The interdependence of monetary and macroprudential policy under the zero lower bound

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October 2016 No 310

National Bank
OF BELGIUM
Eurosystem

The Interdependence of Monetary and Macroprudential Policy under the Zero Lower Bound*

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August 31, 2017

Abstract

This paper considers the interdependence of interest rate rules and macroprudential policies in a New Keynesian business cycle model, where entrepreneurs and banks engage in a loan contract and both are subject to idiosyncratic default risk. We analyze the transmission of firm and bank risk as well as TFP shocks under the zero lower bound (ZLB) and different macroprudential policy coefficients. The ZLB constraint exacerbates the fall in GDP in response to the firm risk shock but not to the bank risk shock, which acts as a supply shock. From a policy perspective, a bolder responsiveness of the capital requirement instrument mitigates the recession in response to bank/firm risk shocks since it reduces the probability of bank/firm default, respectively.

Keywords: capital requirement, macroprudential policy, monetary policy, zero lower bound.

JEL classification: E44, E52, E58, E61, G28.

*We thank Ferre de Graeve, Peter Karadi, Patrick Pintus, Markus Roth, Carlos Thomas, Raf Wouters and seminar participants at the National Bank of Belgium, Macfinrobods meeting, Université catholique de Louvain, University of Kent for helpful comments. The views expressed in this paper are solely the authors' and do not necessarily reflect the views of the Bundesbank or the Eurosystem.

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1 Introduction

As the following quote by the European Central Bank's chief economist shows, the interaction of macroprudential and monetary policy is a highly relevant issue in central banking:

"*...a central bank may be prevented from tightening monetary conditions as would be otherwise appropriate, if it fears that, by doing so, banks may suffer losses and see their fragile health conditions undermined.*"

Peter Praet, 11th March 2015, speech at the Conference 'The ECB and Its Watchers XVI'.

The recent academic literature agrees with policy makers in recognizing that monetary and macroprudential policies cannot be analyzed in isolation, and that an encompassing framework is therefore needed.[1] This paper analyzes, within a dynamic stochastic general equilibrium (DSGE) framework, how interest rate policies and bank capital requirements interact and affect the business cycle. It proposes a model that combines New Keynesian price setting frictions with financial market imperfections.

Credit demand and financial intermediation are modelled as follows. Similarly to Bernanke et al. (1999), henceforth BGG, entrepreneurs have insufficient net worth to buy capital and therefore borrow from banks. Entrepreneurs are subject to idiosyncratic default risk, which gives rise to a costly state verification problem. When an entrepreneur declares default, banks incur monitoring costs in order to observe the entrepreneur's realized return on capital. As in Zhang (2009), Benes and Kumhof (2015) and Clerc et al. (2015), we depart from BGG by stipulating a default threshold that is contingent on the aggregate return to capital. In BGG, debt contracts do not have this contingency, such that the entrepreneur's net worth varies together with aggregate risk. Since the financial intermediary is then perfectly insulated from such risk, its balance sheet plays no role. Here, in contrast, banks suffer balance sheet losses if entrepreneurial defaults are higher than expected.

Banks have limited liability. When a bank fails, it is monitored by a bank resolution authority, an action which destroys part of the bank's remaining assets. Bank defaults do not, however, affect the return on deposits. Full deposit insurance - financed through lump sum taxes on households - removes any incentive for depositors to monitor the banks' activities and thus the deposit rate is equal to the policy rate. At the same time, bank equity is limited to the accumulated wealth of bankers, who are the only agents allowed to invest in banking. This results in a high equity return per unit invested. As a consequence of expensive equity and cheap deposit funding, banks have an incentive to maximize leverage. Due to limited liability, banks do not internalize the cost of increased

[1] See Leeper and Nason (2014), Smets, (2014), and Brunnermeier and Sannikov (2016).

banking sector fragility. The role of macroprudential policy, then, is to put a cap on bank leverage so as to limit the amount of resources lost due to bank failures.

What do our macroeconomic policies look like? On the one hand, a consensus framework for monetary policy has emerged in the form of interest rate feedback rules, as proposed by Taylor (1993). We restrict attention to conventional monetary policy that sets interest rates, and abstract from unconventional measures. As explained below, we take into account the zero lower bound constraint on nominal interest rates.

Macroprudential policy, on the other hand, is modelled in different ways, depending on the type of borrower, the financial contract and the policy instrument in question. Our focus is on corporate borrowing from the financial sector. From a quantitative point of view, nonfinancial corporate debt is more important than household debt. Figure 1 shows that the debt-to-GDP ratio of non-financial business amounted to 110% in 2000 and increased to almost 140% in 2017. The debt-to-GDP ratio of households, instead, shows an increasing trend up to 2008, when it reached a record high of 99%, and then started to decline gradually to the value of 80%.[2]

[insert Figure 1 here]

The long-run policy instrument in our model is a minimum bank capital-to-asset ratio, which forces banks to fund part of their assets using relatively more expensive equity capital. This is combined with a cyclical instrument that is meant to dampen the financial cycle. The cyclical macroprudential instrument can take one of two forms. We model it either as a countercyclical capital buffer (CCB) to capture Basel III regulation, or as a "leaning against the wind" (LATW) policy, whereby the interest rate responds to lending with a positive coefficient, a practice followed e.g. by the Swedish central bank.

Monetary policy is constrained by the zero lower bound (ZLB), which forces the central bank to be too tight in a downturn due to the fact that interest rates cannot turn negative. Within our modelling framework, we discuss the effects of the ZLB and macroprudential policy on the transmission mechanism of the model by looking at impulse responses to technology shocks and to bank and firm risk shocks.

Our determinacy analysis reveals that the coefficient on lending in the macroprudential rule, i.e. the CCB coefficient, must be above a certain threshold in order for the Taylor Principle to be satisfied. The LATW policy always requires a passive monetary policy for a unique equilibrium.

Under a countercyclical macroprudential policy ("CCB policy"), the ZLB has severe consequences on output when the economy is hit by an adverse firm risk shock. Thus, in

[2]Similarly, Euro Area data (ECB, 2012) show that the debt-to-GDP ratio of non-financial corporations is quantitatively more relevant than debt-to-GDP ratio of households. The former amounted to 60% in 2000 and increased up to almost 80% in 2011, while the debt-to-GDP ratio of households was almost 50% in 2000 and 65% in 2011.

the presence of firm risk shocks, the ZLB acts as an important constraint on monetary policy and it is all the more important for macroprudential policy to be active. In the case of the other two types of shocks, inflation and output move in opposite directions and hence the ZLB-constraint is less consequential. The stronger the response of the CCB policy, the lower the firm default rate and the milder the output contraction. The ZLB has virtually no effect on real variables in response to a firm risk shock under a LATW policy which requires an accommodative monetary policy. A contractionary bank risk shock, instead, acts as a supply disturbance due to the reduced capacity of bankers to provide loans, leading to a fall in output and a rise in inflation. Similarly to the firm risk shock, a more aggressive CCB policy makes the simulated recession less severe by reducing the bank default rate.

The paper is structured as follows. Section 2 outlines the model. Section 3 presents the determinacy analysis. Section 4 investigates the dynamic properties of the model. Finally, Section 5 concludes.

2 Model

We now sketch the model, which features a costly state verification problem both for entrepreneurs and for banks. Banks monitor failed entrepreneurs and a bank resolution authority monitors failed banks. Given the non-state-contingent nature of the loan contract, entrepreneurial defaults affect bank balance sheets. We first discuss the non-financial sector; second, we explain the workings of the financial sector. Third, we present the monetary and macroprudential policy rules. Finally, the rest of the model contains the household sector, goods production and market clearing.

2.1 Non-Financial Sector

This section discusses in detail the loan contract between entrepreneurs and banks. Townsend (1979) analyzes a costly state verification problem where the entrepreneur's return cannot be observed by the lender without incurring a monitoring cost. He shows that the optimal contract in the presence of idiosyncratic risk is a standard debt contract in which the repayment does not depend on the entrepreneur's project outcome. This argument is used in the financial accelerator model of Bernanke, Gertler and Gilchrist (1999), where the debt contract between the borrower and the lender specifies a fixed repayment rate. In the case of default, the lender engages in costly monitoring and seizes the entrepreneur's remaining capital.

As in Bernanke et al. (1999), the risk to the entrepreneur has an aggregate as well as an idiosyncratic component. The latter depends on the aggregate return to capital, which is observable. Carlstrom, Fuerst, Ortiz and Paustian (2014) ask "why should the loan contract call for costly monitoring when the event that leads to a poor return is observable by all parties?". Indeed, Carlstrom, Fuerst and Paustian (2016) show that the privately optimal contract includes indexation to the aggregate return to capital, which they call R^k-indexation. They argue that this type of contract comes close to financial contracts observed in practice. Furthermore, Carlstrom et al. (2014) estimate a high degree of indexation in a medium-scale business cycle model. Consistent with these findings, we stipulate a financial contract whereby the entrepreneur's default threshold depends on the aggregate return to capital.

Entrepreneurs

There is a continuum of risk-neutral entrepreneurs indicated by the superscript 'E'.[3] They combine net worth and bank loans to purchase capital from the capital production sector and rent it to intermediate goods producers. Entrepreneurs face a probability $1-\chi^E$ of surviving to the next period. Let $\mathcal{W}_t^E$ be entrepreneurial wealth accumulated from operating firms. Entrepreneurs have zero labor income. Aggregate entrepreneurial net worth n_{t+1}^E is the wealth held by entrepreneurs at t who are still in business in $t+1$,

$$n_{t+1}^E = \left(1-\chi^E\right)\mathcal{W}_{t+1}^E. \tag{1}$$

Entrepreneurs who die consume their residual wealth, i.e. $c_{t+1}^E = \chi^E \mathcal{W}_{t+1}^E$. Aggregate entrepreneurial wealth in period $t+1$, measured in terms of final consumption goods, is given by the value of their capital stock bought in the previous period, $q_t K_t$, multiplied by the ex-post nominal return on capital R_{t+1}^E, multiplied by the fraction of returns which are left to the entrepreneur $1-\Gamma_{t+1}^E$, discounted by the gross rate of inflation, $\Pi_{t+1} = P_{t+1}/P_t$, that is,

$$\mathcal{W}_{t+1}^E = \left(1-\Gamma_{t+1}^E\right)\frac{R_{t+1}^E q_t K_t}{\Pi_{t+1}}. \tag{2}$$

The discussion of the contracting problem between entrepreneurs and banks below contains a derivation of Γ_{t+1}^E.

The entrepreneur purchases capital K_t at the real price q_t per unit. The amount $q_t K_t$ spent on capital goods exceeds her net worth n_t^E. She borrows the remainder,

$$b_t = q_t K_t - n_t^E, \tag{3}$$

from the full range of banks, which in turn obtain funds from depositors and equity holders ('bankers'). Capital is chosen at t and used for production at $t+1$. It has an ex-post gross return $\omega_{t+1}^E R_{t+1}^E$, where R_{t+1}^E is the aggregate return on capital (as stated above) and ω_{t+1}^E is an idiosyncratic disturbance. The idiosyncratic productivity disturbance is *iid*

[3] In the model appendix, we use the index $j \in (0,1)$ to refer to an individual entrepreneur. For notational convenience, we drop the index here.

log-normally distributed with mean $\mathbb{E}\{\omega^E_{t+1}\} = 1$ and a time-varying standard deviation $\sigma^E_t = \sigma^E \varsigma^E_t$, where ς^E_t is a firm risk shock. The probability of default for an individual entrepreneur is given by the respective cumulative distribution function evaluated at the threshold $\overline{\omega}^E_{t+1}$, to be specified below,

$$F^E_{t+1} = F^E(\overline{\omega}^E_{t+1}) \equiv \int_0^{\overline{\omega}^E_{t+1}} f^E(\omega^E_{t+1}) \mathrm{d}\omega^E_{t+1}, \tag{4}$$

where $f^E(\cdot)$ is the respective probability density function.

