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Macroprudential policies in a low interest-rate environment*

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Abstract

This paper analyzes the role of macroprudential policies in a low interest-rate environment, in which monetary policy can be occasionally restricted by a lower bound. We study this issue by using a DSGE model with housing and collateral constraints. The macroprudential instrument is a loan-to-value ratio (LTV) rule. We find that, when the steady-state interest rate is high, the two policies can work independently with different instruments and separate objectives. When the steady-state interest rate is low, however, monetary policy hits the zero lower bound more frequently and the macroprudential authority can act as a complementary macro-financial stabilizer for both real and financial cycles.

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Non-Technical Summary

In the aftermath of the global financial crisis, a new set of challenges has emerged for macroeconomic policy makers. One of the major changes in the post-crisis environment is a significant and permanent decline in interest rates. In many economies, the short-term nominal interest rate has been close to zero. Monetary policymakers have encountered difficulties in stimulating the economy because the interest rate cannot be lowered any further. Moreover, when interest rates are persistently low, agents tend to engage in speculative investment in assets, such as real estate. Therefore, low interest rates may also contribute to asset price bubbles and excessive leverage, which pose risks to financial stability.

One of the policies that has become important after the crisis is the so-called macroprudential policy, aimed at ensuring a more stable financial system. In this paper, we focus on the use of macroprudential policies in an economic environment in which interest rates are low. We argue that, in a low interest-rate environment, the case for using macroprudential policies becomes even stronger. On the one hand, greater financial volatility due to low interest rates calls for macroprudential policies to contain excessive bank lending. On the other hand, macroprudential policy may also complement monetary policy when the interest rate is close to zero and cannot be used to stabilize the economy anymore.

We build an economic model for policy evaluation that can take into account that nominal interest rates are subject to a zero lower bound and cannot become negative. We calibrate the model to characteristics of the US economy where the Federal funds rate has been close to zero for 7 years. Within this setting, we find that when the interest rate is persistently low, activity in the financial markets and the wider economy, becomes more volatile. Therefore, we propose macroprudential policy as a candidate to stabilize the economy in this context. On the one hand, we find that in a low interest-rate environment, tighter macroprudential policies can stabilise financial markets. We also find, on the other hand, that macroprudential policies could help monetary policy stimulate the economy when interest rates are close to zero.

"*Also, to the extent that macroprudential policy reduces systemic risks and creates buffers, this helps monetary policy in the face of adverse financial shocks. It can reduce the risk that monetary policy runs into constraints such as the zero lower bound—recently hit by many advanced economies.*" - "Making Macroprudential Policy Work" Remarks by José Viñals at Brookings, September 16, 2013

1 Introduction

In the post-Global Financial Crisis (GFC) world, there are new challenges to the conduct of macro-financial stabilization policies. One of the major changes in this new environment is a significant decline in the neutral real interest rate. In many advanced economies, estimated long-term neutral rates have declined to much lower levels compared to the pre-crisis period and show no sign of recovery (Laubach and Williams, 2015). While there could be several explanations for this phenomenon, it seems that a plausible one would be demographic developments and the integration of Chinese savings into global financial markets.[1] These low rates are challenging for policy makers for two reasons. First, low neutral rates limit the scope of conventional monetary policy in stabilizing the economy. Second, low interest rates raise concerns about financial imbalances and risks to financial stability (Borio, 2016).

The GFC has shown that the zero (or effective) lower bound (ZLB) on nominal interest rates is not just a theoretical concern. Economies encounter this lower bound with much higher probability than was previously believed. A critical implication of a low interest-rate environment is that, when central banks use conventional monetary policy to stabilize the economy, the nominal interest rate may indeed hit its lower bound. The ZLB constraint makes it more difficult for traditional monetary policy to stabilize the economy. The immediate consequence of the limited effectiveness of monetary policy is that business cycles may be more unstable. Moreover, persistently low interest rates may also have important implications for financial stability. In fact, low interest rates affect incentives of financial market participants, leading to excessive risk-taking behavior. For instance, the yield-chasing motive encourages agents to engage in speculative investment in assets, such as real estate. Low interest rates may contribute to asset bubbles and excessive leverage.[2]

