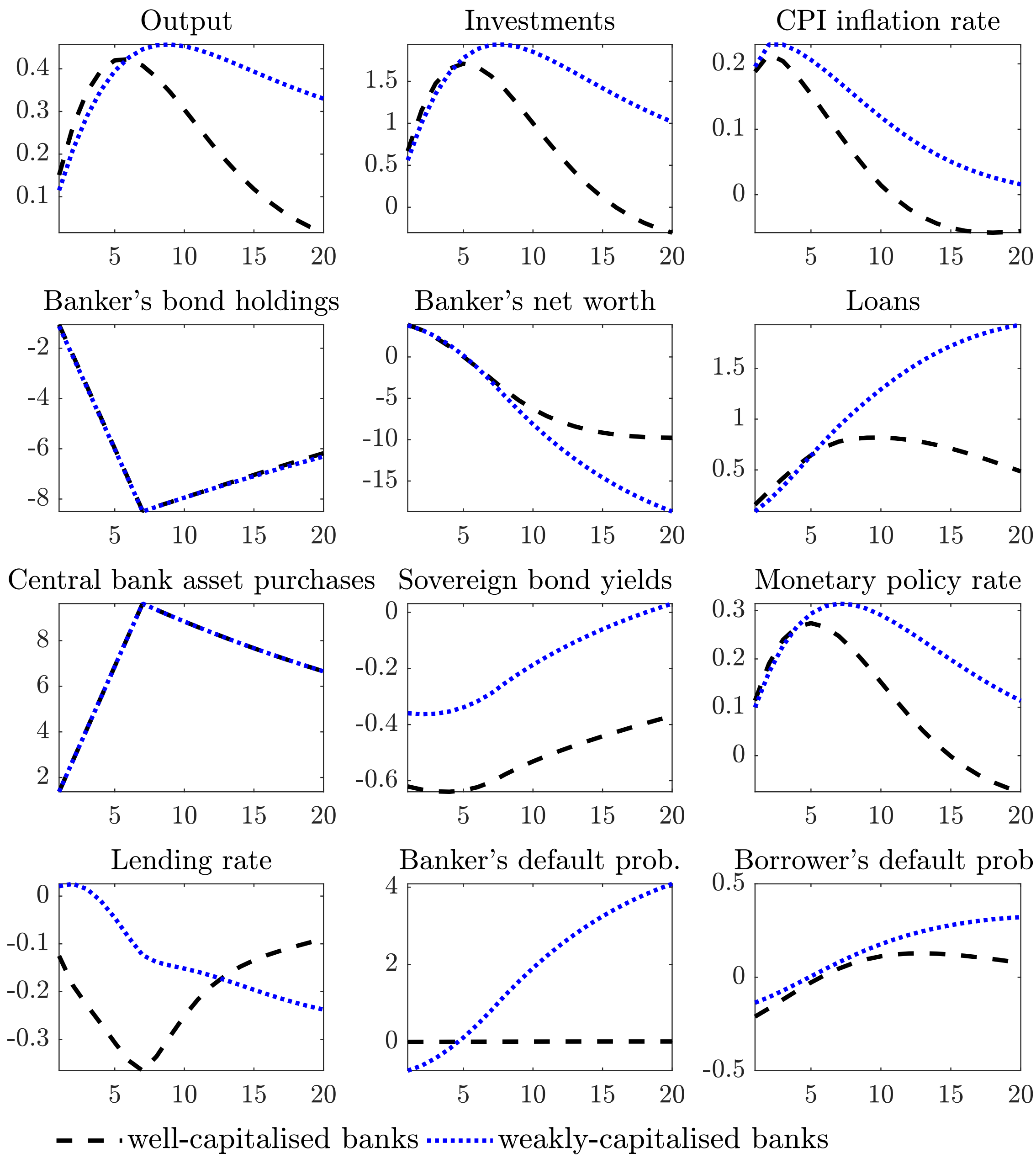
Notes: Impulse response functions after a monetary policy shock and central bank asset purchases assuming well-capitalised banks. Government bond purchases by the central bank last for six quarters amounting to 9.6% of GDP. The monetary policy shock lowers the deposit rate by 50 bp. The impulse responses at the ELB are expressed as the difference between the post-asset purchase effect and the baseline ELB scenario without asset purchases. Horizontal axis: in quarters. Vertical axis: Output, investments, banker's government bond holdings and net worth as well as loans are expressed in percentage deviations from baseline. CPI inflation, the monetary policy rate, the lending rate and the sovereign bond yields are presented in absolute annual percentage point deviations. Central bank asset purchases are reported in percentages of output. The default probability of borrowers and bankers is denoted in absolute annual percentage points. PSPP = Public Sector Purchase Programme. ELB = Effective lower bound.

