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



Working Paper Research

by Vivien Lewis and Stefania Villa

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

*Preliminary*

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## Abstract

This paper considers the interdependence of monetary and macroprudential policy in a New Keynesian business cycle model under the zero lower bound constraint. Entrepreneurs borrow in nominal terms from banks and are subject to idiosyncratic default risk. The realized loan return to the bank varies with aggregate risk, such that bank balance sheets are affected by higher-than-expected firm defaults. Monetary and macroprudential policies are given by an interest rate rule and a capital requirement rule, respectively. We first characterize the model's stability properties under different steady state policies. We then analyze the transmission of a risk shock under the zero lower bound and different macroprudential policies. We finally investigate whether these policies are indeed optimal.

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

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

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# 1 Introduction

As the following quote shows, the interaction of macroprudential and monetary policy is a relevant policy 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.

This paper considers the interaction of macroprudential and monetary policy within a DSGE modelling framework. More specifically, we focus on the implications of these two policies on the stability and dynamics of corporate debt.

The recent literature recognizes that monetary and macroprudential policies cannot be analysed in isolation, and that an encompassing framework is therefore needed (see Leeper and Nason, 2014, Smets, 2014, and Brunnermeier and Sannikov, 2016). In this paper, we propose a dynamic stochastic general equilibrium (DSGE) model with both financial frictions and New Keynesian features, i.e. product market power and price setting frictions, where the cyclical and long-run dimensions of both policies can be analysed jointly.

Our perspective is that monetary policy is constrained by two features of the economic environment to the effect that it cannot be as countercyclical as it ought to be in a world without financial frictions. The first constraint is imposed by an ineffective macroprudential policy which is unable to restrain credit sufficiently, such that monetary policy is forced to let inflation rise so as to reduce real debt burdens. As a result of this ‘financial dominance’, monetary policy is too accommodating in a (credit-fuelled) boom.<sup>1</sup> The second constraint is the zero lower bound (ZLB), which forces monetary policy to be too tight in a downturn due to the fact that interest rates cannot turn negative.

Within our modelling framework, we investigate whether a change in the inflation target or in the steady state capital requirement can alleviate these two constraints on interest rate setting. We then discuss the effects of the two constraints on the transmission mechanism of the model by looking at the impulse response functions. We finally examine the welfare implications of alternative macroprudential policies.

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 balance sheet policies. As explained below, we take into account the zero lower bound constraint on nominal interest rates. We analyse both long run and cyclical monetary policy by varying the inflation target, i.e. the steady state inflation rate, as well as the policy coefficients

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<sup>1</sup>See Lewis and Roth (2016) for an analysis.

in the interest rate rule.

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 of attention is corporate borrowing from banks. The relevant long-run policy instrument is a minimum bank capital-to-asset ratio. 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 the 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.

Townsend (1979) analyses 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. However, 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.

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. This result simply reflects the fact that an active monetary policy which dampens inflation fluctuations cannot simultaneously bolster balance sheets by eroding the real value of debt. Therefore, an active monetary policy requires a passive macroprudential rule, i.e. one with a high CCB coefficient, that succeeds in stabilizing debt levels. Conversely, reducing debt burdens through an accommodating monetary policy necessary implies a violation of the Taylor Principle. The LATW policy always requires a passive monetary policy for a unique equilibrium.

Turning to the effect of steady state policies, our first result is that a higher inflation target does not affect the determinacy region, neither under the CCB policy nor under

the LATW policy as long as the repayment rate is not indexed to inflation.

Second, a higher capital requirement as advocated by e.g. Admati and Hellwig (2013) reduces the threshold CCB coefficient and thus enlarges the determinacy region characterized by an inflation coefficient in the interest rate rule above unity. Therefore, when monetary policy is active, a higher steady state capital requirement ensures that a smaller cyclical response of macroprudential policy to lending is required to guarantee a unique and stable equilibrium. In sum, a high capital requirement is desirable in that it allows the central bank to concentrate on its original goal of stabilizing inflation.

Third, we find that the ZLB has severe consequences on output when the economy is hit by a risk shock and a CCB policy is in place coupled with active monetary policy. The stronger the response of the CCB policy, the stronger the output contraction. When monetary policy is passive, instead, the constraint represented by the ZLB does not cause large output losses while an aggressive macroprudential policy (either CCB or LATW) does.

We perform a welfare comparison of alternative monetary and macroprudential rules and we find that optimal policy features a passive monetary policy and a moderate CCB policy.

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 under the two constraints, while Section 5 examines the welfare implications of alternative policies. Finally, Section 6 concludes.

## 2 Model

This section first discusses the non-standard features of the model concerning entrepreneurs and banks. As in Bernanke et al (1999), henceforth BGG, entrepreneurs have insufficient net worth to buy capital and therefore obtain loans 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 repayment rate that is contingent on the aggregate return to capital. In BGG, debt contracts specify a fixed repayment. As a result, the entrepreneur's net worth varies together with aggregate risk. Since the financial intermediary is 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. The macroprudential regulator requires banks to hold a minimum fraction of their assets as equity capital.

## 2.1 Entrepreneurs

There is a continuum of risk neutral entrepreneurs indicated by the superscript ‘ $E$ ’.<sup>2</sup> 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  $t + 1$ ,

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

Entrepreneurs who fail consume their residual wealth, i.e.  $c_{t+1}^E = \chi^E \mathcal{W}_{t+1}^E$ . Aggregate entrepreneurial wealth in period  $t + 1$  is given by the value of their capital stock bought in the previous period,  $q_t K_t$ , multiplied by the ex-post rate of 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,  $\Pi_{t+1} = P_{t+1}/P_t$ ,

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

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

The entrepreneur purchases capital  $K_{t+1}$  at the real price  $q_t$  per unit. 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 and  $\omega_{t+1}^E$  is an idiosyncratic disturbance. The idiosyncratic productivity disturbance is *iid* log-normally distributed with mean  $\mathbb{E}\{\omega_{t+1}^E\} = 1$ . The probability of default for an individual entrepreneur is given by the respective cumulative distribution function evaluated at the threshold  $\bar{\omega}_{t+1}^E$  (to be specified below),

$$F_{t+1}^E = F^E(\bar{\omega}_{t+1}^E) = \int_0^{\bar{\omega}_{t+1}^E} f^E(\omega_{t+1}^E) d\omega_{t+1}^E, \quad (3)$$

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

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

$$R_{t+1}^E = \frac{r_{t+1}^K + (1 - \delta) q_{t+1}}{q_t} \Pi_{t+1}. \quad (4)$$

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<sup>2</sup>In the model appendix, use the index  $j \in (0, 1)$  to refer to an individual entrepreneur. For notational convenience, we drop the index here.

## 2.2 Financial Contract

The entrepreneur spends  $q_t K_t$  on capital goods, which exceeds her net worth  $n_t^E$ . She borrows the remainder,  $b_t = q_t K_t - n_t^E$ , from the bank, which in turn obtains funds from households and bankers. Thereafter, the idiosyncratic productivity shock realizes. Those entrepreneurs whose productivity is below the threshold,

$$\bar{\omega}_{t+1}^E = \frac{Z_t^E b_t}{R_{t+1}^E q_t K_t} = \frac{x_t^E}{R_{t+1}^E}, \quad (5)$$

declare default. In (5),  $x_t^E \equiv Z_t^E b_t / (q_t K_t)$  is the entrepreneur's leverage, the contractual debt repayment divided by the value of capital purchased. Here, the cutoff  $\bar{\omega}_{t+1}^E$  is contingent on the realization of the aggregate state  $R_{t+1}^E$ , 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 derived as follows. In the default case, the entrepreneur has to turn the whole return  $\omega_{t+1}^E R_{t+1}^E q_t K_t$  over to the bank. Of this, a fraction  $\mu^E$  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 agreement  $\bar{\omega}_{t+1}^E R_{t+1}^E q_t K_t$ . The remainder,  $(\omega_{t+1}^E - \bar{\omega}_{t+1}^E) R_{t+1}^E q_t K_t$ , is left for the residual claimant, the entrepreneur. Consequently, if the entrepreneur does not default, the payment is independent of the realization of the idiosyncratic shock but depends solely on the productivity threshold. Under these considerations, we define the share of the project return accruing to the bank, gross of monitoring costs, as

$$\Gamma_{t+1}^E = \Gamma^E(\bar{\omega}_{t+1}^E) \equiv \int_0^{\bar{\omega}_{t+1}^E} \omega_{t+1}^E f(\omega_{t+1}^E) d\omega_{t+1}^E + (1 - F_{t+1}^E) \bar{\omega}_{t+1}^E, \quad (6)$$

such that remainder,  $1 - \Gamma_{t+1}^E$ , 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,

$$G_{t+1}^E = G^E(\bar{\omega}_{t+1}^E) \equiv \int_0^{\bar{\omega}_{t+1}^E} \omega_{t+1}^E f^E(\omega_{t+1}^E) d\omega_{t+1}^E. \quad (7)$$

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

$$\mathbb{E}_t \left\{ \left[ 1 - \Gamma^E \left( \frac{x_t^E}{R_{t+1}^E} \right) \right] R_{t+1}^E q_t K_t \right\}, \quad (8)$$

where the expectation is taken with respect to the random variable  $R_{t+1}^E$ .