The ex-post gross return to entrepreneurs, in terms of consumption, of holding a unit of capital from t to $t+1$ is given by the rental rate on capital, r^K_{t+1}, plus the capital gain net of depreciation, $(1-\delta)\, q_{t+1}$, divided by the real price of capital, in period t. In nominal terms, this is:

$$R^E_{t+1} = \frac{r^K_{t+1} + (1-\delta)\, q_{t+1}}{q_t} \Pi_{t+1}. \tag{5}$$

The financial contract, which we turn to next, determines how the project return is divided between the entrepreneur and the bank.

Financial Contract

After the financial contract is signed, the entrepreneurs' idiosyncratic productivity shock realizes. Those entrepreneurs whose productivity is below the threshold,

$$\overline{\omega}^E_{t+1} = \frac{Z_t b_t}{R^E_{t+1} q_t K_t} = \frac{x^E_t}{R^E_{t+1}}, \tag{6}$$

declare default. In (6), $x^E_t \equiv Z_t b_t/(q_t K_t)$ is the entrepreneur's loan-to-value ratio, the contractual debt repayment divided by the value of capital purchased. Here, the cutoff $\overline{\omega}^E_{t+1}$ is contingent on the realization of the aggregate state R^E_{t+1}, such that aggregate shocks produce fluctuations in firm default rates, which in turn impinge on bank balance sheets.

The details of the financial contract are as follows. In the default case, the entrepreneur has to turn the whole return $\omega^E_{t+1} R^E_{t+1} q_t K_t$ over to the bank. Of this, a fraction μ^E is lost as a monitoring cost that the bank needs to incur to verify the entrepreneur's project return. In the non-default case, the bank receives only the contractual payment $\overline{\omega}^E_{t+1} R^E_{t+1} q_t K_t$. The remainder, $(\omega^E_{t+1} - \overline{\omega}^E_{t+1}) R^E_{t+1} q_t K_t$, goes to the residual claimant, the entrepreneur. Consequently, if the entrepreneur does not default, the payment to the bank is independent of the realization of the idiosyncratic shock but contingent on the aggregate return R^E_{t+1}.

Following the notation in BGG (1999), we define the share of the project return

$R^E_{t+1} q_t K_t$ accruing to the bank, gross of monitoring costs, as

$$\Gamma^E_{t+1} = \Gamma^E(\overline{\omega}^E_{t+1}) \equiv \int_0^{\overline{\omega}^E_{t+1}} \omega^E_{t+1} f(\omega^E_{t+1}) \mathrm{d}\omega^E_{t+1} + \left(1 - F^E_{t+1}\right) \overline{\omega}^E_{t+1}, \tag{7}$$

such that remainder, $1 - \Gamma^E_{t+1}$, represents the share of the return which is left for the entrepreneur. The share of the project return subject to firm defaults is defined as follows,

$$G^E_{t+1} = G^E(\overline{\omega}^E_{t+1}) \equiv \int_0^{\overline{\omega}^E_{t+1}} \omega^E_{t+1} f^E(\omega^E_{t+1}) \mathrm{d}\omega^E_{t+1}. \tag{8}$$

Being risk-neutral, the entrepreneur cares only about the expected return on his investment given by

$$\mathbb{E}_t \left\{ \left[1 - \Gamma^E \left(\frac{x^E_t}{R^E_{t+1}} \right) \right] R^E_{t+1} q_t K_t \right\}, \tag{9}$$

where the expectation is taken with respect to the random variable R^E_{t+1}.

The bank finances loans using equity n^B_t and deposits d_t; its balance sheet is $b_t = n^B_t + d_t$. Furthermore, it is subject to the following capital requirement,

$$n^B_t \geq \phi_t b_t, \tag{10}$$

which says that equity must be at least a fraction ϕ_t of bank assets.[4] The bank's ex-post gross return on loans, in nominal terms, is given by

$$R^F_{t+1} = \left(\Gamma^E_{t+1} - \mu^E G^E_{t+1} \right) \frac{R^E_{t+1} q_t K_t}{b_t}. \tag{11}$$

In order for the bank to agree to the terms of the contract, the return which the bank earns from lending to the entrepreneur must be equal to or greater than the return that the bank would obtain from investing its equity in the interbank market,

$$\begin{aligned} & \mathbb{E}_t \left\{ \left(1 - \Gamma^F_{t+1}\right) \left[\Gamma^E \left(\frac{x^E_t}{R^E_{t+1}} \right) - \mu^E G^E \left(\frac{x^E_t}{R^E_{t+1}} \right) \right] R^E_{t+1} q_t K_t \right\} \\ \geq \quad & \phi_t \mathbb{E}_t \left\{ R^B_{t+1} (q_t K_t - n^E_t) \right\}, \end{aligned} \tag{12}$$

where R^B_{t+1} is the ex-post gross nominal equity return and $1 - \Gamma^F_{t+1}$ is the share of the loan return accruing to the banker after the bank has made interest payments to its depositors (to be derived in Section 2.4 below).

The entrepreneur's objective is to choose x^E_t and K_{t+1} to maximize her expected profit (9), subject to the bank's participation constraint (12), which can be written as an equality without loss of generality. The optimality conditions of the contracting problem

[4]Our required capital ratio is based on total assets given that in the model, we do not work with different risk classes.

are

$$\mathbb{E}_t\{-\Gamma_{t+1}^{E\prime} + \xi_t \left(1 - \Gamma_{t+1}^{F}\right) \left(\Gamma_{t+1}^{E\prime} - \mu^E G_{t+1}^{E\prime}\right)\} = 0, \tag{13}$$

$$\mathbb{E}_t\{\left(1 - \Gamma_{t+1}^{E}\right) R_{t+1}^{E} + \xi_t \left[\left(1 - \Gamma_{t+1}^{F}\right) \left(\Gamma_{t+1}^{E} - \mu^E G_{t+1}^{E}\right) R_{t+1}^{E} - \phi_t R_{t+1}^{B}\right]\} = 0, \tag{14}$$

where ξ_t is the Lagrange multiplier on the bank participation constraint (12).

2.2 Financial Sector

The financial sector consists of a range of banks with idiosyncratic productivity. Banks receive equity funding from bankers and deposit funding from households. Deposits are fully insured; depositors therefore have no incentive to monitor a bank's activities and receive the risk-free return that coincides with the policy rate. Since bankers are the only agents in the economy allowed to hold bank equity, the size of total equity funding is restricted to the bankers' accumulated wealth. This restriction keeps the equity return - per unit of equity held - high. Bankers have limited liability and can walk away if a bank defaults. As deposit funding is cheap and equity funding is expensive, banks therefore have an incentive to maximize leverage and will hold only the minimum amount of capital as required by the macroprudential authority. Those financial institutions that are unable to pay depositors using their returns on corporate loans fail; they are monitored by a tax-funded bank resolution authority.

Bankers

Following Gertler and Karadi (2011), households have a unit mass and consist of two types of people. A proportion $\mathcal{F}$ of household members are bankers and the remaining $1-\mathcal{F}$ are workers. Similar to Merz (1995), where only a fraction of household members are employed, consumption is nevertheless equalized across members through perfect intra-household risk sharing. Every period, some individuals switch between the two occupations. In particular, a person who is currently a banker has a constant probability $1-\chi^B$ of remaining a banker in the next period, which is independent of the time already spent in the banking sector.[5] Every period $(1-\chi^B)\mathcal{F}$ bankers thus quit banking and become workers. The same number of workers randomly become bankers, such that the proportions of bankers and workers within the household remain fixed. Bankers who quit transfer their wealth to their respective household. The household uses a fraction ι of this transfer to provide its new bankers with startup funds, as is described below.

A banker's only investment opportunity is to provide equity to banks. We suppose that a banker holds a diversified portfolio of bank equity, by investing his net worth in all banks. Let n_t^B denote the aggregate net worth of bankers. Bankers obtain an ex-post

[5] The average lifetime of a banker is thus $1/(1-\chi^B)$. Bankers have a finite horizon such that they do not accumulate enough wealth to fund all investments without the need for external borrowing.

aggregate nominal return of R^B_{t+1} on their investment, which determines their wealth in the next period,

$$\mathcal{W}^B_{t+1} = \frac{R^B_{t+1} n^B_t}{\Pi_{t+1}}. \tag{15}$$

The return on equity is the ratio of bank profits to banker net worth,

$$R^B_{t+1} = \frac{(1 - \Gamma^F_{t+1}) R^F_{t+1} b_t}{n^B_t}, \tag{16}$$

where the share of the bank's return on loans accruing to the banker, $1 - \Gamma^F_{t+1}$, is derived below. Combining (15) and (16), we can write banker wealth as $\mathcal{W}^B_{t+1} = (1 - \Gamma^F_{t+1}) \frac{R^F_{t+1} b_t}{\Pi_{t+1}}$.

Aggregate net worth of existing bankers is the wealth held by bankers at t who are still around one period later, $n^B_{et+1} = (1 - \chi^B)\mathcal{W}^B_{t+1}$. A banker who leaves the banking business turns his residual equity over to the household. Newly entering bankers receive "startup" funds from their respective households, which are a fraction ι/χ^B of the value of exiting bankers' wealth, i.e. $n^B_{nt+1} = \iota \mathcal{W}^B_{t+1}$. Therefore, aggregate banker net worth is given by the sum of existing and new bankers' net worth,

$$n^B_{t+1} = (1 - \chi^B + \iota)\mathcal{W}^B_{t+1}, \tag{17}$$

and bank profits retained by the households are $\Xi^B_{t+1} = (1 - \iota/\chi^B)\chi^B \mathcal{W}^B_{t+1}$.

Banks

There is a range of banks indexed by i, each with idiosyncratic productivity ω^{Fi}_{t+1}. Since all banks behave in the same way in equilibrium, we suppress the index i from here on. Banks are subject to limited liability, the representative bank's profit in period $t + 1$ is therefore

$$\Xi^F_{t+1} = \max\left[\omega^F_{t+1} R^F_{t+1} b_t - R^D_{t+1} d_t, 0\right], \tag{18}$$

The bank fails if it has negative profits. Similar to the entrepreneurial sector, there exists a threshold productivity level $\overline{\omega}^F_{t+1}$ below which a bank fails,

$$\overline{\omega}^F_{t+1} R^F_{t+1} b_t = R^D_{t+1} d_t. \tag{19}$$

Using the definition of the bank productivity cutoff (19) to replace $R^D_{t+1} d_t$, we can rewrite bank profits (18) as $\Xi^F_{t+1} = \max\left[\omega^F_{t+1} - \overline{\omega}^F_{t+1}, 0\right] R^F_{t+1} b_t$. The random variable ω^F_{t+1} is log-normally distributed with mean $\mathbb{E}\{\omega^F_{t+1}\} = 1$ and a time-varying standard deviation $\sigma^F_t = \sigma^F \varsigma^F_t$, where ς^F_t is a bank risk shock. In the following, we introduce notation that is analogous to the entrepreneurial sector. Let F^F_t denote the probability of bank default, such that

$$F_{t+1}^F = F^F(\overline{\omega}_{t+1}^F) \equiv \int_0^{\overline{\omega}_{t+1}^F} f(\omega_{t+1}^F)\mathrm{d}\omega_{t+1}^F. \tag{20}$$

The share of the return on loans subject to bank defaults is defined as

$$G_{t+1}^F = G^F(\overline{\omega}_{t+1}^F) \equiv \int_0^{\overline{\omega}_{t+1}^F} \omega_{t+1}^F f(\omega_{t+1}^F)\mathrm{d}\omega_{t+1}^F, \tag{21}$$

of which a fraction μ^F is lost when the bank resolution authority monitors a failed bank. We derive the share of the bank's loan return $R_{t+1}^F b_t$ accruing to the banker as

$$\max\left[\omega_{t+1}^F - \overline{\omega}_{t+1}^F, 0\right] \;=\; \int_{\overline{\omega}_{t+1}^F}^{\infty} \omega_{t+1}^F f(\omega_{t+1}^F)\mathrm{d}\omega_{t+1}^F - \overline{\omega}_{t+1}^F \int_{\overline{\omega}_{t+1}^F}^{\infty} f(\omega_{t+1}^F)\mathrm{d}\omega_{t+1}^F = 1 - \Gamma_{t+1}^F,$$

where we have used the definition

$$\Gamma_{t+1}^F = \Gamma^F(\overline{\omega}_{t+1}^F) \equiv \int_0^{\overline{\omega}_{t+1}^E} \omega_{t+1}^F f(\omega_{t+1}^F)\mathrm{d}\omega_{t+1}^F + \left(1 - F_t^F\right)\overline{\omega}_{t+1}^F. \tag{22}$$

With this simplified notation, we can write bank profits as $\Xi_{t+1}^F = (1 - \Gamma_{t+1}^F)R_{t+1}^F b_t$.