In this paper, we argue that, in a low interest-rate environment, the case for using macroprudential policies becomes even stronger. On the one hand, greater financial volatility due to low interest rates calls for macroprudential policies to contain excesses in bank lending. The crisis has also shown us that,

[1] See Bean et al. (2015).
[2] See Cœuré (2015) for further discussion.

in recessions, there is the need to support the provision of lending. On the other hand, macroprudential policy may also be useful to complement monetary policy, when it is subject to the lower bound.[3] To illustrate this point, we build a dynamic stochastic general equilibrium (DSGE) model with collateral constraints on borrowers and an occasionally binding ZLB for the interest rate. Monetary policy in the model is described by a standard Taylor rule, which is subject to an occasionally binding ZLB. Macroprudential policy is characterized by a rule on the loan-to-value ratio (LTV) that responds to deviations of credit and output from their respective steady states. We calibrate the model to match a low interest-rate environment by setting the steady-state interest rate equal to 2%.[4] We solve the model using the "occbin" toolkit proposed by Guerrieri and Iacoviello (2015).

Using this framework, we answer the following research questions: first, without an active role for macroprudential policy, what are the consequences of a steady-state interest rate falling from 4% to 2% for business and financial cycles? Second, can macroprudential policy contribute to both financial and macroeconomic stability in the low interest-rate environment? We are aware of the limitations of the model to answer such questions because DSGE models do not reflect key aspects of financial stability or systemic risk.[5] In addition, in this model, macroprudential policies are not micro-founded, we assume that they are exogenously implemented as requested by regulation and are beneficial for the economy because they partly correct the distortions introduced by collateral constraints on borrowers.

Our simulation results show that, in a 2% steady-state interest-rate environment, the nominal interest rate hits the ZLB more frequently and stays there for longer periods than in a model with a 4% steady-state interest rate. This, in turn, leads to both volatile macroeconomic and financial cycles. There are two channels that give rise to more volatile macro dynamics: firstly, through the collateral channel, negative productivity shocks drive down house prices and tighten the collateral constraint for the borrowers. This, in turn, negatively affects credit. This feedback loop between house prices and credit gives rise to a powerful financial accelerator, emphasized in Iacoviello (2005). Secondly, when the interest rate is restricted by the occasionally binding ZLB, it provides an additional amplification of the shock. In this case, the anticipation that the interest rate will be forced to stay at zero for certain periods reinforces the effects of the negative productivity shock. Inflation falls and pushes up the real cost of borrowing.

[3] In policy debates, the use of macroprudential policies to act as macroeconomic stabilizers is controversial, since these policies are designed for other goals. Nevertheless, the ZLB is an extreme case in which monetary policy is in real need for alternatives (Caruana, 2011).

[4] Hamilton et al (2015) interpret the equilibrium level of the real federal funds rate as the long run or steady-state value of the real funds rate and find that it has fallen to about 2% in advanced economies.

[5] In the context of the model, we use low volatility in financial markets as a proxy for financial stability.

This, in turn, depresses house prices and credit even further than under the collateral channel.

Having shown that, in a low interest-rate environment, the occasionally binding ZLB leads to more volatile real and financial cycles, we move on to study the effects of active macroprudential policy rules as a complement to a less effective monetary policy. In particular, we compute the optimal simple rule for the LTV by minimizing a loss function for the macroprudential regulator. We consider an LTV rule that responds to credit and output gaps. We find that, in the 4% interest-rate environment, countercyclical macroprudential policies can lead to more stable financial cycles, while business cycles can be effectively managed by monetary policy, because the ZLB is rarely binding. In this case, the so-called "Tinbergen principle" applies: macroeconomic stability can be assigned to the monetary authority, while the macroprudential authority only takes care of financial stability. The two policies work independently with different instruments. By contrast, when the steady-state interest rate falls to 2% and monetary policy is occasionally restricted, the two policy spheres interdependent. In particular, macroprudential tools may materially contribute to the management of aggregate demand.[6] Our simulations show that, in the low interest-rate environment, a purely financial-stability focused macroprudential authority needs to use its instrument more aggressively to stabilize financial cycles than in normal times. Furthermore, we find that allowing macroprudential policy to respond directly to output strengthens economic stability, because a binding ZLB not only makes monetary policy ineffective, but also becomes an additional amplification channel of aggregate shocks.