The bank finances loans using equity  $n^B$  (obtained from bankers) and deposits  $d$  (obtained from households), such that its balance sheet is given by

$$n_t^B + d_t = b_t. \quad (9)$$



Furthermore, it is subject to the following capital requirement,

$$n_t^B \geq \phi_t b_t = \phi_t (q_t K_t - n_t^E), \quad (10)$$

which says that equity must be at least a fraction  $\phi_t$  of bank assets.<sup>3</sup> The bank's ex-post gross return on loans to entrepreneurs is given by

$$R_{t+1}^F = (\Gamma_{t+1}^E - \mu^E G_{t+1}^E) \frac{R_{t+1}^E q_t K_t}{b_t}. \quad (11)$$

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 the bank would obtain from investing its equity in the interbank market,

$$\begin{aligned} & \mathbb{E}_t \left\{ (1 - \Gamma_{t+1}^F) \left[ \Gamma^E \left( \frac{x_t^{Ej}}{R_{t+1}^E} \right) - \mu^E G^E \left( \frac{x_t^{Ej}}{R_{t+1}^E} \right) \right] R_{t+1}^E q_t K_t \right\} \\ & \geq \phi_t \mathbb{E}_t \{ R_{t+1}^B (q_t K_t - n_t^E) \}, \end{aligned} \quad (12)$$

where  $1 - \Gamma_{t+1}^F$  is the share of the project return accruing to the banker after the bank has made interest payments to the depositors (to be derived in Section 2.4 below).

The entrepreneur's objective is to choose  $x_t^E$  and  $K_{t+1}$  to maximize her expected profit (8), 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 are

$$\mathbb{E}_t \{ -\Gamma_{t+1}^{E'} + \xi_t^E (1 - \Gamma_{t+1}^F) (\Gamma_{t+1}^{E'} - \mu^E G_{t+1}^{E'}) \} = 0, \quad (13)$$

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

where  $\xi_t^E$  is the Lagrange multiplier on the bank participation constraint (12).

## 2.3 Bankers

Bankers face a probability  $1 - \chi^B$  of surviving to the next period. They have wealth  $\mathcal{W}_t^B$  and do not supply labor. Aggregate net worth of bankers  $n_{t+1}^B$  is the wealth held by bankers at  $t$  who are still around in  $t + 1$ ,

$$n_{t+1}^B = (1 - \chi^B) \mathcal{W}_{t+1}^B. \quad (15)$$

Bankers who die consume their residual equity, i.e.  $c_{t+1}^E = \chi^B \mathcal{W}_{t+1}^E$ . Their only investment opportunity is to provide equity to the bank. Bankers obtain an ex-post aggregate return

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<sup>3</sup>Our required capital ratio is based on total assets given that in the model, we do not work with different risk classes.

of  $R_{t+1}^B$  on their investment, which determines their wealth in the next period,

$$\mathcal{W}_{t+1}^B = \frac{R_{t+1}^B n_t^B}{\Pi_{t+1}}. \quad (16)$$

The ex-post gross rate of return on a banker's equity  $R_{t+1}^B$  is given by the ratio of bank profits, net of interest payments to depositors, to banker net worth,

$$R_{t+1}^B = (1 - \Gamma_{t+1}^F) \frac{R_{t+1}^F b_t}{n_t^B}. \quad (17)$$

## 2.4 Banks

There are a range of banks, indexed by  $i$ , each with idiosyncratic productivity  $\omega_{t+1}^{Fi}$ . Banks are subject to limited liability, i.e. bank profits cannot fall below zero. Bank  $i$ 's profit in period  $t + 1$  is therefore

$$\Xi_{t+1}^{Fi} = \max [\omega_{t+1}^{Fi} R_{t+1}^F b_t^i - R_t^D d_t^i, 0], \quad (18)$$

The bank fails if it is not able to pay depositors using its returns on corporate loans. Similar to the entrepreneurial sector, there exists a threshold productivity level  $\bar{\omega}_{t+1}^{Fi}$  below which bank  $i$  fails,

$$\bar{\omega}_{t+1}^{Fi} R_{t+1}^F b_t^i = R_t^D d_t^i. \quad (19)$$

Using equation (19) to replace  $R_t^D d_t^i$ , we can rewrite bank's profits (18) as

$$\Xi_{t+1}^{Fi} = \max [\omega_{t+1}^{Fi} - \bar{\omega}_{t+1}^{Fi}, 0] R_{t+1}^F b_t^i.$$

The random variable  $\omega_{t+1}^{Fi}$  is log-normally distributed with mean one and a time varying standard deviation  $\sigma_t^F = \sigma^F \zeta_t^F$ , where  $\zeta_t^F$  is a bank risk shock.<sup>4</sup> We can write

$$\begin{aligned} \max [\omega_{t+1}^{Fi} - \bar{\omega}_{t+1}^{Fi}, 0] &= \int_0^{\bar{\omega}_{t+1}^{Fi}} \omega_{t+1}^{Fi} f^F(\omega_{t+1}^{Fi}) d\omega_{t+1}^{Fi} - \bar{\omega}_{t+1}^{Fi} \int_0^{\bar{\omega}_{t+1}^{Fi}} f^F(\omega_{t+1}^{Fi}) d\omega_{t+1}^{Fi} \\ &= 1 - \underbrace{\left( \int_{\bar{\omega}_{t+1}^{Fi}}^{\infty} \omega_{t+1}^{Fi} f^F(\omega_{t+1}^{Fi}) d\omega_{t+1}^{Fi} + \bar{\omega}_{t+1}^{Fi} \int_0^{\bar{\omega}_{t+1}^{Fi}} f^F(\omega_{t+1}^{Fi}) d\omega_{t+1}^{Fi} \right)}_{\equiv \Gamma_{t+1}^{Fi}(\bar{\omega}_{t+1}^{Fi})} \end{aligned}$$

All banks behave the same in equilibrium, such that we drop the index  $i$  from here on. Using simplified notation, bank profits are given by  $\Xi_{t+1}^F = (1 - \Gamma_{t+1}^F) R_{t+1}^F b_t$ .

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<sup>4</sup>In the present analysis, we suppress bank risk shocks.

## 2.5 Rest of the Model

The remainder of the model is fairly standard. Households choose their optimal consumption and labor supply within the period, and their optimal bank deposits across periods. Within the production sector we distinguish 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 Dixit-Stiglitz technology and sell them to the household sector. Intermediate goods producers use capital and labor to produce the goods used as inputs by the final goods producers. They set prices subject to quadratic adjustment costs, which introduces the New Keynesian Phillips curve in our model. Finally, capital goods producers buy the consumption good and convert it to capital, which they sell to the entrepreneurs.

### 2.5.1 Households

Households are infinitely lived and maximize lifetime utility as follows,

$$\max_{c_t, l_t, d_t} \mathbb{E}_t \sum_{s=0}^{\infty} \beta^{t+s} \left[ \ln c_{t+s} - \varphi \frac{l_{t+s}^{1+\eta}}{1+\eta} \right], \quad (20)$$

where  $0 < \beta < 1$  is the discount factor,  $c_t$  is consumption,  $l_t$  is labor supply,  $\varphi$  is the weight on labor disutility and  $\eta \geq 0$  is the inverse Frisch elasticity of labor supply. The household chooses  $c_t$ ,  $l_t$  and bank deposits  $d_t$  to maximize utility (20) subject to a sequence of budget constraints

$$c_t + d_t + t_t \leq w_t l_t + \frac{R_t^D d_{t-1}}{\Pi_t} + \Xi_t^K, \quad (21)$$

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  $t$ ,  $\Pi_t = P_t/P_{t-1}$  is the gross inflation rate and  $\Xi_t^K$  are capital producers' profits that are redistributed to households. 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,  $1 = \mathbb{E}_t \{ \beta_{t,t+1} R_{t+1}^D / \Pi_{t+1} \}$ , where  $\beta_{t,t+s} = \beta^{t+s} \frac{\Lambda_{t+s}}{\Lambda_t}$  is the household's stochastic discount factor and the Lagrange multiplier on the budget constraint (21),  $\Lambda_t = 1/c_t$  captures the shadow value of household wealth in real terms.

### 2.5.2 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 maximize

profits  $P_t Y_t - \int_0^1 Y_{it} P_{it} di$ , subject to the production function  $Y_t = \left( \int_0^1 Y_{it}^{\frac{\varepsilon-1}{\varepsilon}} di \right)^{\frac{\varepsilon}{\varepsilon-1}}$ , where  $\varepsilon > 1$  is the elasticity of substitution between industry 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  $P_t = \left( \int_0^1 P_{it}^{1-\varepsilon} di \right)^{\frac{1}{1-\varepsilon}}$ . In a symmetric equilibrium, the price of a variety and the price index coincide,  $P_t = P_{it}$ .