2.3 Monetary and Macroprudential Policies

We now specify two types of macroeconomic policies: monetary policy and macroprudential policy. There are two dimensions in which these policies work: at the steady state and out of steady state. At the steady state, the policy maker chooses a target value for inflation, Π, and a bank capital ratio, ϕ. Out of steady state, inflation and the capital requirement are set according to feedback rules. We consider a monetary policy rule by which the central bank may adjust the policy rate in response to its own lag, inflation and lending. The respective feedback coefficients are τ_R, τ_Π and τ_b, such that:

$$\frac{R_t}{R} = \left(\frac{R_{t-1}}{R}\right)^{\tau_R}\left(\frac{\Pi_t}{\Pi}\right)^{\tau_\Pi}\left(\frac{b_t}{b}\right)^{\tau_b}. \tag{23}$$

Thanks to full deposit insurance financed through lump-sum taxation, the policy rate and the deposit rate are identical, $R_t = R_t^D$. Macroprudential policy is given by a rule for the capital requirement,

$$\frac{\phi_t}{\phi} = \left(\frac{b_t}{b}\right)^{\zeta_b}. \tag{24}$$

The objective of monetary policy is to stabilize inflation so as to minimize the price adjustment costs that firms face. The objective of macroprudential policy is to stabilize the bank default rate so as to minimize the bank resolution costs incurred by taxpayers in the case of bank failures.

2.4 Rest of the Model

The remainder of the model is a standard New Keynesian setup. Households choose their optimal consumption and labor supply within the period, and their optimal bank deposits across periods. Within the production sector, we distinguish between final goods producers, intermediate goods producers, and capital goods producers. Final goods producers are perfectly competitive. They create consumption bundles by combining intermediate goods using a constant-elasticity-of-substitution technology and sell them to the household sector and to capital producers. Intermediate goods producers use capital and labor to produce, with a Cobb-Douglas technology, the goods used as inputs by the final goods producers. They set prices subject to quadratic adjustment costs, which introduces a New Keynesian Phillips curve in our model. Finally, capital goods producers buy the final good and convert it to capital, which they sell to the entrepreneurs.

Households

Households are infinitely lived and have expected lifetime utility,

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left(\ln c_t - \varphi \frac{l_t^{1+\eta}}{1+\eta} \right), \tag{25}$$

where $\beta \in (0,1)$ is the subjective discount factor, c_t is consumption, l_t is labor supply, φ is the relative weight on labor disutility and $\eta \geq 0$ is the inverse Frisch elasticity of labor supply. The household chooses paths for c_t, l_t and bank deposits d_t to maximize (25) subject to a sequence of budget constraints,

$$c_t + d_t + t_t \leq w_t l_t + \frac{R_t^D d_{t-1}}{\Pi_t} + \Xi_t^K + \Xi_t^B + \Xi_t^P, \tag{26}$$

where t_t are lump sum taxes (in terms of the final consumption good), w_t is the real wage, R_t^D is the gross interest rate on deposits paid in period t, Ξ_t^K and Ξ_t^P are capital goods producers' and intermediate goods producers' profits, respectively, which are redistributed to households in a lump sum fashion. Finally, Ξ_t^B are profits of exiting bankers, less the startup funding granted to new bankers. The household's first order optimality conditions can be simplified to a labor supply equation, $w_t = \varphi l_t^{\eta}/\Lambda_t$, and a consumption Euler equation, $1 = \mathbb{E}_t \left\{ \beta_{t,t+1} R_{t+1}^D / \Pi_{t+1} \right\}$, where $\beta_{t,t+s} = \beta^s \frac{\Lambda_{t+s}}{\Lambda_t}$ is the household's stochastic discount factor between t and $t+s$ and the Lagrange multiplier on the budget constraint (26), $\Lambda_t = 1/c_t$, captures the shadow value of household wealth in real terms.

Final Goods Producers

A final goods firm bundles the differentiated industry goods Y_{it}, with $i \in (0,1)$, taking as given their price P_{it}, and sells the output Y_t at the competitive price P_t. The optimization problem of the final goods firm is to choose the amount of inputs Y_{it} that maximizes profits $P_tY_t - \int_0^1 Y_{it}P_{it}\mathrm{d}i$, subject to the production function $Y_t = (\int_0^1 Y_{it}^{\frac{\varepsilon-1}{\varepsilon}}\mathrm{d}i)^{\frac{\varepsilon}{\varepsilon-1}}$, where $\varepsilon > 1$ is the elasticity of substitution between intermediate goods. The resulting demand for intermediate good i is $Y_{it}^d = (P_{it}/P_t)^{-\varepsilon}Y_t$. The price of final output, which we interpret as the price index, is given by $P_t = (\int_0^1 P_{it}^{1-\varepsilon}\mathrm{d}i)^{\frac{1}{1-\varepsilon}}$. In a symmetric equilibrium, the price of a variety and the price index coincide, $P_t = P_{it}$.

Intermediate Goods Producers

Firms use capital and labor to produce intermediate goods according to a Cobb-Douglas production function. The assumption of constant returns to scale allows us to write the production function as an aggregate relationship. Each individual firm produces a differentiated good using $Y_{it} = A_tK_{it-1}^{\alpha}l_{it}^{1-\alpha}$, where $\alpha \in (0,1)$ is the capital share in production, A_t is aggregate technology, K_{it-1} is capital and l_{it} is labor. Intermediate goods firms choose factor inputs to maximize per-period profits given by $\frac{P_{it}Y_{it}}{P_t} - r_t^K K_{it-1} - w_tl_{it}$, where the real rental rate on capital r_t^K and the real wage w_t are taken as given, subject to the technological constraint and the demand constraint. The resulting demands for capital and labor are $w_tl_{it} = (1-\alpha)s_{it}Y_{it}$ and $r_t^K K_{it-1} = \alpha s_{it}Y_{it}$, respectively, where the Lagrange multiplier on the demand constraint, s_{it}, represents real marginal costs. By combining the two factor demands, we obtain an expression showing that real marginal costs are symmetric across producers,

$$s_t = \frac{w_t^{1-\alpha}(r_t^K)^{\alpha}}{\alpha^{\alpha}(1-\alpha)^{1-\alpha}}\frac{1}{A_t}. \tag{27}$$

Firm i sets an optimal path for its product price P_{it} to maximize the present discounted value of future profits, subject to the demand constraint and to price adjustment costs,

$$\mathbb{E}_t \sum_{s=0}^{\infty} \beta_{t,t+s}\left[\frac{P_{it+s}Y_{it+s}^d}{P_{t+s}} - \frac{\kappa_p}{2}\left(\frac{P_{it+s}}{\Pi_{t+s-1}^{\lambda_p}P_{it+s-1}} - 1\right)^2 Y_{it+s} + s_{t+s}\left(Y_{it+s} - Y_{it+s}^d\right)\right]. \tag{28}$$

Price adjustment costs are given by the second term in square brackets in (28); they depend on firm revenues and on last period's aggregate inflation rate. The parameter $\kappa_p > 0$ scales the price adjustment costs and $0 \leq \lambda_p \leq 1$ captures indexation to past inflation Π_{t-1}. Under symmetry, all firms produce the same amount of output, and the firm's price P_{it} equals the aggregate price level P_t, such that the price setting condition is

$$\kappa_p \frac{\Pi_t}{\Pi_{t-1}^{\lambda_p}} \left(\frac{\Pi_t}{\Pi_{t-1}^{\lambda_p}} - 1 \right) = \varepsilon s_t - (\varepsilon - 1) + \kappa_p \mathbb{E}_t \left\{ \beta_{t,t+1} \frac{\Pi_{t+1}}{\Pi_t^{\lambda_p}} \left(\frac{\Pi_{t+1}}{\Pi_t^{\lambda_p}} - 1 \right) \frac{Y_{t+1}}{Y_t} \right\}. \qquad (29)$$

In (29), perfectly flexible prices are given by $\kappa_p \to 0$. If $\lambda_p = 0$, there is no indexation to past inflation and we obtain a purely forward-looking New Keynesian Phillips Curve. Under symmetry across intermediate goods producers, profits (in real terms) are thus $\Xi_t^P = Y_t - r_t^K K_{t-1} - w_t l_t - \frac{\kappa_p}{2}(\Pi_t \Pi_{t-1}^{-\lambda_p} - 1)^2 Y_t$.

Capital Goods Production

The representative capital-producing firm chooses a path for investment I_t to maximize profits given by $\mathbb{E}_t \sum_{s=0}^{\infty} \beta_{t,t+s} \left[q_{t+s} \Delta x_{t+s} - I_{t+s} \right]$. Net capital accumulation is defined as:

$$\Delta x_t = K_t - (1-\delta) K_{t-1} = \left[1 - \frac{\kappa_I}{2} \left(\frac{I_t}{I_{t-1}} - 1 \right)^2 \right] I_t, \qquad (30)$$

where $\delta \in (0,1)$ is the capital depreciation rate and the term $\frac{\kappa_I}{2} \left(\frac{I_t}{I_{t-1}} - 1 \right)^2$ captures investment adjustment costs as in Christiano, Eichenbaum and Evans (2005). The optimality condition for investment is given by:

$$\begin{aligned} 1 &= q_t \left[1 - \frac{\kappa_I}{2} \left(\frac{I_t}{I_{t-1}} - 1 \right)^2 - \kappa_I \left(\frac{I_t}{I_{t-1}} - 1 \right) \frac{I_t}{I_{t-1}} \right] \\ &\quad + \mathbb{E}_t \left\{ q_{t+1} \beta_{t,t+1} \kappa_I \left(\frac{I_{t+1}}{I_t} - 1 \right) \left(\frac{I_{t+1}}{I_t} \right)^2 \right\}. \end{aligned} \qquad (31)$$

Capital producers' profits, in real terms, are $\Xi_t^K = q_t \left[K_t - (1-\delta) K_{t-1} \right] - I_t$.