Figure 4: Non-standard monetary policy with weakly-capitalized banks



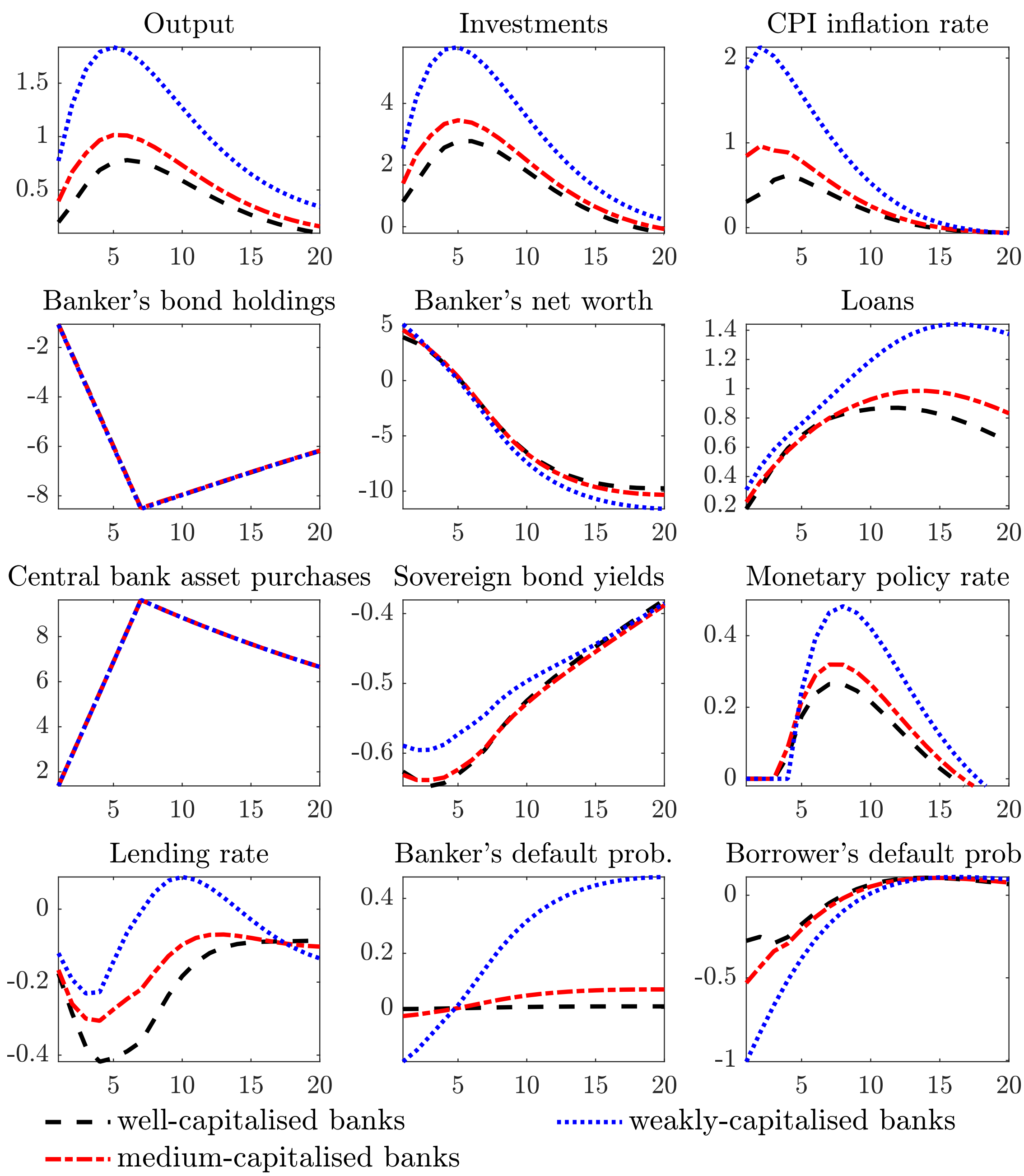
Notes: Impulse responses refer to central bank asset purchases assuming weakly-capitalised banks with and without limited liability. Government bond purchases by the central bank last six quarters. Horizontal axis: in quarters. Vertical axis: Output, investments, banker's government bond holdings and net worth as well as loans are expressed in percentage deviations from baseline. CPI inflation, the monetary policy rate, the lending rate and the sovereign bond yields are presented in absolute annual percentage point deviations. Central bank asset purchases are reported in percentages of output. The default probability of borrowers and bankers is denoted in absolute annual percentage points.