### 2.5.3 Intermediate Goods Producers

Firms use capital and labor to produce intermediate goods according to a constant returns to scale (CRS) production function. BGG (1999) assume that the production function is Cobb-Douglas. The CRS assumption is important; it allows us to write the production function as an aggregate relationship. Each individual firm produces a differentiated good using  $Y_{it} = A_t K_{it}^\alpha l_{it}^{1-\alpha}$ , where  $0 < \alpha < 1$  is the capital share in production,  $A_t$  is aggregate technology,  $K_{it}$  are capital services and  $l_{it}$  is labor input. Intermediate goods firm choose factor inputs to maximize per-period profits given by  $\frac{P_{it} Y_{it}}{P_t} - r_t^K K_{it} - w_t l_{it}$ , where  $r_t^K$  is the real rental rate on capital, subject to the technological constraint and the demand constraint. The resulting demands for capital and labor are  $w_t l_{it} = (1 - \alpha) s_{it} Y_{it}$  and  $r_t^K K_{it} = \alpha s_{it} Y_{it}$ , 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,

$$s_t = \frac{w_t^{1-\alpha} (r_t^K)^\alpha}{\alpha^\alpha (1-\alpha)^{1-\alpha}} \frac{1}{A_t}. \quad (22)$$

Firm  $i$  sets a price  $P_{it}$  to maximize the present discounted value of future profits, subject to the demand constraint and to price adjustment costs,

$$\max_{P_{it}} \mathbb{E}_t \sum_{s=0}^{\infty} \beta^{t+s} \left[ \frac{P_{it+s}}{P_{t+s}} Y_{it+s}^d - \frac{\kappa_p}{2} \left( \Pi_{t-1}^{-\lambda_p} \frac{P_{it}}{P_{it-1}} - 1 \right)^2 Y_{it+s} + s_{t+s} (Y_{it+s} - Y_{it+s}^d) \right]. \quad (23)$$

Price adjustment costs are given by the second term in square brackets in (23); 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  $\Pi_{t-1}$ . 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

$$\kappa_p \frac{\Pi_t}{\Pi_{t-1}^{\lambda_p}} \left( \frac{\Pi_t}{\Pi_{t-1}^{\lambda_p}} - 1 \right) = \varepsilon s_t - (\varepsilon - 1) + \kappa_p \mathbb{E}_t \left\{ \beta_{t,t+1} \frac{\Pi_{t+1}}{\Pi_t^{\lambda_p}} \left( \frac{\Pi_{t+1}}{\Pi_t^{\lambda_p}} - 1 \right) \frac{Y_{t+1}}{Y_t} \right\}. \quad (24)$$

In (24), perfectly flexible prices are given by  $\kappa_p \rightarrow 0$ . If  $\lambda_p = 0$ , there is no indexation to past inflation and we obtain a purely forward-looking New Keynesian Phillips Curve.

## Capital Goods Production

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

$$\Delta x_t = K_t - (1 - \delta)K_{t-1} = \left[ 1 - \frac{\kappa_I}{2} \left( \frac{I_t}{I_{t-1}} - 1 \right)^2 \right] I_t, \quad (25)$$

where  $\delta$  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:

$$1 = q_t \left[ 1 - \frac{\kappa_I}{2} \left( \frac{I_t}{I_{t-1}} - 1 \right)^2 - \kappa_I \left( \frac{I_t}{I_{t-1}} - 1 \right) \frac{I_t}{I_{t-1}} \right] + \mathbb{E}_t \left\{ q_{t+1} \beta_{t,t+1} \kappa_I \left( \frac{I_{t+1}}{I_t} - 1 \right) \left( \frac{I_{t+1}}{I_t} \right)^2 \right\}. \quad (26)$$

### 2.5.4 Market Clearing and Equilibrium

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

$$Y_t = c_t + \chi^E \mathcal{W}_{t+1}^E + \chi^B \mathcal{W}_{t+1}^B + \frac{\kappa_I}{2} \left( \frac{I_t}{I_{t-1}} - 1 \right)^2 I_t + \mu^E G_t^E \frac{R_t^E q_{t-1} K_t}{\Pi_t}.$$

Firms' labor demand must equal labor supply.

$$(1 - \alpha) s_t \frac{Y_t}{l_t} = \frac{\varphi_t l_t^\eta}{\Lambda_t}.$$

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,  $\phi_t$ . Notice that because of full deposit insurance, the policy rate is identical to the risk-free deposit rate,  $R_t = R_t^D$ .

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  $\{R_t^E, R_t^F, R_t^B\}_{t=0}^{\infty}$  for which, given the monetary and macroprudential policies  $\{R_t, \phi_t\}_{t=0}^{\infty}$  and shocks to technology and firm risk  $\{A_t, \varsigma_t\}_{t=0}^{\infty}$  entrepreneurs maximize the expected return on their investment, firms maximize profits, households maximize utility and all markets clear.

We derive the deterministic steady state with trend inflation. In the model, a time period is interpreted as one quarter. To this end, we first normalize technology in steady

state by setting  $A = 1$  and we set  $\Pi = 1.005$  to yield an annualized inflation rate of 2 percent. Below, we analyse the effect on determinacy of varying the inflation target. Second, we solve numerically for labor  $l$ , firm leverage  $x^E$ , the share of the loan return going to depositors  $\Gamma^F$ , and the return on capital,  $R^E$ . Given initial values for those steady state parameters, we can solve for the remaining steady state variables recursively. The equilibrium conditions of the model and the recursive steady state equations are provided in the online appendix.

### 2.5.5 Aggregate Uncertainty

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

$$\ln A_t = \rho_A \ln A_{t-1} + \varepsilon_t^A, \quad (27)$$

where  $0 < \rho_A < 1$  and  $\varepsilon_t^A$  is an *iid* shock with mean zero and variance  $\sigma_A^2$ .

As noted above, the random variable  $\omega_{t+1}^{Ej}$  follows a log-normal distribution with mean one and a standard deviation  $\sigma_t^E = \sigma^E \varsigma_t$ , which introduces time variability of firm risk via an AR(1) process,

$$\ln \varsigma_t = \rho_\varsigma \ln \varsigma_{t-1} + \varepsilon_t^\varsigma,$$

such that  $0 < \rho_\varsigma < 1$  and  $\sigma^\varsigma$  denotes the standard deviation of the *iid* normal shock  $\varepsilon_t^\varsigma$ .

## 2.6 Calibration and Steady State

We calibrate the model to a quarterly frequency. The calibration of our model parameters is summarized in Table 2. Most of the structural parameters have standard values. The subjective discount factor  $\beta$  is set to 0.99, implying a quarterly risk-free (gross) interest rate of  $\frac{1}{0.99} = 1.01$  or a real annual (net) interest rate of roughly 2%, given that steady state gross inflation is set to  $\Pi = 1.005$ . The inverse Frisch elasticity of labor supply is set to  $\eta = 0.2$ , which is common for macroeconomic models. The capital share in production is set to  $\alpha = 0.3$ , the substitution elasticity between goods varieties is  $\varepsilon = 6$ , implying a gross steady state markup of  $\varepsilon/(\varepsilon - 1) = 1.2$ . The Rotemberg price adjustment cost parameter is  $\kappa_p = 20$ . Capital depreciation in steady state is  $\delta = 0.025$  per quarter, while the investment adjustment cost parameter is set to  $\kappa_I = 2$ .

[ insert Table 2 here ]

We now turn to the financial parameters. The exit rate is set to 6% for both entrepreneurs and bankers, i.e.  $\chi^E = \chi^B = 0.06$ . Monitoring costs are the fraction of the return that is lost when a debtor declares default. This parameter is set to  $\mu^E = 0.3$ . The size of the idiosyncratic shock hitting entrepreneurs is  $\sigma^E = 0.12$ . The steady state capital

requirement for banks, i.e. the ratio of equity to loans, is set to 8%, that is  $\phi = 0.08$ .

The steady state is computed numerically as shown in Table 1. The implied steady state values of several model variables are displayed in Table 3 below. We first discuss the ranking of the various interest rates and spreads in steady state, before turning to the default probability of entrepreneurs.

[ insert Table 3 here ]

The risk-free rate corresponds to the deposit rate  $R^D$  and to the policy rate  $R$  in steady state. The realized return on loans to entrepreneurs is  $R^F = 1.0144$ . This return contains a discount which is related to the monitoring cost  $\mu^E$  that the bank must incur when an entrepreneur declares default. The next higher rate of return is the return on capital,  $R^E = 1.0284$ . The return on capital is yet 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  $\phi_t$ ; the higher is the capital requirement, the more equity banks will hold, and hence the lower is the implied return on equity,  $R^B$ . Table 3 also shows the annualized return spreads on bank loans (1.7%), on entrepreneurial capital (7.3%) and on equity (21.5%). The quarterly default probability of entrepreneurs is 0.66%, which corresponds to an annual default rate of 2.6%.

In our ZLB and welfare analysis below, we simulate the model under autoregressive processes for the technology shock,  $\ln A_t$ , and the firm risk shock,  $\ln \varsigma_t$ . Similarly to Benes and Kumhof (2015) and Batini et al. (2016), we set the standard deviations and the persistences of the shock processes via moment-matching of the empirical standard deviations and the persistences of real output and real lending.<sup>5</sup> 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  $x_j^d$  is its analogue in the data, and we numerically search for those parameters that minimise the loss function. This procedure leads to persistent TFP and risk shocks, with  $\rho_A = 0.8638$  and  $\rho_\varsigma = 0.8033$ , and standard deviations equal to 0.0716 and 0.0867, respectively.

### 3 Determinacy Analysis

Our interest lies in the interdependence of monetary and macroprudential policies. There are two dimensions in which these policies work: at the steady state and out of steady

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<sup>5</sup>Data on the US 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.

state. At the steady state, the policy maker chooses a target value for inflation,  $\Pi$ , and a bank capital ratio,  $\phi$ . 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  $\tau_R$ ,  $\tau_\Pi$  and  $\tau_b$ , such that:

$$\frac{R_t}{R} = \left( \frac{R_{t-1}}{R} \right)^{\tau_R} \left( \frac{\Pi_t}{\Pi} \right)^{\tau_\Pi} \left( \frac{b_t}{b} \right)^{\tau_b}. \quad (28)$$

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,

$$\frac{\phi_t}{\phi} = \left( \frac{b_t}{b} \right)^{\zeta_b}. \quad (29)$$

We consider two setups for monetary and macroprudential policy.

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  $\zeta_b > 0$ . We call this setup ‘macroprudential stabilization’. The macroprudential rule tries to capture the Basel III policy recommendation of a counter-cyclical 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). Tente et al (2015, p.14) discuss how the CCB rate is computed for Germany.