Market Clearing

Consumption goods produced must equal goods demanded by households and entrepreneurs, goods used for investment, resources lost when adjusting prices, and resources lost in the recovery of funds associated with entrepreneur and bank defaults,

$$Y_t = c_t + c_t^E + I_t + \frac{\kappa_p}{2} \left(\frac{\Pi_t}{\Pi_{t-1}^{\lambda_p}} - 1 \right)^2 Y_t + \mu^F G_t^F \frac{R_t^F b_{t-1}}{\Pi_t} + \mu^E G_t^E \frac{R_t^E q_{t-1} K_{t-1}}{\Pi_t}. \qquad (32)$$

Firms' labor demand must equal labor supply, $(1-\alpha) s_t \frac{Y_t}{l_t} = \frac{\varphi_t l_t^\eta}{\Lambda_t}$.

Aggregate Uncertainty

The logarithm of technology follows a stationary AR(1) process,

$$\ln A_t = \rho_A \ln A_{t-1} + \varepsilon_t^A, \tag{33}$$

where $\rho_A \in (0,1)$ and ε_t^A is an *iid* shock with mean zero and standard deviation σ^A. As noted above, the random variables ω_{t+1}^E and ω_{t+1}^F have log-normal distributions with mean one and a standard deviation $\sigma_t^E = \sigma^E \varsigma_t^E$, which introduces time variability of firm and bank risk via the autoregressive processes,

$$\ln \varsigma_t^E = \rho_E \ln \varsigma_{t-1}^E + \varepsilon_t^E, \tag{34}$$

$$\ln \varsigma_t^F = \rho_F \ln \varsigma_{t-1}^F + \varepsilon_t^F, \tag{35}$$

with $\rho_E \in (0,1)$ and $\rho_F \in (0,1)$. Let the parameters σ_ς^E and σ_ς^F denote the standard deviations of the *iid* normal shocks ε_t^E and ε_t^F, respectively.

Equilibrium

The model is closed with a monetary policy rule that governs the policy rate R_t and a macroprudential rule that governs the capital ratio, ϕ_t. We are now ready to provide a formal definition of equilibrium in our economy.

Definition 2.1. An equilibrium is a set of allocations $\{l_t, K_t, I_t, c_t, Y_t, n_t^E, b_t, n_t^B, d_t, x_t^E\}_{t=0}^\infty$, prices $\{w_t, r_t^K, q_t, \Pi_t, s_t\}_{t=0}^\infty$ and rates of return $\{R_t^F, R_t^E, R_t^B\}_{t=0}^\infty$ for which, given the monetary and macroprudential policies $\{R_t, \phi_t\}_{t=0}^\infty$ and shocks to technology, firm and bank risk $\{A_t, \varsigma_t^E, \varsigma_t^F\}_{t=0}^\infty$ entrepreneurs maximize the expected return on their investment, firms and banks maximize profits, households maximize utility and all markets clear.

2.5 Calibration and Steady State

To derive the deterministic steady state, we solve numerically for the entrepreneur and bank productivity cutoffs, $\overline{\omega}^E$ and $\overline{\omega}^F$, the proportion of the project return lost in monitoring, μ^E, the entrepreneur exit rate χ^E, the standard deviations of the idiosyncratic shock hitting firms and banks, σ^E and σ^F, and the bank failure rate F^F. Given initial values for those steady state parameters, we can solve for the remaining steady state variables recursively as shown in Table 1.

[insert Table 1 here]

In the model, a time period is interpreted as one quarter. We normalize technology and risk shocks in steady state by setting $A = \varsigma^E = \varsigma^F = 1$. We also normalize labor,

$l = 1$, and set the weight on labor disutility, φ, equal to 0.7624 to meet this target. The calibration of our model parameters is summarized in Table 2.

[insert Table 2 here]

We set $\Pi = 1.005$ to yield an annualized inflation rate of 2 percent as observed in US data over the period 1984-2016. The subjective discount factor β is set to 0.99, implying a quarterly risk-free (gross) nominal interest rate of $R = \frac{1.005}{0.99}$. The inverse of the Frisch elasticity of labor supply is set to $\eta = 1$, as in Christiano et al. (2014). This value lies in between the micro estimates of the Frisch elasticity, which are typically below 1, and the calibrated values used in macro studies, which tend to be above 1. As is standard in the literature (see Bernanke et al., 1999, and Carlstrom et al., 2016, among many others), the capital share in production is set to $\alpha = 0.35$, while the depreciation rate is $\delta = 0.025$, such that 10% of the capital stock has to be replaced each year. The substitution elasticity between goods varieties is $\varepsilon = 6$, implying a gross steady state markup of $\frac{\varepsilon}{\varepsilon - 1} = 1.2$ (Christensen and Dib, 2008). The Rotemberg price adjustment cost parameter is $\kappa_p = 30$, which corresponds to a price duration of around 3 quarters in the Calvo model of staggered price adjustment; that value is in line with the duration implied by the posterior estimate of the Calvo parameter in Smets and Wouters (2007).[6] The investment adjustment cost parameter is set to $\kappa_I = 2.43$, the estimate of Carlstrom et al. (2014) for the indexation-to-R^k model. The financial parameters and interest rates are displayed in Table 3.

[insert Table 3 here]

We first discuss the financial parameters, before turning to the ranking of the various interest rates and spreads in steady state. Following BGG (1999), we target (i) a ratio of capital to net worth, $\varrho \equiv \frac{qK}{n^E}$, of 2, (ii) a spread between the return on capital and the deposit rate, $\upsilon^E \equiv \frac{R^E}{R^D}$, of 200 basis points per year, and (iii) a quarterly entrepreneur default rate of $F^E = 0.0075$, which corresponds to an annual default rate of 3%. As far as the banking sector is concerned, we set the following two targets: (i) a steady state capital requirement for banks, i.e. the ratio of equity to loans, of 8%, that is $\phi = 0.08$ as recommended by the Basel Accords, and (ii) an equity return premium, $\upsilon^B \equiv \frac{R^B}{R^D}$, of 600 basis points per annum in line with empirical evidence.[7] Bank monitoring costs are calibrated to $\mu^F = 0.3$ as in Clerc et al. (2015).[8] Laeven and Valencia (2010) report a median fraction of bank assets lost due to bank failures - in the US between 1986 and

[6] For the algebraic relationship between the Rotemberg and the Calvo parameter see Cantore et al. (2014).

[7] The series of the spread is computed as the difference between the return on average equity for all U.S. banks and the 10-Year treasury constant maturity rate in the period 1984Q1-2016Q3.

[8] Differently from the monitoring cost related to the entrepreneurial sector, bank monitoring costs μ^F do not affect the computation of the steady state financial variables (see equations (32)-(33) in Table 1). They only appear in the aggregate resource constraint.

2008 - of around 20%. As in Gertler and Karadi (2011), the proportional transfer to the entering bankers is set to $\iota = 0.002$.

In the following, we report the implied financial parameters and provide an interpretation for our results. In the corporate sector, we obtain a productivity cutoff of roughly one half, $\overline{\omega}^E = 0.499$, a monitoring cost equal to $\mu^E = 10\%$, a standard deviation of the idiosyncratic shock to the project return of $\sigma^E = 0.271$, and an entrepreneur exit rate of $\chi^E = 0.018$. In the banking sector, we find a productivity cutoff of $\overline{\omega}^F = 0.92$, a standard deviation of the bank risk shock equal to $\sigma^F = 0.029$, a bank failure rate of 0.9% per annum. The banker exit rate is found to be $\chi^B = 0.022$.

In our model, bank resolution costs are substantially higher than firm monitoring costs ($\mu^F > \mu^E$). This may reflect the greater opaqueness of bank balance sheets, which makes monitoring more difficult (Morgan, 2002). Moreover, the role of banks in financial intermediation suggests that the costs and externalities associated with bank failures are particularly high. E.g. Kupiec and Ramirez (2013) find that bank failures cause non-bank commercial failures and have long-lasting negative effects on economic growth. Our implied banker turnover rate χ^B is in the ballpark of the numbers found in the literature, e.g. Gertler and Kiyotaki (2010) and Angeloni and Faia (2013) impose a value of 0.028 and 0.03, respectively. On the one hand, our probability of bank default F^F lies below the value reported in De Walque et al. (2010) using the Z-score method to compute the probability that banks' own funds are not sufficient to absorb losses, which yields 0.4% p.a., and the ratio of bank failures to the number of commercial banks, which is 0.9% p.a. for the period 1984-2015 according to the Federal Deposit Insurance Corporation.[9] On the other hand, if we count bank *closings* rather than failures, we find a rate of 2.7% p.a. in US data.[10] Our value therefore lies within this range of estimates.

The risk-free rate corresponds to the deposit rate R^D and to the policy rate R in steady state. The realized return on bank loans is R^F. This return contains a discount which is related to the monitoring cost that the bank must incur when an entrepreneur declares default. The next higher rate of return is the return on capital, R^E. The return on capital is higher than the realized loan return R^F, because it needs to compensate the entrepreneur for running the risk of default while it is not reduced by the monitoring cost. Finally, the return on equity earned by bankers R^B exceeds the realized loan return, because it contains a compensation to bankers (or equity holders) for the risk of bank default. In addition, the loan return is a decreasing function of the capital requirement ϕ; the higher is the capital requirement, the more equity banks will hold, and hence the lower is the implied return on equity, R^B.

[9]The annual number of banks and bank failures in the US, starting in 1936, can be downloaded from www.fdic.gov.

[10]Bank closings are downloaded from the Bureau of Labor Statistics Business Dynamics database, http://data.bls.gov/cgi-bin/dsrv?db. The industry considered is 'Credit intermediation and related activities'.

We assume autoregressive processes for the (log) technology shock, $\ln A_t$, the (log) firm risk shock, $\ln \varsigma_t^E$, and the (log) bank risk shock, $\ln \varsigma_t^F$. Similarly to Benes and Kumhof (2015) and Batini et al. (2016), we set the standard deviations and the persistence of the shock processes via moment-matching of the empirical standard deviations and the persistences of real output, real lending and equity in the financial business in the United States.[11] In particular, we construct a quadratic loss function $\sum_{j=1}^{6}(x_j^m - x_j^d)^2$, where x_j^m is the j-th moment in the model and x_j^m is its analogue in the data, and we numerically search for those parameters that minimize the loss function. This procedure leads to estimates of persistent TFP and bank risk shocks, with $\rho_A = 0.9594$ and $\rho_F = 0.9798$, while the firm risk shock is somewhat less persistent, with $\rho_E = 0.7810$. The standard deviations are small and equal to $\sigma^A = 0.001$, $\sigma_\varsigma^E = 0.001$, and $\sigma_\varsigma^F = 0.0001$, respectively.

3 Determinacy Analysis

Our interest lies in the interdependence of monetary and macroprudential policies. We consider two setups.

First, we stipulate an interest rate rule for monetary policy with $\tau_b = 0$ and we allow for macroprudential policy to set a bank capital requirement in response to changes in borrowing, such that $\zeta_b > 0$. The macroprudential rule captures the Basel III policy recommendation of a countercyclical capital buffer ('CCB') prescribing a rise in the capital requirement in response to a rise in the credit-to-GDP gap above a certain threshold, see Basel Committee on Banking Supervision (2010a, 2010b).[12]

Second, we keep the bank capital ratio constant at ϕ and allow for the policy interest rate to respond to borrowing, such that $\tau_b > 0$ and $\zeta_b = 0$. The latter setup is a 'leaning against the wind' (LATW) policy and it is inspired both by policy debates and by actual policy actions. E.g. starting in 2010, the Swedish central bank raised interest rates with the explicit aim of responding to household indebtedness, see Svensson (2014).[13]

We begin by analyzing the equilibrium properties of the benchmark model, given a plausible range of policy coefficients for τ_Π and ζ_b in the CCB setup and for τ_Π and τ_b in the LATW setup. More precisely, we show the combination of non-negative policy coefficients that give rise to a unique stable equilibrium, explosive dynamics, and multiple equilibria. The corresponding areas in the graphs below are labelled 'determinate', 'explosive' and 'multiple', respectively.