Figure 5: Non-standard monetary policy with well-capitalised or weakly-capitalized banks



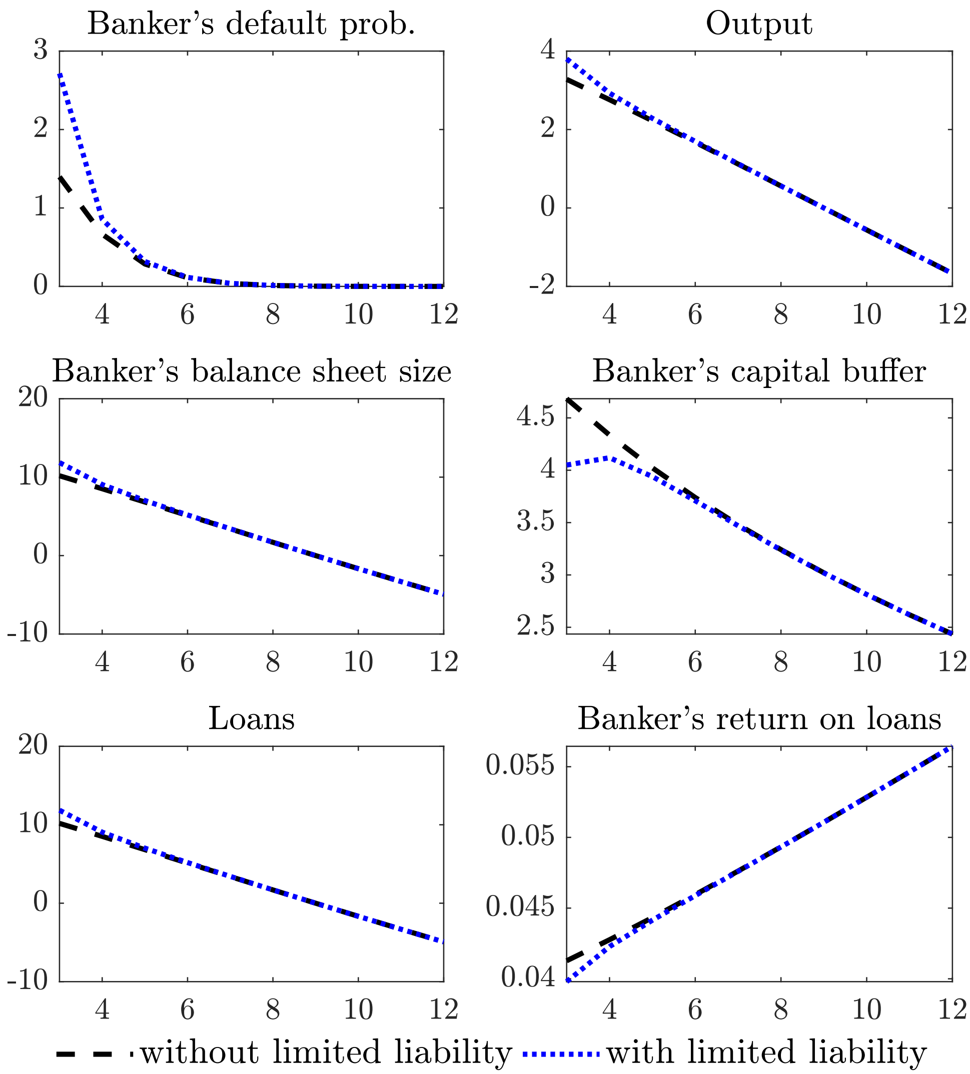
Notes: Impulse responses refer to central bank asset purchases assuming banks with limited liability. Well- and weakly-capitalised banks correspond to minimum capital requirements of 9% and 4% respectively. Government bond purchases by the central bank last six quarters amounting to 9.6% of GDP. Horizontal axis: in quarters. Vertical axis: Output, investments, banker's government bond holdings and net worth as well as loans are expressed in percentage deviations from baseline. CPI inflation, the monetary policy rate, the lending rate and the sovereign bond yields are presented in absolute annual percentage point deviations. Central bank asset purchases are reported in percentages of output. The default probability of borrowers and bankers is denoted in absolute annual percentage points.