Second, we keep the bank capital ratio constant at  $\phi$  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).<sup>6</sup>

### 3.1 Determinacy Regions

We first analyse the equilibrium properties of the benchmark model, given a plausible range of policy coefficients for  $\tau_\Pi$  and  $\zeta_b$  in the macroprudential stabilization setup and for  $\tau_\Pi$  and  $\tau_b$  in 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 1 here ]

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<sup>6</sup>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 1 shows the determinacy regions for the model with a countercyclical capital buffer. As is discussed in detail in Lewis and Roth (2016), 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  $(\zeta_b, \tau_\Pi)$ -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  $\zeta_b$ , 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 1), the model features explosive equilibrium dynamics characterized by Fisherian debt-deflation effects. For high values of  $\zeta_b$  and a low responsiveness to inflation in the interest rate rule (the bottom right region in Figure 1), 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 2 here ]

Figure 2 illustrates the determinacy properties in the model with LATW. We obtain two regions. Irrespective of the ‘leaning-against-the-wind’ policy coefficient  $\tau_b$ , 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  $\tau_b$ , the lower is the threshold level  $\bar{\tau}_\pi$  below which the model has a determinate solution.

### 3.2 Varying Policy Targets

We now explore how the policy targets, the steady state inflation rate  $\Pi$  and steady state capital requirement  $\phi$ , affect the determinacy regions. In a New Keynesian model with quadratic price adjustment costs and a standard Taylor Rule, Ascari and Ropele (2009) show that a higher inflation target enlarges the parameter region characterized by determinacy. Here, increasing the inflation target  $\Pi$  has no effect on the determinacy regions in either setup (figure not shown). We conjecture that this result is due to the nature of the financial contract in the model, which does not make the repayment contingent on the inflation rate. We leave the analysis allowing for inflation-indexed debt for future research.

We now turn to the long run capital requirement. In the setup with a countercyclical capital buffer, increasing the steady state capital ratio  $\phi$  has the effect of reducing the threshold value for the CCB coefficient  $\bar{\zeta}_b$ . In other words, a less aggressive macroprudential policy is necessary for the Taylor Principle to be satisfied. Therefore, a large CCB

coefficient and a high steady state capital requirement appear to be substitutable in the sense of allowing the central bank to be more aggressive and follow a mandate of inflation stabilization.

[ insert Figure 3 here ]

In the LATW setup, we find that a change in the steady state capital requirement  $\phi$  does not alter the determinacy regions.

## 4 A dynamic analysis of the two constraints

This section analyses the interdependence of monetary and macroprudential policy via impulse response function analysis. In particular, it discusses the effects of the two constraints on the transmission mechanism of the model. 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:

$$\frac{Z_t}{Z} = \left( \frac{Z_{t-1}}{Z} \right)^{\tau_R} \left( \frac{\Pi_t}{\Pi} \right)^{\tau_\Pi} \left( \frac{b_t}{b} \right)^{\tau_b} \quad (30)$$

$$R_t = \max(Z_t, 1) \quad (31)$$

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

Ineffective/mild macroprudential policy is modeled by appropriately calibrating the parameter of the macroprudential rule. We let the responsiveness of the capital requirement rule to vary in the interval,  $\zeta_b \in [0, 11]$ , when the Taylor principle is violated, while  $\zeta_b \in [12, 20]$  when the Taylor principle is satisfied and CCB policy is always effective. In the LATW case, instead, we set the responsiveness of the nominal interest rate to loans in line with empirical evidence (e.g. Melina and Villa, 2015). In particular  $\tau_b \in [0, 0.9]$ . As explained in Section 3, the LATW policy requires a passive monetary policy stance.

We consider the three policy scenarios characterized by a unique equilibrium: (1) aggressive CCB and active monetary policy; (2) ineffective/mild CCB policy and passive monetary policy; and (3) LATW policy and passive monetary policy. For each scenario we compare two models, with and without the ZLB constraint on the nominal interest rate. We set the interest rate smoothing to zero ( $\tau_R = 0$ ) as in Section 3 and the response to inflation to the value that guarantees determinacy under each scenario. In particular, in the second and third scenario monetary policy is passive, with  $\tau_\pi = 0.9$ , while  $\tau_\pi = 1.2$  in the presence of effective CCB. Appendix A.1 investigates the sensitivity of the results to a different responsiveness of monetary policy, while Appendix A.2 examines an alternative

specification of the macroprudential instruments.

We simulate a large risk shock of the same size for the three scenarios so to hit the ZLB. We focus on the risk shock because Christiano et al. (2014) find that these innovations in the volatility of cross-sectional idiosyncratic uncertainty are the most important shocks driving the business cycle. The risk shock makes entrepreneurs more likely to declare default. Investment projects become riskier and, as a result, the external finance premium rises and investment falls. The fall in return on capital implies a reduction in entrepreneurial net worth, while the increase in the external finance premium leads to a rise in bank profits and bank net worth.

Figure 4 shows impulse responses to a contractionary shock with aggressive macroprudential and active monetary policy. 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 of regime when the constraint is not binding. The main results are as follows. First, the simulated recession is more severe when the economy hits the ZLB. The presence of CCB makes banks less likely to declare default, hence their productivity cutoff,  $\bar{\omega}_F$ , decreases.

[ insert Figure 4 here ]

In order to better understand the effects of a more aggressive CCB policy, Figure 5 shows the impulse responses of the nominal interest rate for three values of  $\zeta_b$ . For  $\zeta_b \leq 13$ , the risk shock is not large enough for the nominal interest rate to hit the lower bound. The higher  $\zeta_b$ , the higher the gap between the actual and notional interest rate. As explained by Guerrieri and Iacoviello (2015), the expectation of contractionary shocks in the constrained economy further reduces prices and output, since agents expect that monetary policy is unable to accommodate these shocks.

[ insert Figure 5 here ]

A more and more effective CCB policy generates higher volatility in the interest rate in particular under the ZLB. And the macroprudential rule (29) clearly has non-linear effects. A higher responsiveness forces banks to keep high capital ratios and the rise in net worth can become extremely large. For  $\zeta_b = 20$ , the increase in net worth is more than 30% deviations from steady state in the constrained scenario. The fall in the bank' productivity cutoff is substantial and the transmission mechanism is magnified. The return on equity, as well as lending rates, increase by more under the ZLB. Hence the external finance premium rises by more when the ZLB hits the economy. As a result, investment decreases more. Moreover, since there is a larger shift in the AD curve when monetary policy is bounded, the fall in inflation is greater. Finally, in the presence of the

ZLB, nominal loan growth is more volatile. This is due to the fact that lending rates are more volatile in the constrained economy. This figure also shows the effects of a more aggressive macroprudential policy. While the effects are limited when monetary policy is unconstrained, a higher responsiveness of the macroprudential instrument is detrimental under the ZLB.

Figure 6 shows the dynamics of the model in the other region of determinacy of the CCB policy, i.e. ineffective/mild CCB and passive monetary policy. Similarly to Figure 4, the recession is more severe when monetary policy is constrained. Since monetary policy is passive, the difference in the fall in output and the other variables between the ZLB and the unconstrained case is less evident than that in the presence of active monetary policy. The CCB policy is still present for  $\zeta_b > 0$ , hence the bank's productivity cutoff  $\bar{\omega}_F$  decreases. Bank net worth and the capital ratio rise. So do the lending rate and the return on equity. Given the constraint on the nominal interest rate, the external finance premium increases by more in the unconstrained scenario. This explains the more pronounced fall in investment. When the Taylor rule is operating, there is a larger decline in inflation.

[ insert Figure 6 here ]

The figure also presents the case of ineffective CCB policy, i.e.  $\zeta_b = 0$ . Hence, this figures makes it possible to examine: (i) which constraint is more harmful in terms of output losses: and (ii) what happens in the contemporaneous presence of the two constraints, the ZLB and ineffective macroprudential policy. Macroprudential regulation is completely unable to stabilize debt. When monetary is unconstrained we observe a large volatility of inflation and of the real return on capital. This effect is attenuated under the ZLB. The fall in output is deeper when the CCB is ineffective. The contemporaneous presence of the two constraints do not exacerbate the recession compared to case of ineffective CCB in isolation because in the presence of the ZLB the decrease in investment is less pronounced due to the smaller increase in the external finance premium. Hence, when monetary policy is passive, the constraint represented by ineffective macroprudential policy is more detrimental than the constraint on the ZLB. In fact, a more and more effective macroprudential policy makes the recession less severe.

Figure 7 shows the third and last scenario characterized by passive monetary policy and LATW policy. Under this scenario the effects of the ZLB on output are negligible. This can be explained by the fact that inflation and bank loans move in opposite directions in response to a contractionary risk shock: inflation falls while bank loans increase due to rise in deposits and bank net worth. 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. When the ZLB hits the economy, the inability of monetary policy to steer its instrument does not have dramatic effects on output

due to the presence of the two conflicting objectives. In addition, a stronger LATW policy causes a more pronounced contraction in output. In fact a higher  $\tau_b$  reduces the amount of loans. This in turn restricts investment opportunities, causing investment to fall. An aggressive macroprudential policy is therefore detrimental. The chart in fact shows that the recession is less severe when  $\tau_b = 0$ . The effects of the risk shock when monetary policy is passive are similar: similarly to Figure 6, the external finance premium increases by more in the unconstrained scenario. This explains the more pronounced fall in investment. And inflation falls by more when the Taylor rule is operating.

[ insert Figure 7 here ]

Finally, the LATW policy does not have a significant effect on the bank' productivity cutoff due to the absence of capital requirements. Hence the transmission mechanism originating from bank's balance sheet is partially reduced. The size of the shock is the same across the three scenarios, but the response of bank net worth – in terms of percentage deviation from steady state – is much less under the LATW policy.