[insert Figure 2 here]

[11] Data are taken from the Alfred database of the St. Louis Fed and the Flow of Funds for the period 1952Q1-2016Q1. The time series are detrended using the HP filter.

[12] Tente et al. (2015, p.14) discuss how the CCB rate is computed for Germany.

[13] DSGE models featuring financial frictions often incorporate "macroprudential" rules which allow stabilization of the financial variables (e.g. Benes and Kumhof, 2015; Clerc et al., 2015).

Figure 2 shows the determinacy regions for the model with a countercyclical capital buffer. As is discussed in detail in Lewis and Roth (2017), the result resembles the one in Leeper (1991) regarding the determinacy properties in a model with monetary and fiscal policy interactions. The positive orthant in (ζ_b, τ_Π)-space is neatly divided into four regions, with the dark shaded areas at the top right and the bottom left showing policy coefficients that give rise to a unique stable equilibrium. In the absence of a countercyclical capital buffer, $\zeta_b = 0$, we see that the Taylor Principle is violated. In effect, there is a threshold value for the CCB coefficient $\bar{\zeta}_b$ above which the Taylor Principle holds. For lower values of ζ_b, macroprudential policy does not stabilize lending, a situation we may call 'financial dominance', which forces monetary policy to violate the Taylor Principle and allow for inflation to rise. If it instead adheres to the Taylor Principle (upper left region in Figure 2), the model features explosive equilibrium dynamics characterized by Fisherian debt-disinflation effects. For high values of ζ_b and a low responsiveness to inflation in the interest rate rule (the bottom right region in Figure 2), multiple equilibria exist. This suggests that the central bank can only be hawkish - and set an inflation coefficient above unity - if macroprudential policy is sufficiently responsive to increases in lending above steady state.

[insert Figure 3 here]

Figure 3 illustrates the determinacy properties in the model with LATW. We obtain two regions. Irrespective of the 'leaning-against-the-wind' policy coefficient τ_b, the Taylor Principle is violated and we need an inflation coefficient below 1 for determinacy. Stronger responses to inflation result in explosive dynamics. The higher the LATW coefficient τ_b, the lower is the threshold level $\overline{\tau}_\pi$ below which the model has a determinate solution.

4 A Dynamic Analysis of the Monetary and Macroprudential Policy

This section analyzes the interdependence of monetary and macroprudential policy via impulse response function analysis. In particular, it discusses the effects of monetary and macroprudential policy on the transmission mechanism of the model in response to a firm risk shock, a technology shock and a bank risk shock. It first focuses on active monetary policy combined with CCB; it then discusses the dynamics under the LATW policy (coupled with passive monetary policy).

To implement the zero lower bound (ZLB) constraint on the nominal interest rate we apply the piecewise linear perturbation method developed by Guerrieri and Iacoviello (2015). The model with occasionally binding constraint (OBC) is equivalent to a model with two regimes: (i) under one regime, the OBC is slack; and (ii) under the other regime the OBC binds. Monetary policy is then specified as follows:

$$\frac{Z_t}{Z} = \left(\frac{Z_{t-1}}{Z}\right)^{\tau_R} \left(\frac{\Pi_t}{\Pi}\right)^{\tau_\Pi} \left(\frac{b_t}{b}\right)^{\tau_b}, \tag{36}$$

$$R_t = \max(Z_t, 1), \tag{37}$$

where Z_t is the notional policy rate and R_t is the actual policy rate.

The size of each shock is large enough for the constraint to bind. In all the figures of the impulse responses we assume that the economy stays at the steady state in the first four quarters and the shock occurs in the fifth quarter. The blue line represents responses of the piecewise linear solution, where the nominal interest rate reaches the zero lower bound. The red dashed line represents responses in a regime where the constraint is ignored. The two scenarios (constrained and unconstrained) share the same pattern of impulse response functions until the economy hits the ZLB.

4.1 Firm Risk Shock

When there is an exogenous increase in firm risk, firms are more likely to default and investment projects become riskier. Net worth of firms and bankers both fall, in line with the positive unconditional correlation between these variables found in U.S. data.[14] This shock generates responses more in line with the data – compared to the other two shocks in the model – similarly to the results by Christiano et al. (2014) and Nuño and Thomas (2017).This contractionary shock acts as a demand shock, since both output and inflation fall. We first analyzes the transmission mechanism under active monetary policy ($\tau_\pi = 1.2$) and aggressive macroprudential policy ($\zeta_b = 11$) in Figure 4. We then explore peak responses across a range of CCB parameters. We finally examine the effects of the LATW policy combined with passive monetary policy.

[insert Figure 4 here]

The main results are as follows. First, the simulated recession is more severe when the ZLB is taken into account, since the contraction in output is greater. The households' intertemporal choice of consuming versus saving is affected by the ZLB. In response to the contractionary firm risk shock, the larger fall in the nominal interest rate in the unconstrained scenario makes saving less profitable. Hence, the shadow value of consumption increases by more in the unconstrained scenario compared to the case of the

[14]This correlation is always positive in the U.S. post-WII period, and it is equal to 0.45 in the 2000-2017 sample. Net worth of firms is computed as the difference between total assets and total liabilities, while net worth of bankers is the difference between bank credit of all commercial banks and deposits of all commercial banks, as in Gelain and Ilbas (2017). Data are downloaded from the FRED database of the Federal Reserve Bank of St. Louis.

ZLB. Therefore, ignoring the ZLB constraint implies that impulse responses are biased and too optimistic in this case. The resulting fall in the stochastic discount factor, $\beta_{t,t+1}$, is larger under the constrained scenario. As a consequence, Tobin's q decreases by more in the constrained economy, as evident from the investment demand equation (31). The fall in investment is hence demand-driven.

In turn, the fall in the rental rate of capital, r_t^K, is larger under the constrained scenario than if the ZLB is ignored. Given the definition of the rate of return on capital, R_t^E, the ex-post gross return to entrepreneurs experiences a larger fall. This explains why the firm productivity cutoff rises by more. As a consequence, firm net worth falls by more. The share of the project return accruing to the bank, Γ_t^E, is positively related to $\overline{\omega}_t^E$, see equation (7). Hence, this variable increases by more in the constrained scenario. This means that bank profit, Ξ_{t+1}^F – positively linked to Γ_t^E via the bank return on loans, R_t^F – falls by less.

The higher share of project return accruing to the bank under the ZLB also causes a less pronounced fall in bank net worth and a less severe increase in the bank default rate, as shown by Figure 4. The amount of deposits decreases by less in the constrained scenario since the fall in the nominal interest rate is less pronounced. The less severe contraction in saving and the less pronounced fall in bank net worth explain why the reduction in loans is smaller under the constrained scenario.

Since the nominal interest rate is constrained, the fall in inflation is more pronounced under the ZLB constraint. Overall, the ZLB-constraint: (1) worsens the macroeconomic consequences of the shock (as in Guerrieri and Iacoviello, 2015); (2) worsens the outcome for entrepreneurs; and (3) dampens the negative effects on banks.

In order to analyze the effects of the macroprudential instrument, Figure 5 shows the peak responses when the responsiveness of the capital requirement rule varies in the interval $\zeta_b \in [11, 15]$. A more and more aggressive intervention aimed at stabilizing financial conditions makes firms less likely to declare default, hence their productivity cutoff, $\bar{\omega}_E$, decreases by more. The fall in entrepreneurial net worth becomes less severe, so does investment, and hence output. Given the positive relationship between the share of the project return accruing to the bank and the firm productivity cutoff, the increasing fall in the latter variable explains why the reduction in bank net worth gets bigger for a larger CCB coefficient ζ_b. So, we learn from this exercise that the macroprudential instrument can reduce the adverse effects of a negative demand shock. However, in the case of a firm risk shock the CCB policy implies making firms better off relative to bankers, hence we observe a reduction in bank net worth.

[insert Figure 5 here]

For the same size of the shock, the strong macroprudential intervention helps the economy avoid the zero lower bound. In fact, for values of $\zeta_b \geqslant 12$, the patterns of the monetary policy rate coincide under the two scenarios. The fall in deposits occurs only for low values of ζ_b, while the increase in the nominal interest rate for values of $\zeta_b \geqslant 12$ makes deposits attractive. Overall, the peak responses of loans – and capital ratio – are dominated by the path of bank net worth, whose fall is sizeable. The capital ratio, which is given – by definition – by net worth of banks divided by loans, also falls for a stronger macroprudential intervention.

Figure 6 shows the transmission mechanism of the firm risk shock under passive monetary policy ($\tau_\pi = 0.25$) and LATW, with a coefficient of τ_b equal to 0.25, as in Melina and Villa (2017). Monetary policy is accommodating, letting inflation increase. The rise in inflation causes a fall in the shadow value of consumption, contrary to the case of CCB and active monetary policy. Hence, the increase in the return on capital leads to a rise in firm net worth. The nominal interest rate falls but inflation rises, hence the real interest rate unambiguously falls and this causes an increase in investment. It should be noted that, although the firm risk shock causes an increase in the firm default rate, the presence of limited liability leads to an increase in the entrepreneurs' appetite for investing because entrepreneurs do not internalize the full cost of losses. In fact, the entrepreneur's payoff is zero in the case of default. The fall in the shadow value of consumption combined with the rise in investment leads to an output expansion.

In the absence of CCB, the LATW policy does not have a significant effect on the banks' productivity cutoff due to the absence of capital requirements – the capital ratio remains constant. While the CCB policy directly affects the banking variables, the LATW policy uses the nominal interest rate also to influence developments in financial conditions, having indirect effects on the banking variables. Hence the transmission mechanism originating from bank balance sheets is partially reduced under the LATW policy. Hence, this policy plays a limited role in stabilizing economic conditions (on this see also Faia and Monacelli, 2007, and Melina and Villa, 2017). Under this scenario the ZLB has virtually no effect on real variables mainly because of the accommodative monetary policy. Inflation and bank loans move in opposite directions in response to a contractionary risk shock: inflation rises while loans fall. Therefore, the two objectives in the Taylor rule are conflicting, but monetary and macroprudential policies are conducted with the same instrument, the nominal interest rate. As a consequence, when the ZLB hits the economy, the inability of monetary policy to steer its instrument does not have strong effects.

[insert Figure 6 here]

4.2 Technology Shock

Figure 7 shows impulse responses to a technology shock. Since we are interested in the effects of the ZLB, we simulate an expansionary shock that causes an increase in output and a fall in inflation. The technology shock has a direct impact on output by making factors more productive, and leads to a fall in prices due to the expansion in aggregate supply.

[insert Figure 7 here]

Similarly to Clerc et al. (2015), bank default increases, leading to a fall in the bank lending rate. This *bank funding channel* (Clerc et al., 2015) stimulates the supply of loans and investment. On the entrepreneurial side, the increase in the loan-to-value ratio, x_t^E, determines a higher firm productivity cutoff, hence the firm default rate increases. This explains the moderate fall in firm net worth. The effects of the ZLB on financial variables are evident while the effects on real variables are small. It should be noted that this expansionary shock moves inflation and output in opposite directions. Hence, the constraint on the nominal interest rate can affect inflation, whose fall is more pronounced in the unconstrained scenario, whereas the feedback effects on output are minor for a moderate CCB coefficient.