Figure 6: Non-standard monetary policy for different regulatory capital ratio at the ELB



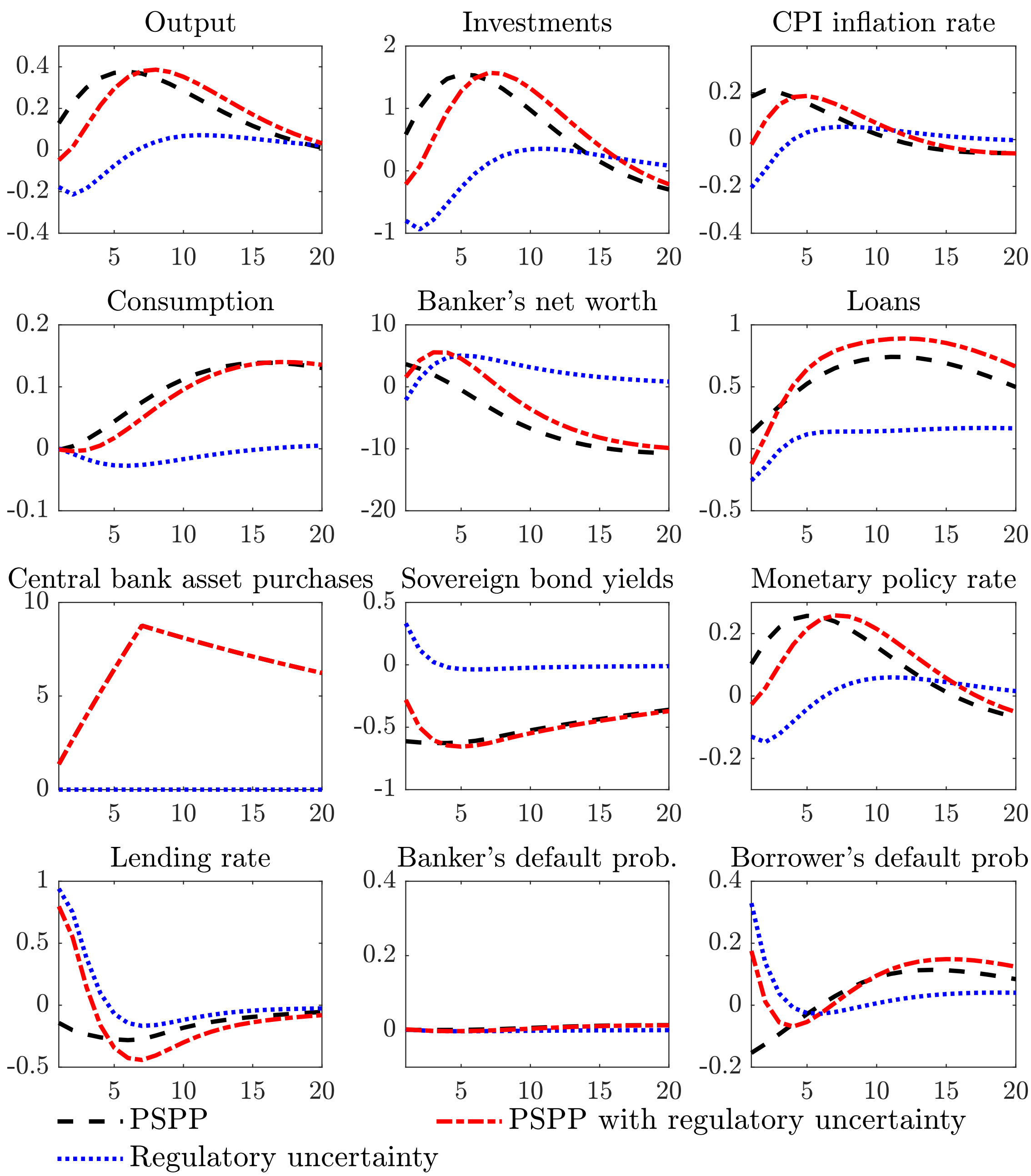
Notes: Impulse responses refer to central bank asset purchases assuming banks with a capital requirement ratio of 5%, 7% and 9%, respectively. The simulations are conducted for banks with limited liability at the ELB of the policy rate and are expressed as the difference between the post-asset purchase effect and the baseline ELB scenario without asset purchases. Government bond purchases by the central bank last six quarters amounting to 9.6% of GDP. Horizontal axis: in quarters. Vertical axis: Output, investments, banker's government bond holdings and net worth as well as loans are expressed in percentage deviations from baseline. CPI inflation, the monetary policy rate, the lending rate and the sovereign bond yields are presented in absolute annual percentage point deviations. Central bank asset purchases are reported in percentages of output. The default probability of borrowers and bankers is denoted in absolute annual percentage points. ELB = Effective lower bound.

Figure 7: Steady-state sensitivity to minimum capital requirements for banks with and without limited liability