## 5 Optimal Simple Policy Rules

This section investigates whether the LATW policy and the CCB policy are indeed optimal. Following the literature on optimal simple rules (see Schmitt-Grohe and Uribe, 2007, and Levine et al., 2008, among many others), we let  $\tau_R$  to be greater than zero to allow for the possibility of integral rules with a unitary persistence parameter, i.e.  $\rho_r = 1$  (see also Melina and Villa, 2015).<sup>7</sup>

Then we numerically search for those feedback coefficients in rules (28) and (29) to maximize the present value of life-time utility, which reads

$$\mathcal{W}_t = E_t \left[ \sum_{s=0}^{\infty} \beta^s U(c_{t+s}, 1 - l_{t+s}) \right], \quad (32)$$

given the equilibrium conditions of the model. Assuming no growth in the steady state, we rewrite equation (32) in recursive form as

$$\mathcal{W}_t = U(c_t, 1 - l_t) + \beta E_t [\mathcal{W}_{t+1}]. \quad (33)$$

We perform welfare comparisons by computing the consumption-equivalent welfare

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<sup>7</sup>These are effectively price-level rules that make the price level trend-stationary as shown in Woodford (2003).

loss with respect to a reference regime A. The welfare loss is implicitly defined as

$$E_t \left\{ \sum_{s=0}^{\infty} \beta^s [U((1-\omega)c_{t+s}^A, 1-l_{t+s}^A)] \right\} = E_t \left\{ \sum_{s=0}^{\infty} \beta^s [U(c_{t+s}^B, 1-l_{t+s}^B)] \right\},$$

where  $\omega \times 100$  represents the percent permanent loss in consumption that should occur in regime A in order agents to be as well off in regime A as they are in regime B.

[ insert Table 4 here ]

Table 4 first shows the results arising from the computation of an optimized standard Taylor-type rule in which the nominal interest rate features inertia and reacts to inflation when  $\zeta_b = \tau_b = 0$ . We find that optimal policy should not feature interest rate smoothing and the response to inflation is close to 1. We then move to optimal policy in the presence of the CCB rule. A positive coefficient on the CCB rule coupled with a response to inflation of 0.99 leads to an improvement in welfare. In fact, we compute the welfare loss relative to the CCB policy and find that adopting a standard Taylor rule results in a permanent loss in consumption of 0.26%. Under the LATW scenario it is optimal not to respond to inflation neither to loans. In fact the optimized coefficients are zero. The welfare loss relative to the CCB policy is larger and equal to 0.26%. This policy is therefore the most detrimental compared to the other two cases.

## 6 Conclusion

This paper models the interdependence of monetary and macroprudential policy rules. We pay particular attention to the constraints imposed on monetary policy due to, firstly, the zero lower bound on nominal interest rates and, secondly, a weak response of the macroprudential authority to rises in bank lending. We find that a low feedback coefficient in the macroprudential policy rule, which is also known as the countercyclical capital buffer (CCB), forces the central bank to violate the Taylor Principle. On the one hand, the determinacy region can be enlarged by raising the steady state minimum capital requirement imposed on banks. In this respect, the CCB and the steady state capital requirement are substitutable policy instruments. On the other hand, the steady state inflation target does not change the determinacy properties of the model as long as financial contracts are not index-linked. We also model a leaning-against-the-wind policy whereby the nominal interest rate responds to deviation of lending from its steady state. We find that determinacy is ensured only if the Taylor principle is violated.

When monetary policy is active, an aggressive CCB is detrimental in terms of output losses in response to a risk shock. And the presence of the zero lower bound on the nominal interest rate makes the simulated recession more severe. When monetary policy

is passive, instead, the constraint represented by the zero lower bound is marginally harmful for the economy while the output trough is a decreasing function of the CCB policy. These latter results are preserved under the LATW policy which also requires passive monetary policy for determinacy.

Finally we find that the CCB policy coupled with passive monetary policy is optimal, while the LATW policy is detrimental from a welfare perspective.

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Table 1: Computation of Steady State

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(1)	$q = 1$
(2)	$r^K = [R^E - (1 - \delta)]q$
(3)	$s = \frac{\varepsilon-1}{\varepsilon} + \frac{\kappa_p}{\varepsilon} (1 - \beta) (\Pi^{1-\lambda_p} - 1) \Pi^{1-\lambda_p}$
(4)	$K = \left[ \frac{1}{A} \left( \frac{1}{\alpha} \frac{r^K}{s} \right) l^{\alpha-1} \right]^{\frac{1}{\alpha-1}}$
(5)	$I = \delta K$
(6)	$Y = \left( \frac{1}{\alpha} \frac{r^K}{s} \right) K$
(7)	$w = (1 - \alpha) s \frac{Y}{l}$
(8)	$R^D = \frac{\Pi}{\beta}$
(9)	$c = \frac{w}{\varphi l^\eta}$
(10)	$\bar{w}^E = \frac{x^E}{R^E}$
(11)	$G^E = \Phi \left( \frac{\ln \bar{w}^E - \frac{1}{2} (\sigma^E)^2}{\sigma^E} \right)$
(12)	$F^E = \Phi \left( \frac{\ln \bar{w}^E + \frac{1}{2} (\sigma^E)^2}{\sigma^E} \right)$
(13)	$\Gamma^E = G^E + \bar{w}^E (1 - F^E)$
(14)	$G^{E'} = \frac{1}{\bar{w}^E \sigma^E} \Phi' \left( \frac{\ln \bar{w}^E - \frac{1}{2} (\sigma^E)^2}{\sigma^E} \right)$
(15)	$F^{E'} = \frac{1}{\bar{w}^E \sigma^E} \Phi' \left( \frac{\ln \bar{w}^E + \frac{1}{2} (\sigma^E)^2}{\sigma^E} \right)$
(16)	$\Gamma^{E'} = G^{E'} + (1 - F^E) - \bar{w}^E F^{E'}$
(17)	$n^E = (1 - \chi^E) (1 - \Gamma^E) \frac{R^E q K}{\Pi}$
(18)	$b = qK - n^E$
(19)	$n^B = \phi b$
(20)	$d = b - n^B$
(21)	$R^B = \frac{\Pi}{1 - \chi^B}$
(22)	$R^F = \frac{\phi}{1 - \Gamma^F} R^B$

---

(23)	$0 = \Gamma^F - (1 - \phi) \frac{R^D}{R^F}$
(24)	$0 = R^F - (\Gamma^E - \mu^E G^E) \frac{R^E q K}{b}$
(25)	$0 = (1 - \Gamma^E) R^E + \frac{\Gamma^{E'}}{(\Gamma^{E'} - \mu^E G^{E'}) (1 - \Gamma^F)} [(1 - \Gamma^F) (\Gamma^E - \mu^E G^E) R^E - R^B \phi]$
(26)	$0 = c + \left( 1 - \frac{R^D}{\Pi} \right) d - wl$

---

Given initial values for  $\Gamma^F$ ,  $l$ ,  $x^E$  and  $R^E$ , we can compute the 22 parameters  $q$ ,  $r^K$ ,  $s$ ,  $K$ ,  $I$ ,  $Y$ ,  $w$ ,  $R^D$ ,  $c$ ,  $\bar{w}^E$ ,  $G^E$ ,  $F^E$ ,  $\Gamma^E$ ,  $G^{E'}$ ,  $F^{E'}$ ,  $\Gamma^{E'}$ ,  $n^E$ ,  $b$ ,  $n^B$ ,  $d$ ,  $R^B$  and  $R^F$  using equations (1) to (22). We then solve the four-equation system consisting of (23)-(26) numerically for  $\Gamma^F$ ,  $l$ ,  $x^E$ , and  $R^E$ .

Table 2: **Benchmark Calibration**

Parameter	Value	Description
Structural Parameters		
$\beta$	0.99	Household discount factor
$\eta$	0.2	Inverse Frisch elasticity of labour supply
$\alpha$	0.3	Capital share in production
$\varepsilon$	6	Substitutability between goods
$\kappa_p$	20	Price adjustment cost
$\delta$	0.025	Capital depreciation rate
$\kappa_I$	2	Investment adjustment cost
Financial Parameters		
$\chi^E$	0.06	Consumption share of wealth entrepreneurs
$\chi^B$	0.06	Consumption share of wealth bankers
$\mu^E$	0.3	Monitoring cost entrepreneurs
$\sigma^E$	0.12	Idiosyncratic shock size entrepreneurs
$\phi$	0.08	Bank capital requirement
Shock Parameters		
$\sigma^A$	0.0716	Size technology shock
$\rho^A$	0.8638	Persistence technology shock
$\sigma^\varsigma$	0.0867	Size firm risk shock
$\rho^\varsigma$	0.8033	Persistence firm risk shock

Table 3: **Implied Steady State Values**

Variable	Value	Description
Interest Rates		
$R$	1.0152	Policy rate
$R^D$	1.0152	Return on deposits (earned by depositors)
$R^F$	1.0195	Return on loans (earned by banks)
$R^E$	1.0335	Return on capital (earned by entrepreneurs)
$R^B$	1.0692	Return on equity (earned by bankers)
Annualised Spreads and Default Probability		
$400 \cdot (R^F - R)$	1.73	Loan return spread p.a., in %
$400 \cdot (R^E - R)$	7.36	Capital return spread p.a., in %
$400 \cdot (R^B - R)$	21.6	Equity return spread p.a., in %
$400 \cdot F^E$	2.6	Default probability p.a., in %
Leverage		
$x^E$	0.7621	Leverage entrepreneurs
$1 - \phi$	0.92	Leverage banks

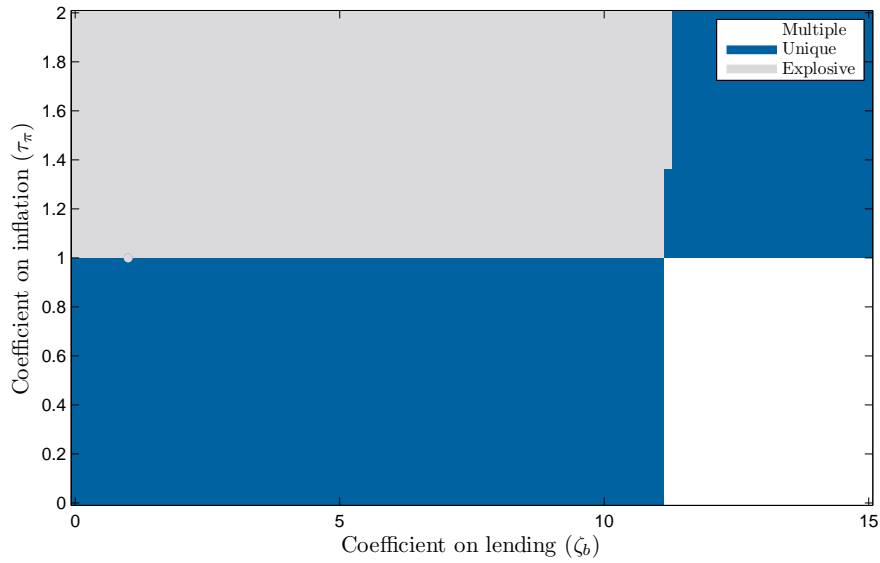
*Note:* All interest rates and rates of return are gross rates when steady state inflation is 1.