Figure 8 shows the effects of a more aggressive CCB in response to the expansionary technology shock. First of all, a more vigorous response of the capital requirement reduces the bank default rate and more strongly so in the constrained scenario. This explains why the increase in investment gets larger for a larger ζ_b up to the value of 14. The bigger effect on investment translates into a magnified impact on output in the constrained scenario. Then, when the economy does not hit the ZLB, the effects of a more aggressive CCB on banking variables are limited. This is largely explained by the behavior of the rental rate of capital, which in turn affects the other interest rates. In fact, in the unconstrained scenario, the increase in r_t^K is only marginally affected by the value of ζ_b. A stronger responsiveness of the capital requirement rule causes a more muted expansion due to the smaller increase in the real return on equity – for larger ζ_b – which in turn restrains the increase in the supply of loans in the unconstrained scenario. Finally, the beneficial effects of CCB on output are non-linear when the ZLB-constraint is operating. The increase in output is larger when $\zeta_b = 14$ and it starts falling for larger values due to the non-linear effects on the bank default rate.

[insert Figure 8 here]

4.3 Bank Risk Shock

Figure 9 shows the transmission mechanism of the bank risk shock under active monetary policy combined with CCB. Banks are more likely to default, hence their default rate increases. This causes a fall in the ex-post gross return on equity – see equation (16) – and in bankers' net worth. The supply of loans is hence reduced. The reduced capacity of the bankers to provide finance for the entrepreneurs acts as a negative supply shock, in line with Gerali et al. (2010) and Meh and Moran (2010). By contrast, Rannenberg (2016) finds that the bank capital shock acts as a demand shock.[15] Differently from Clerc et al. (2015), the bank risk shock leads to an increase in investment. This can be explained by the presence of nominal frictions in our model. In fact, the increase in inflation causes a rise in the rate of return on capital – see equation (5). The higher return on capital explains the fact that entrepreneurs are less likely to default, their net worth increases and they are willing to invest more. Hence, unlike the firm risk shock, the bank risk shock makes one group (entrepreneurs) better off and the other worse off (bankers).

[insert Figure 9 here]

Since the nominal interest rate increases, it is not possible to investigate the effect of the constraint represented by the ZLB. Figure 10, instead, examines the implications of a more aggressive CCB policy in response to the exogenous increase in bank risk. This figure shows peak responses across various degrees of responsiveness of the CCB coefficient – $\zeta_b \in [11, 15]$. Similarly to the case of the contractionary firm risk shock, a stronger response of the macroprudential instruments makes the recession less severe, since the fall in output and loans is attenuated and investment increases by more. A more aggressive CCB reduces the bank default rate and this lessens the contractionary effects of the bank risk shock.

[insert Figure 10 here]

Overall this shock causes a (re-)distribution between banks and firms. Further research should address in more detail the empirical implications resulting from risk shocks, where bank-related and non-financial variables are studied separately.

[15] A few studies estimated the macroeconomic effects of bank capital shocks and found mixed results (e.g. Fornari and Stracca, 2012, and Ciccarelli et al., 2015).

5 Conclusion

This paper models the interdependence of monetary and macroprudential policy rules. The latter is modelled either as a countercyclical capital buffer or as a ”leaning against the wind” policy. We pay particular attention to the constraint imposed on monetary policy arising from the zero lower bound on nominal interest rates and to the responsiveness of the macroprudential authority to rises in bank lending.

We analyze the transmission mechanism of the model in response to a demand shock – modelled as a firm risk shock – and two supply shocks – modelled as shocks to bank risk and technology. Overall, the firm-risk shock combined with a CCB policy generates impulse response functions consistent with patterns observed in the data. The LATW policy, instead, is not effective in stabilizing financial conditions. In addition, our results show that while both firms and bankers are worse off in the case of an increase in firm risk, the bank risk shock as well as the technology shock imply a redistribution of resources between firms, who become better off, and bankers, who become worse off.

We find that the presence of the zero lower bound on the nominal interest rate makes the simulated recession more severe in response to the demand shock of the model, i.e. the firm risk shock. The main policy lesson of this study is that the countercyclical capital requirement is a macroprudential instrument appropriate to mitigate the fall in GDP in response to both firm and bank risk shocks, whereas it has a stabilizing effect on inflation only in the case of the firm risk shock.

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Table 1: **Computation of Steady State**

1-2	$R^D = \frac{\Pi}{\beta}, \quad R^E = R^D \upsilon$
3-4	$q = 1, \quad r^K = [\frac{R^E}{\Pi} - (1-\delta)]q$
5	$s = \frac{\varepsilon - 1}{\varepsilon} + \frac{\kappa_p}{\varepsilon}(1-\beta)(\Pi - 1)\Pi$
6-8	$K = [\frac{1}{A}(\frac{1}{\alpha}\frac{r^K}{s})l^{\alpha-1}]^{\frac{1}{\alpha-1}}, \quad I = \delta K, \quad Y = (\frac{1}{\alpha}\frac{r^K}{s})K$
9-10	$G^E = \Phi(\frac{\ln \overline{\omega}^E - \frac{1}{2}(\sigma^E)^2}{\sigma^E}), \quad \Gamma^E = G^E + \overline{\omega}^E(1 - F^E)$
11-12	$F^{E\prime} = \frac{1}{\overline{\omega}^E \sigma^E}\Phi^\prime(\frac{\ln \overline{\omega}^E + \frac{1}{2}(\sigma^E)^2}{\sigma^E}), \quad G^{E\prime} = \frac{1}{\overline{\omega}^E \sigma^E}\Phi^\prime(\frac{\ln \overline{\omega}^E - \frac{1}{2}(\sigma^E)^2}{\sigma^E})$
13	$\Gamma^{E\prime} = G^{E\prime} + (1 - F^E) - \overline{\omega}^E F^{E\prime}$
14-15	$G^F = \Phi(\frac{\ln \overline{\omega}^F - \frac{1}{2}(\sigma^F)^2}{\sigma^F}), \quad \Gamma^F = (1 - F^F)\overline{\omega}^F + G^F$
16	$\xi = \frac{\Gamma^{E\prime}}{(1-\Gamma^F)(\Gamma^{E\prime} - \mu^E G^{E\prime})}$
17	$n^E = (1-\chi^E)(1-\Gamma^E)\frac{R^E qK}{\Pi}$
18	$b = qK - n^E$
19	$R^F = (\Gamma^E - \mu^E G^E)\frac{R^E qK}{b}$
20	$R^B = (1-\Gamma^F)\frac{R^F}{\phi}$
21	$n^B = \phi b$
22	$\chi^B = \iota + 1 - \frac{\Pi}{R^B}$
23	$c = Y - \chi^E(1-\Gamma^E)\frac{R^E qK}{\Pi} - I - \frac{\kappa_p}{2}(\Pi - 1)^2 Y - \mu^E G^E \frac{R^E qK}{\Pi} - \mu^F G^F \frac{R^F b}{\Pi}$
24	$w = (1-\alpha)s\frac{Y}{l}$
25	$\varphi = \frac{w}{c l^\eta}$
26	$d = b - n^B$
27	$x = \overline{\omega}^E R^E$
28	$0 = -1 + \frac{1}{\beta}(1-\chi^E)\left(1-\Gamma^E\right)\upsilon\varrho$
29	$0 = -\Gamma^{E\prime} + \xi(1-\Gamma^F)(\Gamma^{E\prime} - \mu^E G^{E\prime}) = 0$
30	$0 = (1-\Gamma^E)R^E + \xi[(1-\Gamma^F)(\Gamma^E - \mu^E G^E)R^E - \phi R^B]$
31	$0 = -F^E + \Phi(\frac{\ln(\overline{\omega}^E) + \frac{1}{2}(\sigma^E)^2}{\sigma^E})$
32	$0 = -\overline{\omega}^F + (1-\phi)\frac{R^D}{R^F}$
33	$0 = -F^F + \Phi(\frac{\ln(\overline{\omega}^F) + \frac{1}{2}(\sigma^F)^2}{\sigma^F})$

Given initial values for $\overline{\omega}^E$, μ^E, σ^E, χ^E, $\overline{\omega}^F$, σ^F, we can compute the 27 parameters R^D, R^E, q, r^K, s, K, I, Y, w, G^E, Γ^E, $G^{E\prime}$, $F^{E\prime}$, $\Gamma^{E\prime}$, ξ, n^E, b, n^B, d, x^E, χ^B, R^F, R^B, G^F, Γ^F, c, φ using equations 1 to 27. We then solve the six equations 28-33 numerically for $\overline{\omega}^E$, μ^E, σ^E, χ^E, $\overline{\omega}^F$, σ^F, given the calibrated parameters in Tables 2 and 3 below, together with the values of the 27 steady state variables found above.

Table 2: **Benchmark Calibration**

Parameter Value	Description	Target/Reference
Structural Parameters		
$\beta = 0.99$	Household discount factor	BGG (1999)
$\eta = 1$	Inverse Frisch labor elasticity	Christiano et al. (2014)
$\varphi = 0.7461$	Preference parameter	Labor normalized to 1 in steady state
$\alpha = 0.35$	Capital share in production	BGG (1999)
$\delta = 0.025$	Capital depreciation rate	BGG (1999)
$\varepsilon = 6$	Substitutability between goods	Christensen and Dib (2008)
$\kappa_p = 30$	Price adjustment cost	Smets and Wouters (2007)
$\kappa_I = 2.43$	Investment adjustment cost	Carlstrom et al. (2014)
Shock Parameters$^{(1)}$		
$\sigma^A = 0.001$	Size technology shock	US data
$\rho_A = 0.9594$	Persistence technology shock	US data
$\sigma_\varsigma^E = 0.001$	Size firm risk shock	US data
$\rho_E = 0.7810$	Persistence firm risk shock	US data
$\sigma_\varsigma^F = 0.0001$	Size bank risk shock	US data
$\rho_F = 0.9798$	Persistence bank risk shock	US data
Inflation Target		
$\Pi = 1.005$	Steady state inflation	US data$^{(2)}$

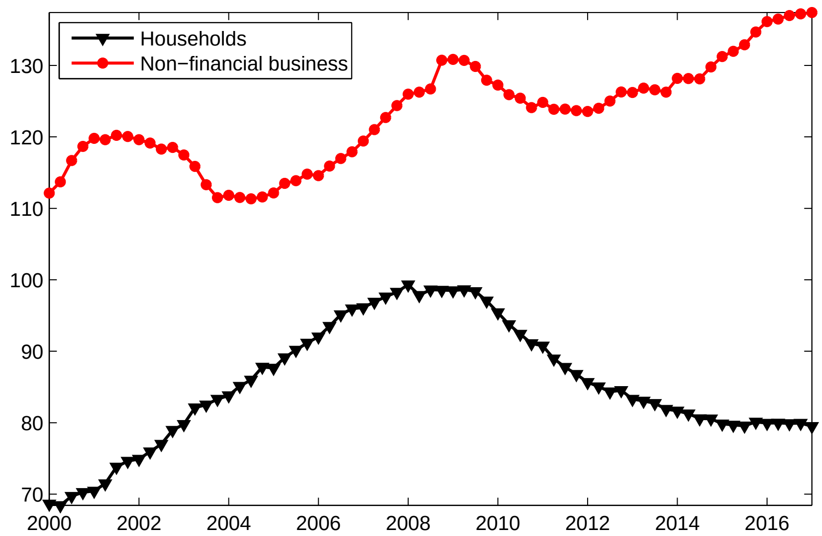
Note: $^{(1)}$See Section 2.6 on calibration strategy to determine the shock parameters. $^{(2)}$Value corresponds to growth of US GDP deflator over the period 1984-2016.