Our paper is related to the strand of research that, following Iacoviello (2005), introduces a rule on the LTV interacting with monetary policy. For instance, Borio and Shim (2007) emphasize the complementary role of macroprudential policy to the monetary policy and its supportive role as a built-in stabilizer. Similarly, N'Diaye (2009) shows that monetary policy can be supported by countercyclical prudential regulation, and Angelini et al. (2014) show interactions between LTV and capital requirements ratios and monetary policies. However, the literature above does not explicitly consider the impact of an occasionally binding ZLB. On the other hand, Neri and Notarpietro (2014), consider a model in which monetary policy is constrained by the ZLB. They find that, in this special circumstance, shocks that would be supposed to reduce inflation and stimulate output can have contractionary effects on economic activity. However, this paper does not take into account macroprudential policies.

Antipa and Matheron (2014) study the interactions of macroprudential and unconventional monetary

[6] Blanchard et al (2013) discuss this topic and also extend it to other situations in which monetary policy is unavailable for some individual countries such as currency unions or exchange rate pegs.

policies when the interest rate hits the zero lower bound. They find that macroprudential policies act as a useful complement to forward guidance policy during ZLB periods. Our paper abstracts from unconventional monetary policy, but we find a similar result regarding complementarity between LTV rules and monetary policy. Lewis and Villa (2016) study the interactions between monetary policy and a countercyclical capital buffer when monetary policy is constrained at the ZLB. Korinek and Simsek (2016) find that when the interest rate is limited by the ZLB, welfare can be improved by ex-ante macroprudential policies such as debt limits and mandatory insurance requirements. Our paper complements this literature and contributes to it by studying the interaction between LTV policy and monetary policy in a low interest-rate environment, in which the ZLB for the interest rate occasionally binds. We provide an extensive analysis on how and under which circumstances macroprudential policy can act not only as a financial but also as a macroeconomic stabilizer.

The rest of the paper continues as follows. Section 2 describes the model. Section 3 shows the dynamics of the model allowing for the ZLB constraint. Section 4 compares simulations for normal times and a low interest-rate environment. Section 5 analyzes macroprudential policy implementation. Section 6 concludes.

2 Model Setup

The economy features patient and impatient households, a final goods firm, a central bank which conducts monetary policy, and a macroprudential authority that sets financial regulation. Households work and consume both consumption goods and housing. Patient and impatient households are savers and borrowers, respectively. Borrowers are credit constrained and need collateral to obtain loans. The representative firm converts household labor into the final good. The central bank follows a Taylor rule for the setting of interest rates and the macroprudential regulator uses the LTV as an instrument for macroprudential policy.

2.1 Savers

Savers maximize their utility function by choosing consumption, housing and labor hours:

$$\max_{C_{s,t},H_{s,t},N_{s,t}} E_0 \sum_{t=0}^{\infty} \beta_s^t \left[\log C_{s,t} + j \log H_{s,t} - \frac{(N_{s,t})^\eta}{\eta} \right],$$

where $\beta_s \in (0,1)$ is the patient discount factor, E_0 is the expectation operator and $C_{s,t}$, $H_{s,t}$ and

$N_{s,t}$ represent consumption at time t, the housing stock and working hours, respectively. $1/(\eta-1)$ is the labor supply elasticity, $\eta > 0$. j represents the weight of housing in the utility function.