Table 4: **Optimized monetary policy rules**

$\tau_R$	$\tau_\pi$	$\tau_b$	$\zeta_b$	$\mathcal{W}$	$100 \times \omega$
<i>Optimized standard Taylor-type rule</i>					
0	0.990	–	–	-34.55670	0.26
<i>Optimized Taylor-type rule and CCB</i>					
–	0.990	–	0.306	-34.55622	0.00
<i>Optimized augmented Taylor-type rule</i>					
–	0.000	0.000	–	-34.55748	0.67

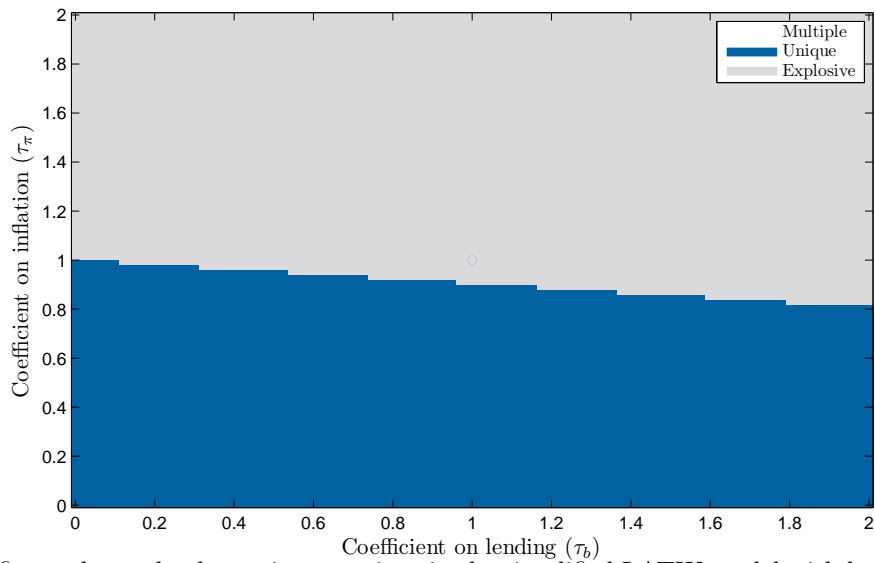
*Note:* The term  $\omega$  represents the welfare loss relative to the reference regime, which is the optimized augmented Taylor-type rule, i.e. LATW policy. The optimized standard Taylor-type rule features interest rate smoothing and response to inflation, while the optimized standard Taylor-type rule and CCB is the CCB policy coupled with a Taylor rule responding only to inflation.

Figure 1: **Determinacy Analysis: CCB Model**



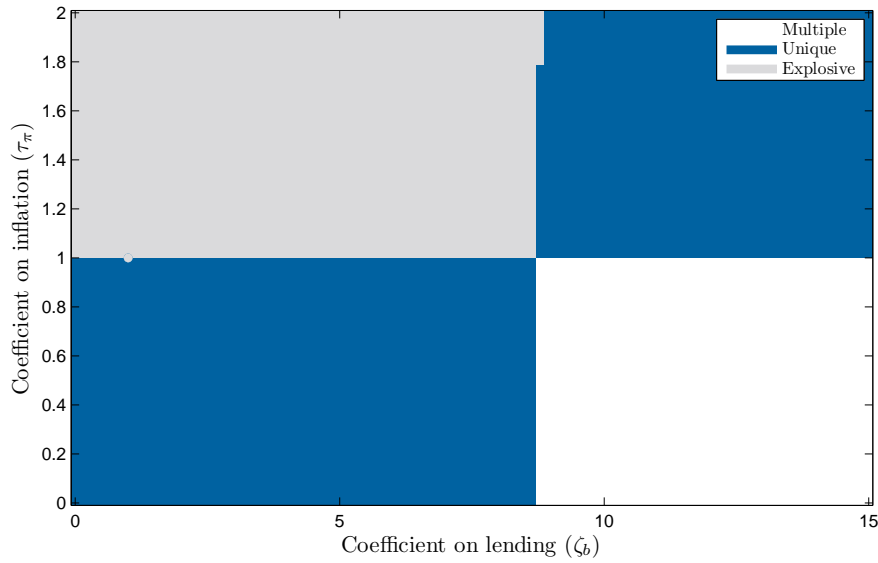
*Note:* The figure shows the determinacy regions in the simplified CCB model without leaning against the wind in the interest rate rule ( $\tau_b = 0$ ) and countercyclical capital buffer ( $\zeta_b > 0$ ).

Figure 2: **Determinacy Analysis: 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 3: **Determinacy Analysis: CCB Model with  $\phi = 10\%$**



*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 ( $\zeta_b > 0$ ), setting  $\phi = 10\%$ .

Figure 4: Peak responses to the risk shock with and without the zero lower bound (ZLB) on the nominal interest rate in the case of aggressive CCB and active monetary policy

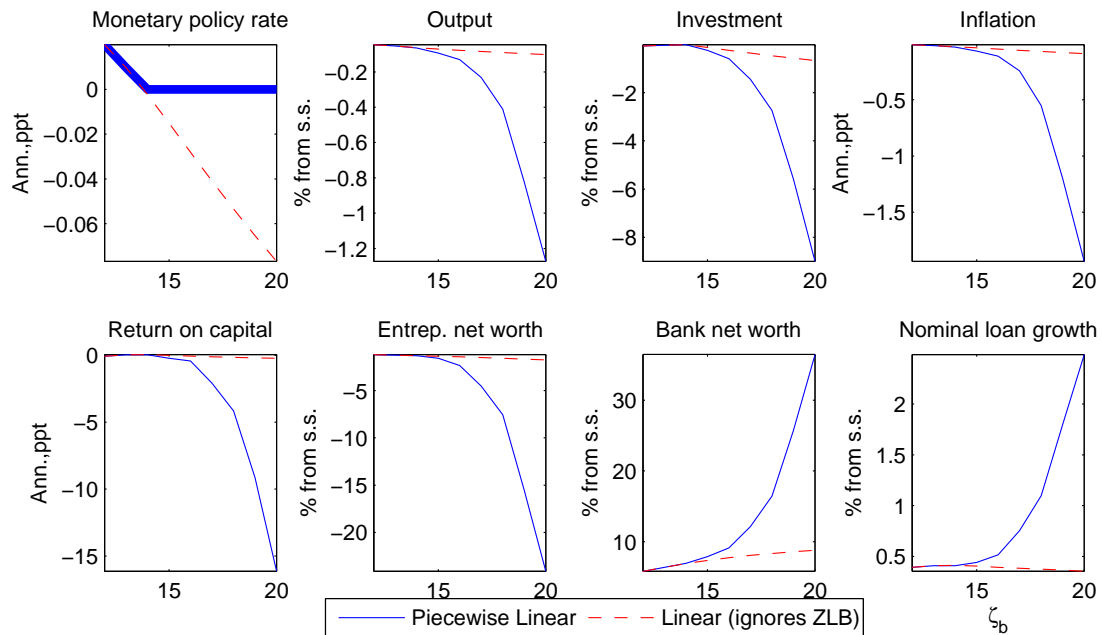
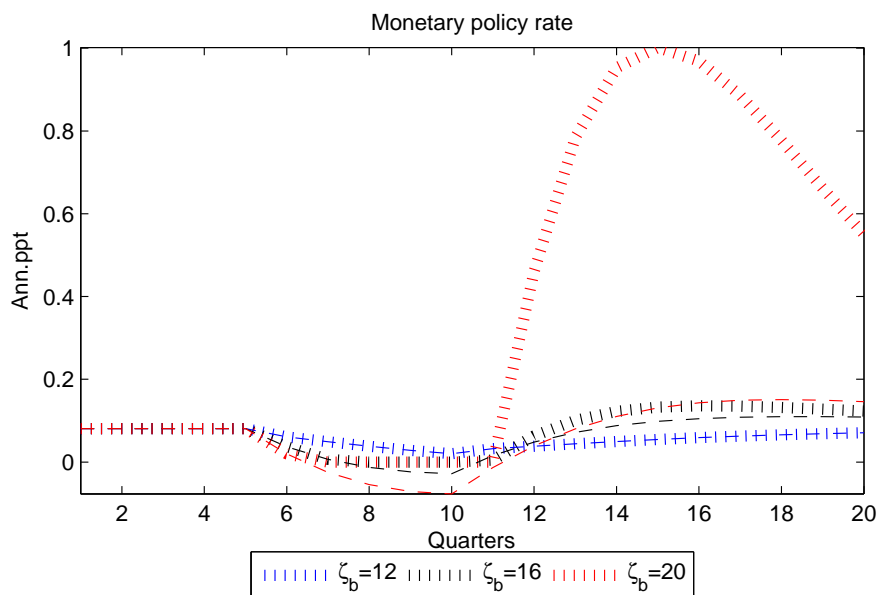


Figure 5: Impulse responses of the monetary policy rate to the risk shock for different values of the responsiveness of the macroprudential instrument



*Note:* Dotted lines refer to constrained economy where the ZLB is hit, while dashed lines refer to the unconstrained economy.