Table 3: **Financial Parameters and Interest Rates**

Value/Target	Description	Target/Reference
Calibrated Financial Parameters		
$\varrho \equiv \frac{qK}{n^E} = 2$	Entrepreneur leverage ratio	BGG (1999)
$\upsilon \equiv \frac{R^E}{R^D} = 1.005$	Capital return spread	BGG (1999)
$400F^E = 3$	Entrepreneur default rate p.a., in %	BGG (1999)
$400F^F = 0.9$	Bank default rate p.a., in %	US data$^{(1)}$
$\phi = 0.08$	Bank capital requirement	Basel Accords
$\mu^F = 0.3$	Bank monitoring cost	Clerc et al. (2015)
$\iota = 0.002$	Transfer to entering bankers	Gertler-Karadi (2011)
Implied Financial Parameters		
$\overline{\omega}^E = 0.499$	Entrepreneur productivity cutoff	–
$\chi^E = 0.018$	Entrepreneur exit rate	–
$\mu^E = 0.100$	Entrepreneur monitoring cost	–
$\sigma^E = 0.271$	Entrepreneur risk volatility	–
$\overline{\omega}^F = 0.919$	Bank productivity cutoff	–
$\sigma^F = 0.029$	Bank risk volatility	–
$\chi^B = 0.022$	Banker exit rate	–
Implied Steady State Rates of Return		
$R = 1.0152$	Policy rate	–
$R^D = 1.0152$	Return on deposits	–
$R^F = 1.0159$	Return on loans	–
$R^E = 1.0202$	Return on capital	–
$R^B = 1.0252$	Return on equity	–

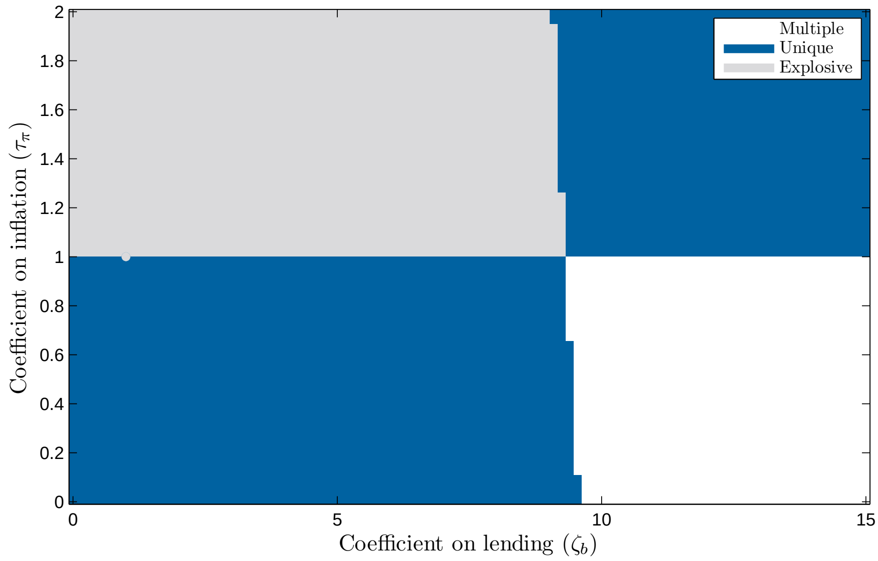
Note: All interest rates and rates of return are gross rates. $^{(1)}$See Section 2.8 on the calibration of the US bank default rate.

Figure 1: **U.S. Debt-to-GDP Ratios**



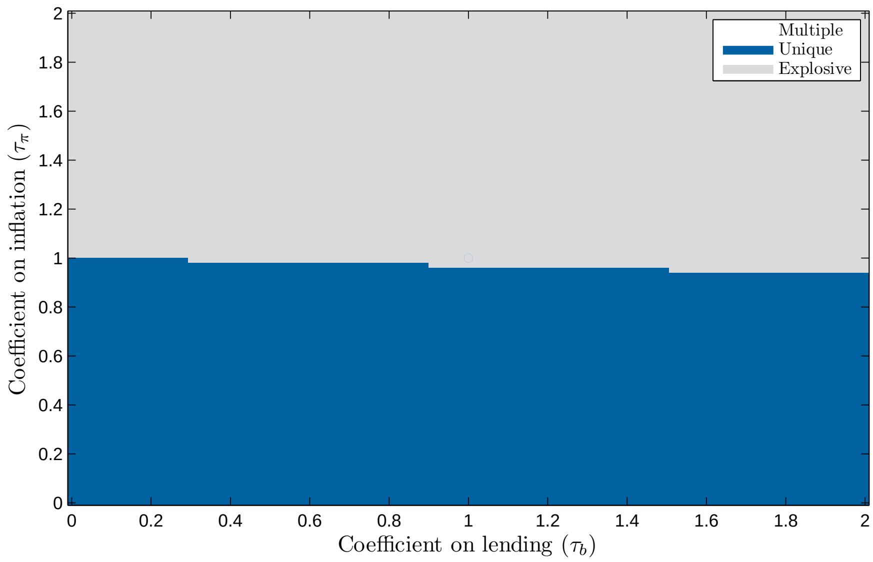
Note: Debt is the amount of total liabilities. Data on debt are downloaded from Flow of Funds Accounts, Federal Reserve Board, Table L.101 for households and nonprofit organizations, and from Table L.102 for non-financial business. Data on GDP are dowloaded from the FRED database of the Federal Reserve Bank of St. Louis.

Figure 2: **Determinacy Anaysis: CCB Model**



Note: The figure shows the determinacy regions in the simplified CCB model without leaning against the wind in the interest rate rule ($\tau_b = 0$) and countercyclical capital buffer ($\zeta_b > 0$).

Figure 3: **Determinacy Anaysis: LATW Model**



Note: The figure shows the determinacy regions in the simplified LATW model with leaning against the wind in the interest rate rule ($\tau_b > 0$) and a constant capital requirement ($\zeta_b = 0$).

Figure 4: Impulse responses to the contractionary firm risk shock with and without the zero lower bound (ZLB) on the nominal interest rate in the case of CCB and active monetary policy ($\zeta_b = 11$ and $\tau_\pi = 1.2$)

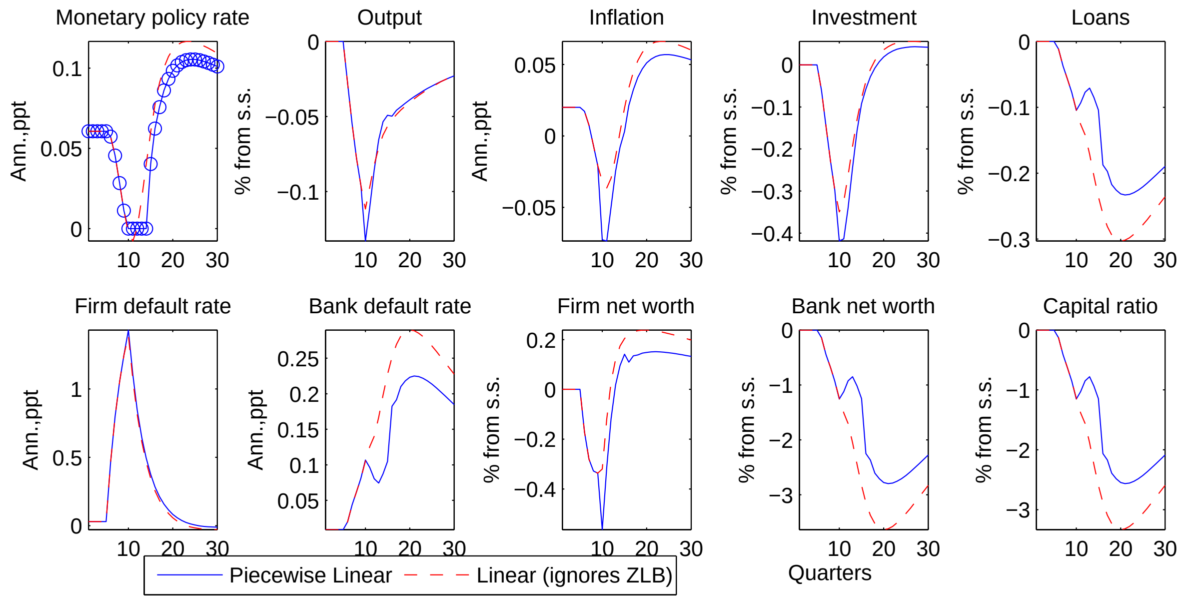


Figure 5: Peak responses to the contractionary firm risk shock with and without the zero lower bound (ZLB) on the nominal interest rate for $\zeta_b \in [11, 15]$

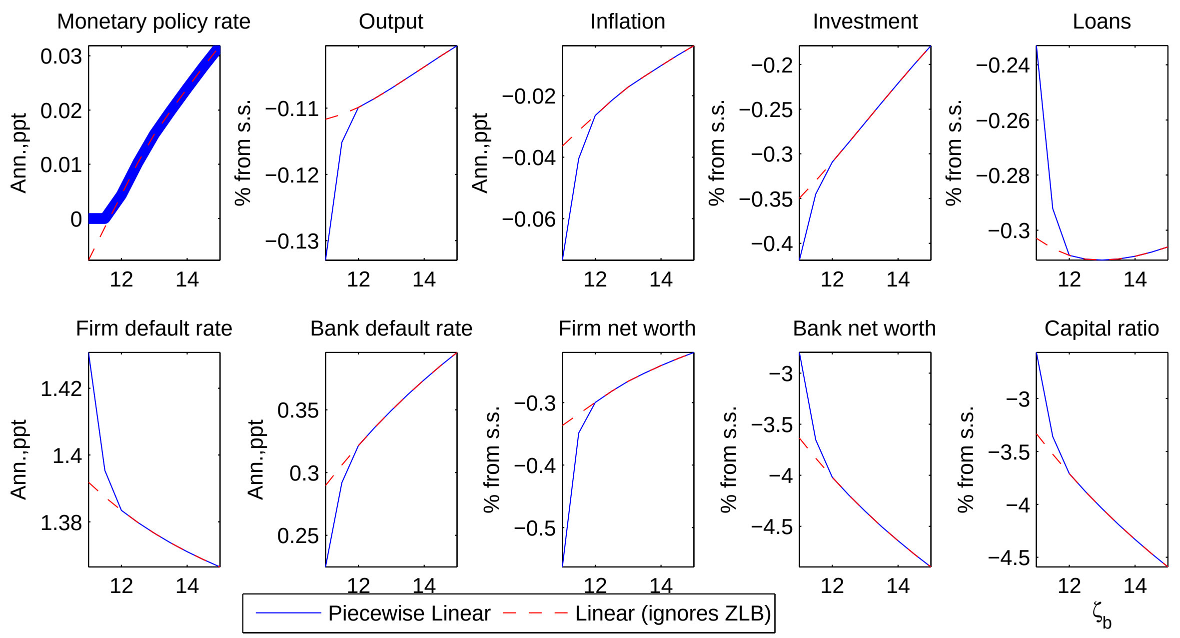


Figure 6: Impulse responses to the contractionary firm risk shock with and without the zero lower bound (ZLB) on the nominal interest rate in the case of LATW and passive monetary policy ($\tau_b = 0.25$ and $\tau_\pi = 0.25$)