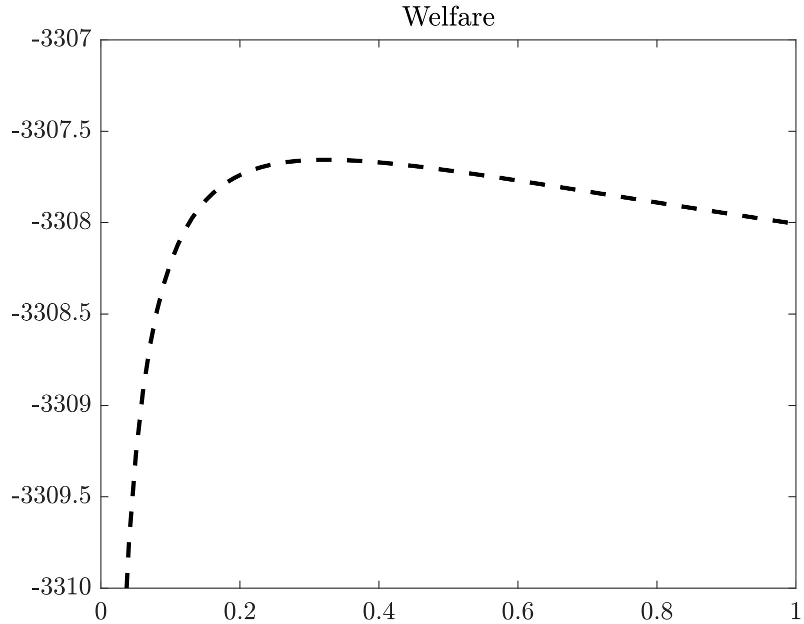
Notes: Steady state dynamics of selected variables for a varying regulatory capital ratio ν_b for banks with and without limited liability. Horizontal axis: The capital requirement is given as the fraction of the banker's asset holdings in percentage points. Vertical axis: Banker's default probability are denoted in annual percentage points. The lending rate is expressed in annual percentage points. Output, banker's balance sheet size and loans are reported in percentage deviation from the benchmark calibration at a capital ratio of 9 %. The banker's capital buffer is expressed as a fraction of the banker's asset holdings in percentage points.

Figure 8: Non-standard monetary policy in the case of well-capitalized banks and regulatory uncertainty



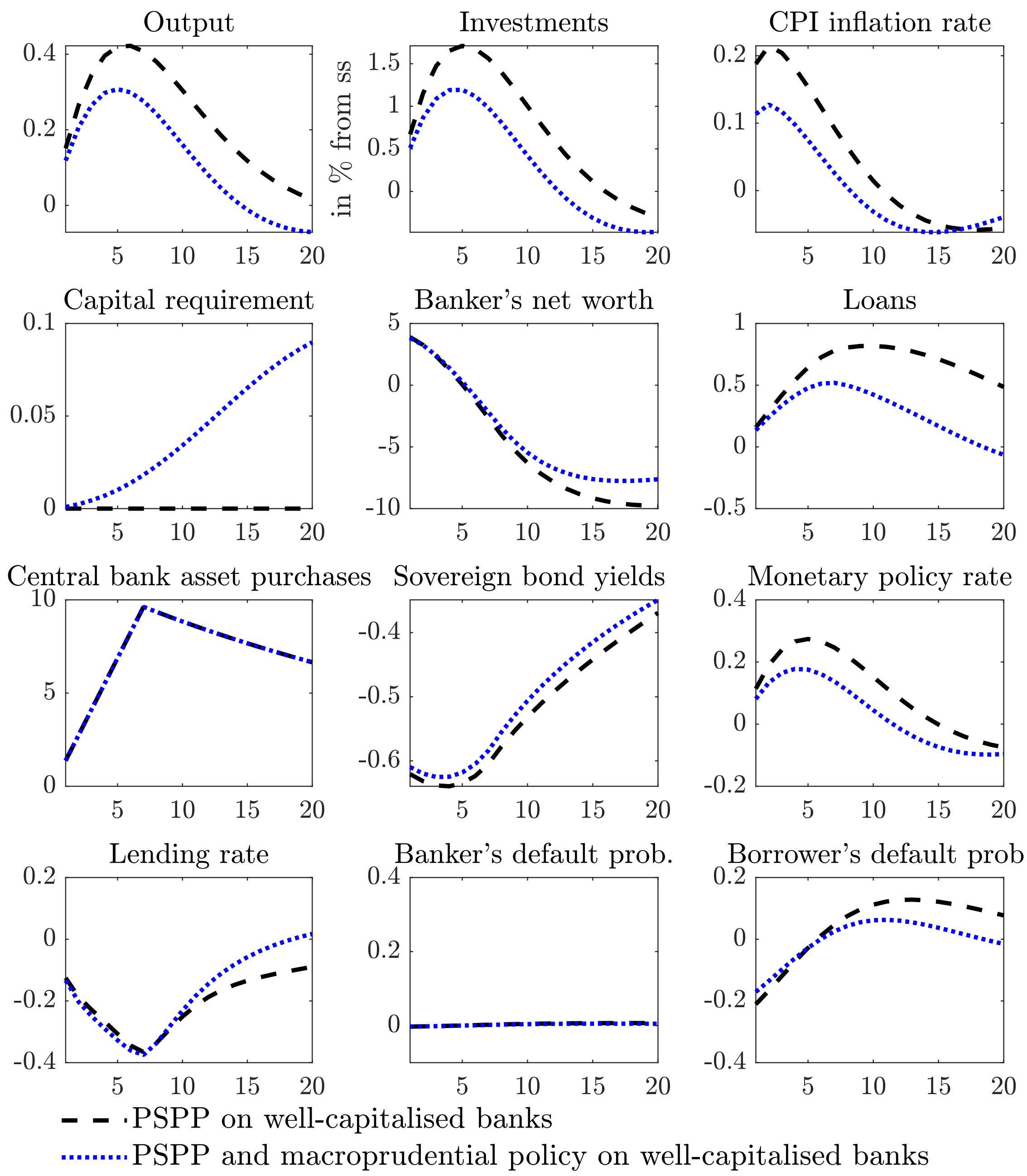
Notes: Impulse responses refer to central bank asset purchases, a one std regulatory uncertainty shock and the combination of both assuming banks with a capital requirement of 9 % and limited liability. Government bond purchases by the central bank last six quarters amounting to 9.6% of GDP. The regulatory uncertainty shock raises the probability of a changing capital requirement ratio which does not materialize. Horizontal axis: in quarters. Vertical axis: Output, investments, consumption and banker's net worth as well as loans are expressed in percentage deviations from the stochastic steady state. CPI inflation, the monetary policy rate, the lending rate and the sovereign bond yields are presented in absolute annual percentage point deviations. Central bank asset purchases are reported in percentages of output. The default probability of borrowers and bankers is denoted in absolute percentage points. PSPP = Public Sector Purchase Programme.