Figure 6: Peak responses to the risk shock with and without the zero lower bound (ZLB) on the nominal interest rate in the case of ineffective/mild CCB policy and passive monetary policy ( $\tau_\pi = 0.9$ )

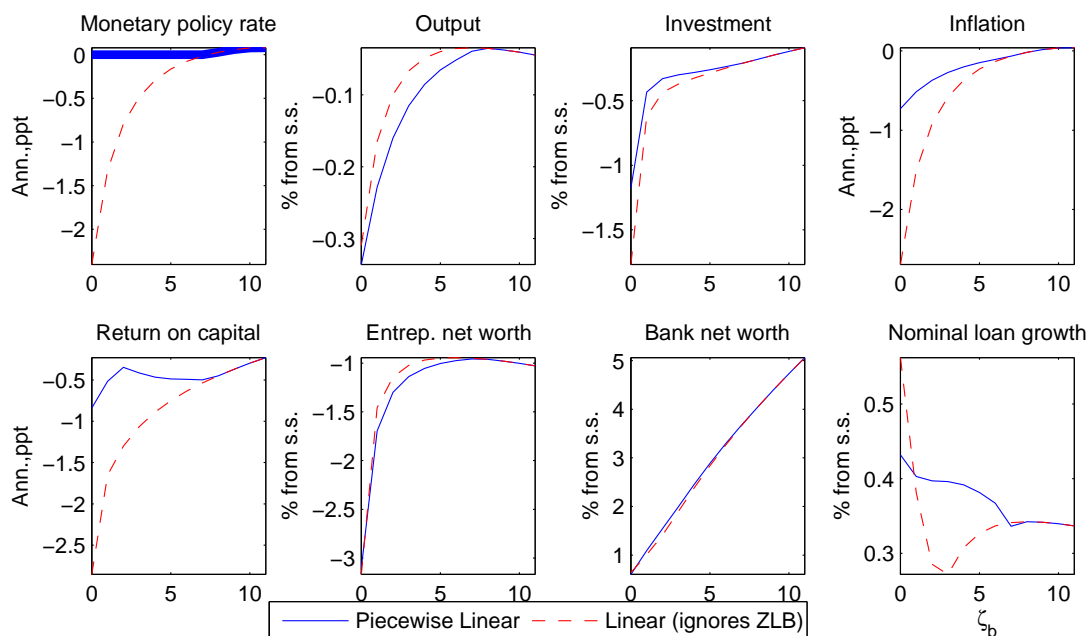
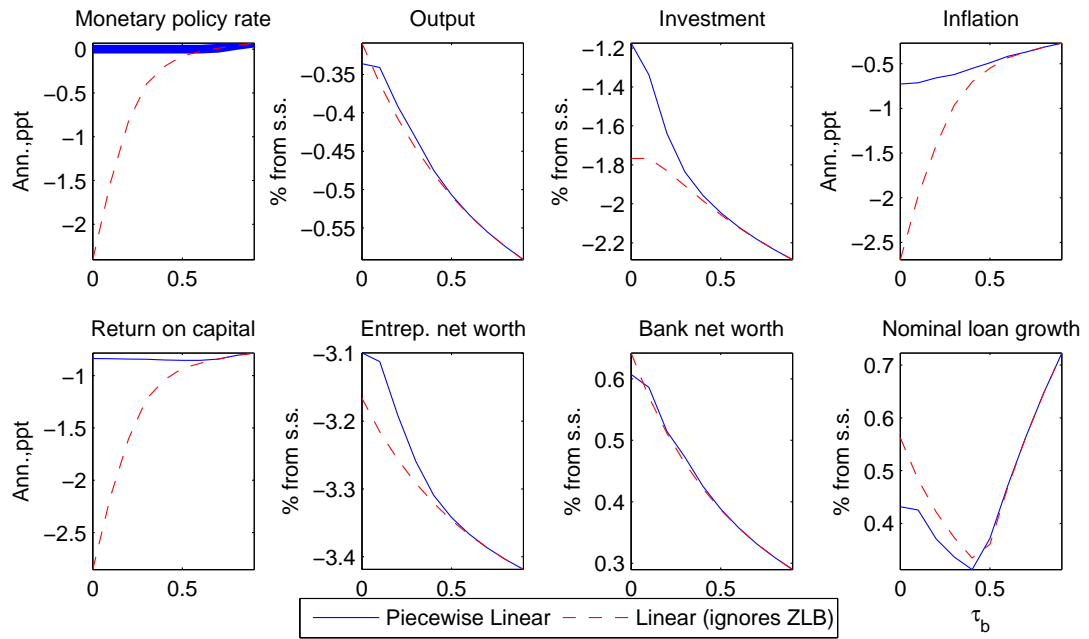




Figure 7: Peak responses to the risk shock with and without the zero lower bound (ZLB) on the nominal interest rate in the case of LATW policy ( $\tau_\pi = 0.9$ )



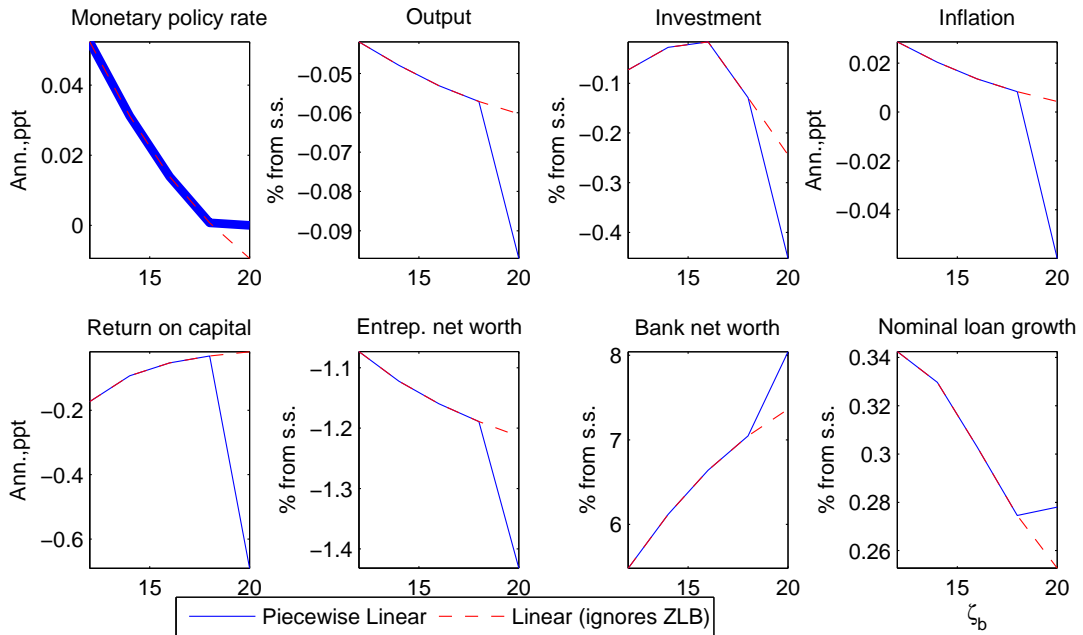
# Appendix

## A Robustness analysis of the transmission mechanism

### A.1 A different responsiveness of monetary policy

This section examines the sensitivity of the peak responses to different values of the responsiveness to inflation in the Taylor rule. Figure 8 shows the case of a very active monetary policy. An aggressive monetary policy helps contain the simulated recession. The comparison with Figure 4 reveals that the recession is less severe for  $\tau_\pi = 2.5$  and the deviation of inflation from its steady state is curbed. The effects to those of a higher and higher  $\zeta_b$  are analogous to those shown in the case of  $\tau_\pi = 1.2$ .

Figure 8: Peak responses to the risk shock with and without the zero lower bound (ZLB) on the nominal interest rate in the case of aggressive CCB and very active monetary policy ( $\tau_\pi = 2.5$ )



Figures 9 and 10 show the case of a more passive monetary policy, with  $\tau_\pi = 0.75$ . Results are robust to the different responsiveness of monetary policy.