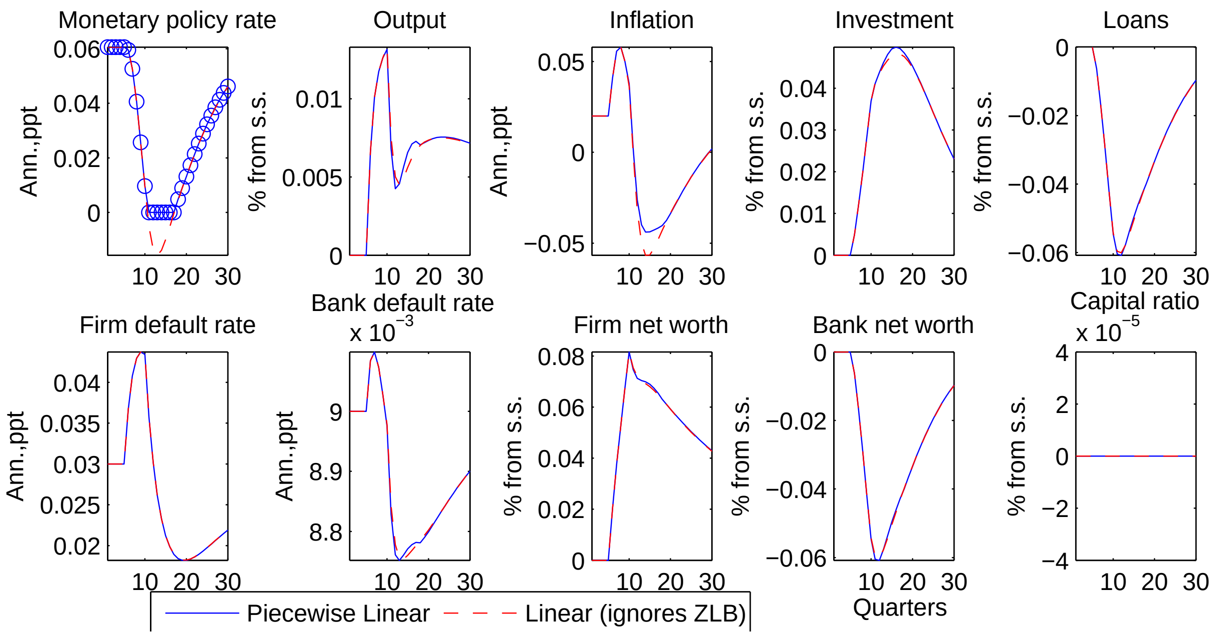


Figure 7: Impulse responses to the expansionary technology shock with and without the zero lower bound (ZLB) on the nominal interest rate in the case of CCB and active monetary policy ($\zeta_b = 11$ and $\tau_\pi = 1.2$)

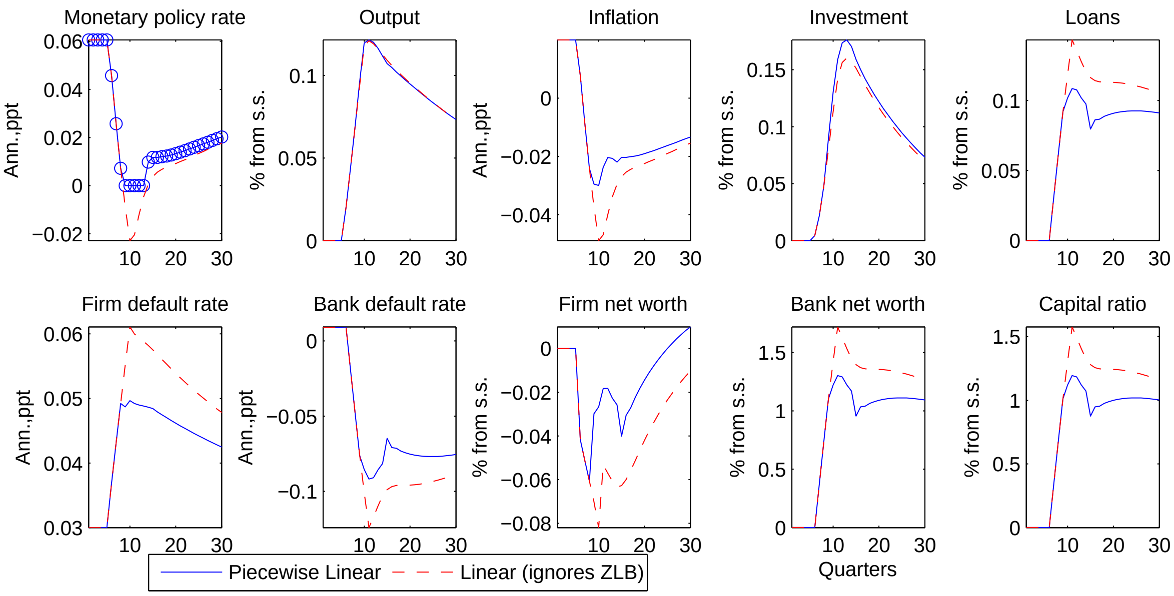


Figure 8: Peak responses to the expansionary technology shock for $\zeta_b \in [11, 15]$

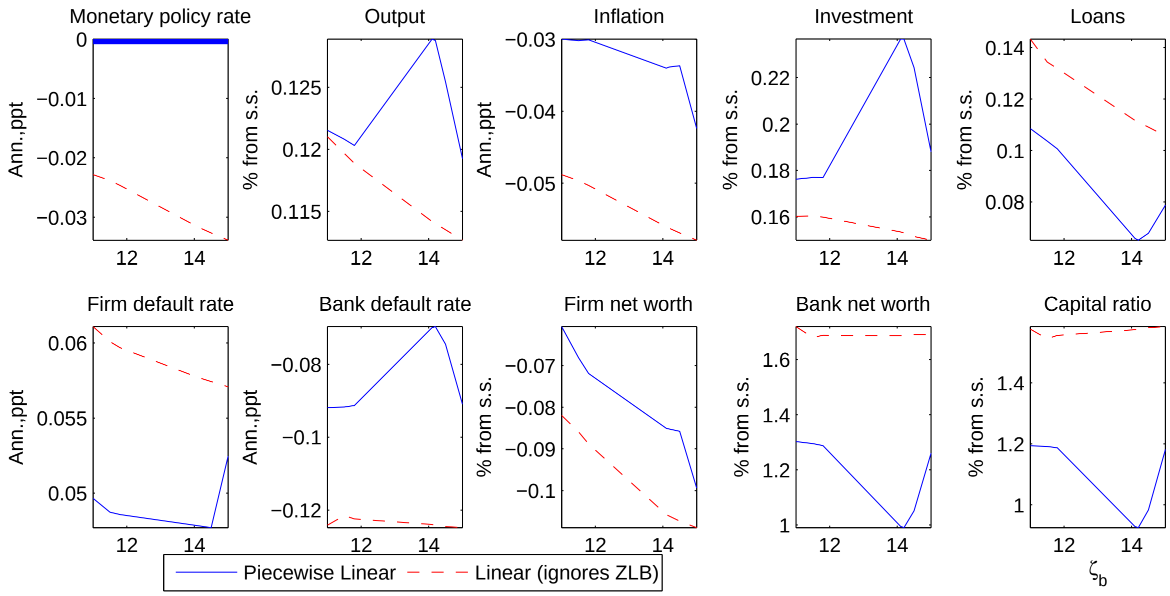


Figure 9: Impulse responses to the contractionary bank risk shock in the case of CCB and active monetary policy ($\zeta_b = 11$ and $\tau_\pi = 1.2$)

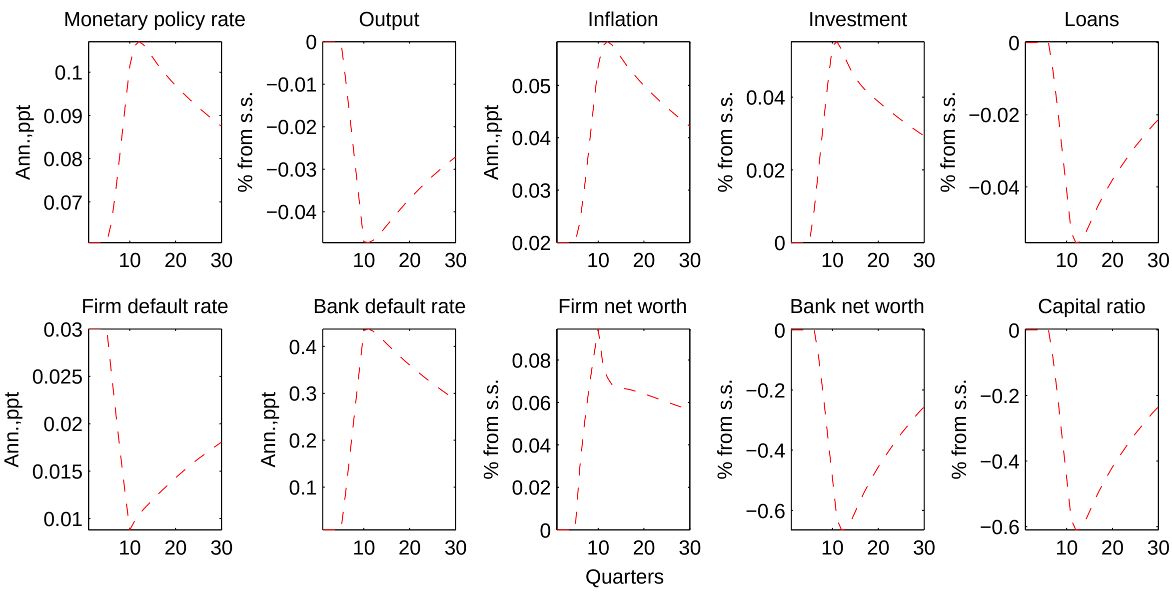
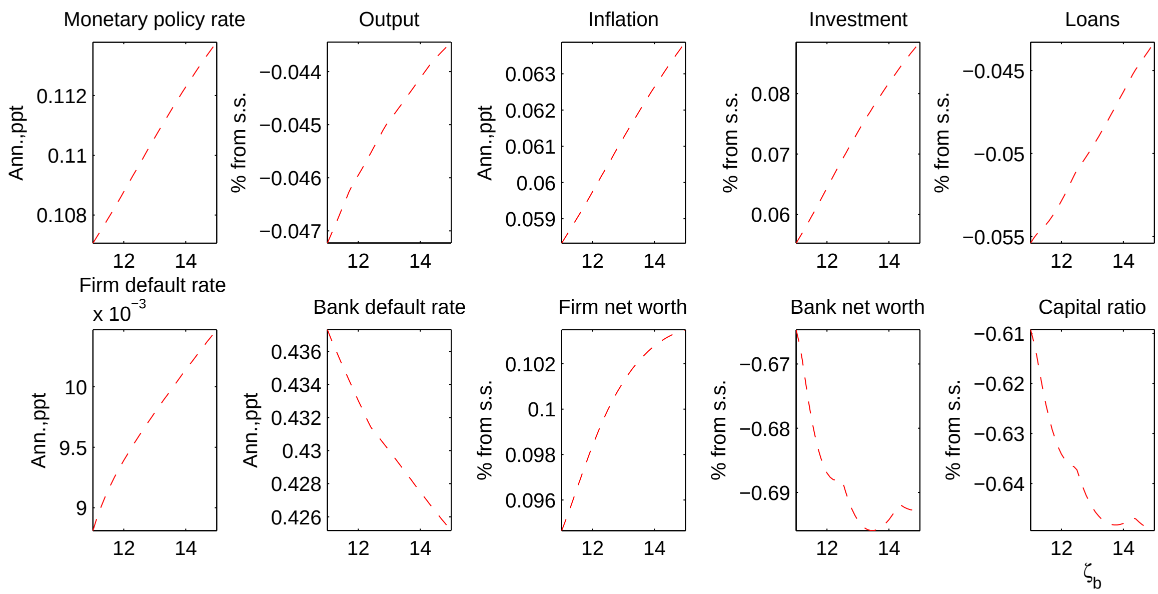


Figure 10: Peak responses to the contractionary bank risk shock for $\zeta_b \in [11, 15]$



National Bank of Belgium
Limited liability company
RLP Brussels – Company's number: 0203.201.340
Registered office: boulevard de Berlaimont 14 – BE-1000 Brussels
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Layout: Analysis and Research Group
Cover: NBB AG – Prepress & Image

Published in October 2016