Figure 9: Social welfare sensitivity to the macroprudential rule parameter



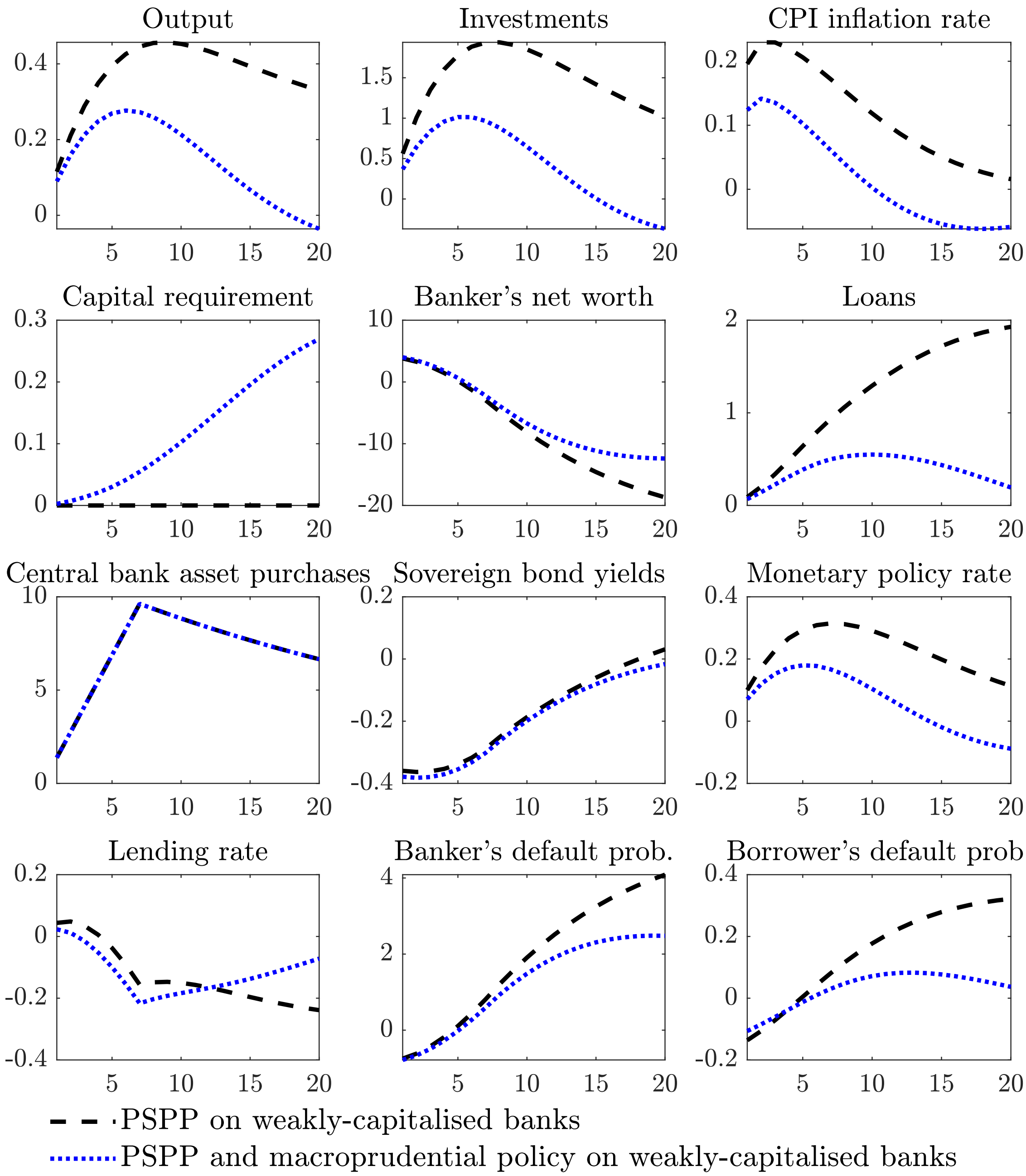
Welfare maximization over a range of values for the reaction parameter in the countercyclical rule. Banks are assumed to be well-capitalised. Notes: Horizontal axis: value of the reaction parameter Φ_{ν_b} in the countercyclical rule. Vertical axis: lifetime utility.

Figure 10: Non-standard monetary policy in the case of well-capitalized banks and macroprudential policy feedback



Notes: Impulse responses refer to central bank asset purchases assuming well-capitalised banks with limited liability. Government bond purchases by the central bank last six quarters. Horizontal axis: in quarters. Vertical axis: Output, investments, banker's net worth and loans are expressed in percentage deviations from the stochastic steady state. CPI inflation, the monetary policy rate, the lending rate and the sovereign bond yields are presented in absolute annual percentage point deviations. Central bank asset purchases are reported in percentages of output. The default probability of borrowers and bankers is denoted in absolute annual percentage points. The capital requirement is given in percentage deviations from the 9 % regulatory ratio. PSPP = Public Sector Purchase Programme.

Figure 11: Non-standard monetary policy in the case of weakly-capitalized banks and macroprudential policy feedback



Notes: Impulse responses refer to central bank asset purchases assuming weakly-capitalised banks with limited liability. Government bond purchases by the central bank last six quarters. Horizontal axis: in quarters. Vertical axis: Output, investments, banker's net worth and loans are expressed in percentage deviations from baseline. CPI inflation, the monetary policy rate, the lending rate and the sovereign bond yields are presented in absolute annual percentage point deviations. Central bank asset purchases are reported in percentages of output. The default probability of borrowers and bankers is denoted in absolute percentage points. The capital requirement is given in percentage deviations from the 3 % regulatory ratio. PSPP = Public Sector Purchase Programme.