Figure 9: Peak responses to the risk shock with and without the zero lower bound (ZLB) on the nominal interest rate in the case of ineffective/mild CCB policy and passive monetary policy ( $\tau_\pi = 0.75$ )

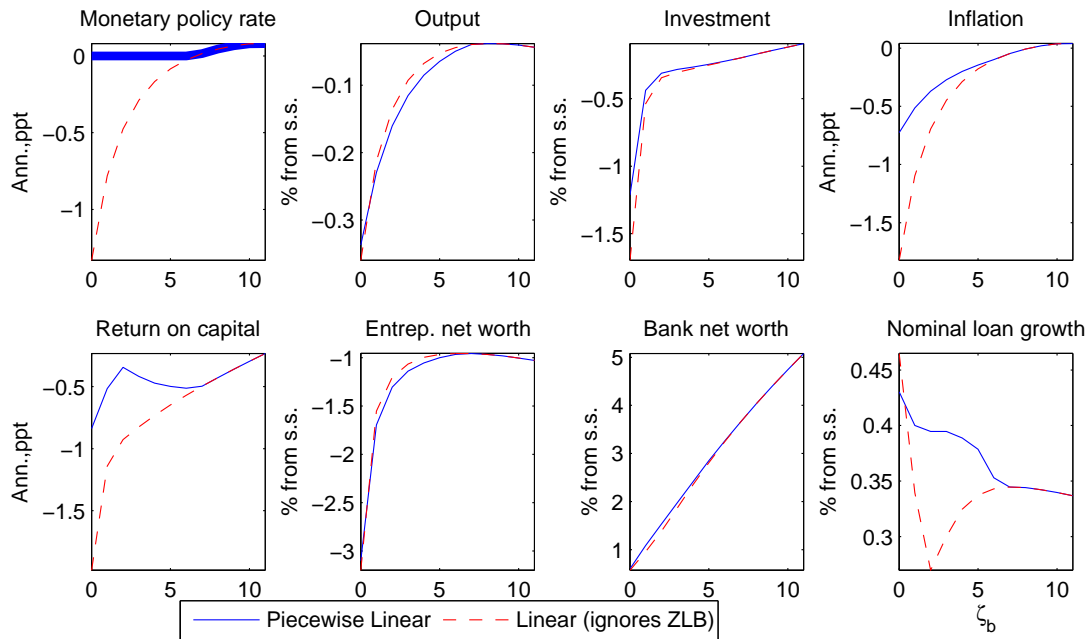


Figure 10: Peak responses to the risk shock with and without the zero lower bound (ZLB) on the nominal interest rate in the case of LATW policy ( $\tau_\pi = 0.75$ )

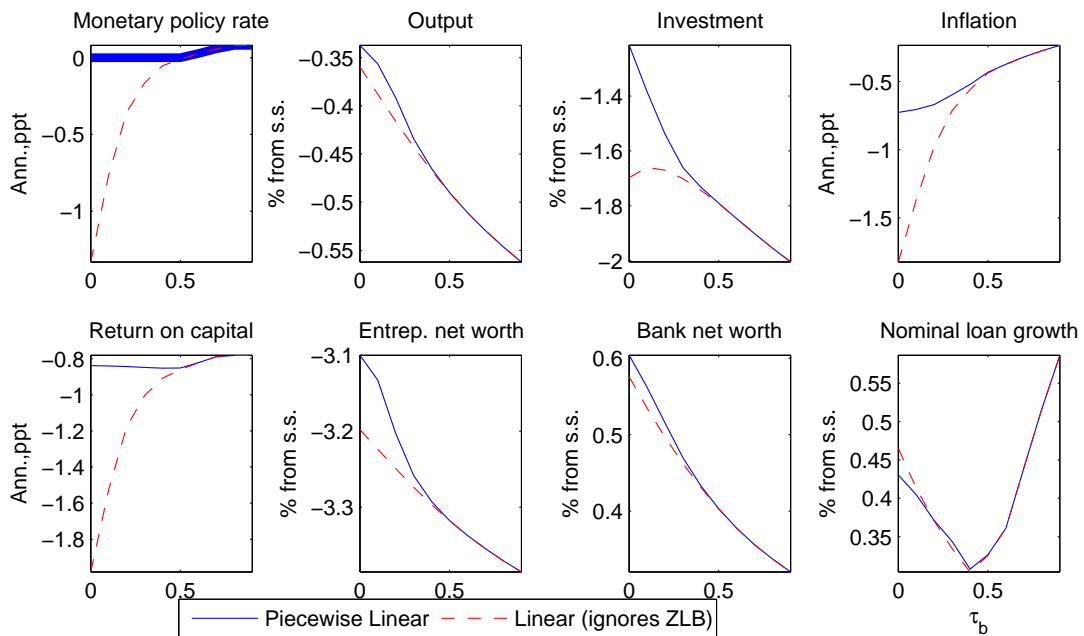
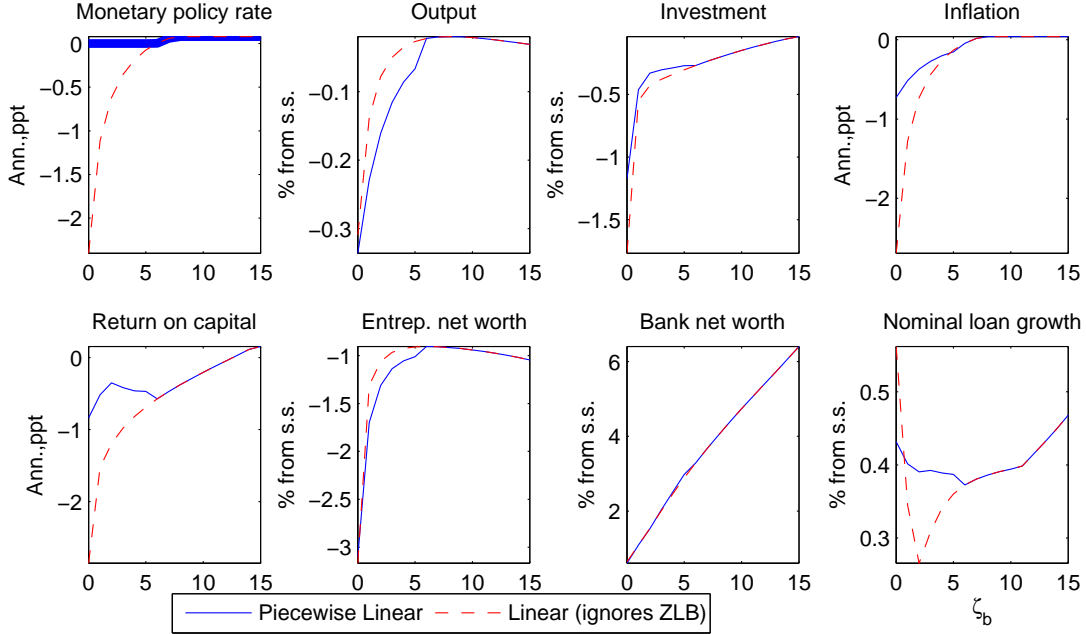


Figure 11: Peak responses to the risk shock with and without the zero lower bound (ZLB) on the nominal interest rate in the case of ineffective/mild CCB policy (responding to credit to GDP) and passive monetary policy



## A.2 An alternative specification of the macroprudential instruments

This section examines the sensitivity of the results to a different specification of the macroprudential instruments. Following Dell’Ariccia et al. (2012) and Badarau and Popescu (2014), the financial variable authorities are interested in is credit-to-GDP. Hence, the Taylor rule is specified as follows:

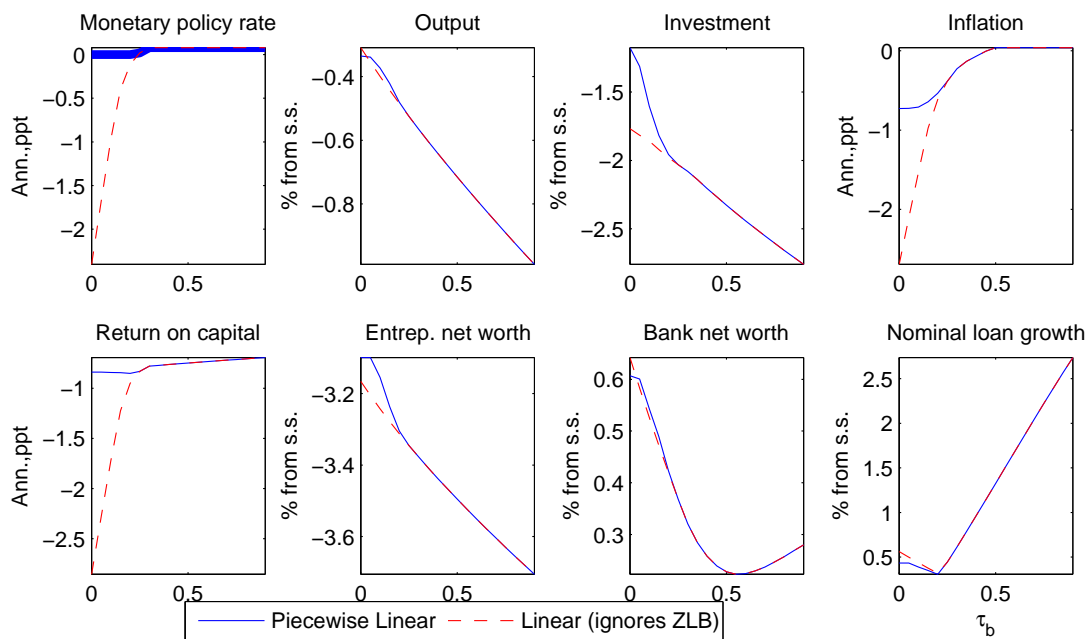
$$\frac{R_t}{R} = \left( \frac{R_{t-1}}{R} \right)^{\tau_R} \left( \frac{\Pi_t}{\Pi} \right)^{\tau_\Pi} \left( \frac{b_t/Y_t}{b/Y} \right)^{\tau_b}. \quad (34)$$

Macroprudential policy is given by a rule for the capital requirement responding to credit-to-GDP,

$$\frac{\phi_t}{\phi} = \left( \frac{b_t/Y_t}{b/Y} \right)^{\zeta_b}. \quad (35)$$

Under this alternative specification the region of determinacy for the LATW policy is the same as in the case of rule (28), while the CCB policy featuring credit-to-GDP has a unique equilibrium only under a passive monetary policy. Hence in Figure 11 we show peak responses under this scenario. The main results are preserved when the macroprudential instrument responds to credit-to-GDP. The finding is analogous in the case of LATW policy, shown in Figure 12.

Figure 12: Peak responses to the risk shock with and without the zero lower bound (ZLB) on the nominal interest rate in the case of LATW policy responding to credit to GDP



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