Savers maximize their utility subject to the following budget constraint:

$$C_{s,t} + b_t + q_t (H_{s,t} - H_{s,t-1}) = \frac{R_{t-1} b_{t-1}}{\pi_t} + w_{s,t} N_{s,t} + F_t, \tag{1}$$

where b_t denotes bank deposits, R_t is the gross return from deposits, q_t is the price of housing in units of consumption, π_t is the inflation rate, and $w_{s,t}$ is the real wage rate. F_t denotes lump-sum profits received from the firms. The first order conditions for this optimization problem are as follows:

$$\frac{1}{C_{s,t}} = \beta_s E_t \left(\frac{R_t}{\pi_{t+1} C_{s,t+1}} \right), \tag{2}$$

$$w_t^s = (N_{s,t})^{\eta-1} C_{s,t}, \tag{3}$$

$$\frac{j}{H_{s,t}} = \frac{1}{C_{s,t}} q_t - \beta_s E_t \frac{1}{C_{s,t+1}} q_{t+1}. \tag{4}$$

Equation (2) is the Euler equation, the intertemporal condition for consumption. Equation (3) is the labor-supply condition and Equation (4) represents the intertemporal condition for housing, in which, at the margin, the benefits from consuming housing equate costs in terms of consumption.

2.2 Borrowers

Borrowers solve the following optimization problem:

$$\max_{C_{b,t}, H_{b,t}, N_{b,t}} E_0 \sum_{t=0}^{\infty} \beta_b^t \left[\log C_{b,t} + j \log H_{b,t} - \frac{(N_{b,t})^\eta}{\eta} \right],$$

where $\beta_b \in (0,1)$ is the discount factor for the borrower ($\beta_b < \beta_s$), subject to the following budget and collateral constraints:

$$C_{b,t} + \frac{R_{t-1} b_{t-1}}{\pi_t} + q_t (H_{b,t} - H_{b,t-1}) = b_t + W_{b,t} N_{b,t}, \tag{5}$$

$$E_t \frac{R_t}{\pi_{t+1}} b_t = k_t E_t q_{t+1} H_{b,t}, \tag{6}$$

where b_t denotes bank loans for borrowers. These are the converse of savers' deposits. k_t can be interpreted as a loan-to-value ratio.[7] The borrowing constraint limits borrowing to the present discounted value of their housing holdings. The first order conditions are as follows:

$$\frac{1}{C_{b,t}} = \beta_b E_t \left(\frac{R_t}{\pi_{t+1} C_{b,t+1}} \right) + \lambda_t R_t, \tag{7}$$

$$w_{b,t} = (N_{b,t})^{\eta-1} C_{b,t}, \tag{8}$$

$$\frac{j}{H_{b,t}} = \frac{1}{C_{b,t}} q_t - \beta_b E_t \left(\frac{1}{C_{b,t+1}} q_{t+1} \right) - \lambda_t k_t E_t \left(q_{t+1} \pi_{t+1} \right). \tag{9}$$

where λ_t denotes the multiplier on the borrowing constraint.[8] These first order conditions can be interpreted analogously to the ones of savers.

2.3 Firms

2.3.1 Final Goods Producers

There is a continuum of identical final goods producers that operate under perfect competition and flexible prices. They aggregate intermediate goods according to the production function

$$Y_t = \left[\int_0^1 Y_t(z)^{\frac{\varepsilon-1}{\varepsilon}} dz \right]^{\frac{\varepsilon}{\varepsilon-1}}, \tag{10}$$

where $\varepsilon > 1$ is the elasticity of substitution between intermediate goods. The final good firm chooses $Y_t(z)$ to minimize its costs, resulting in demand of intermediate good z:

$$Y_t(z) = \left(\frac{P_t(z)}{P_t} \right)^{-\varepsilon} Y_t. \tag{11}$$

The price index is then given by:

$$P_t = \left[\int_0^1 P_t(z)^{1-\varepsilon} dz \right]^{\frac{1}{\varepsilon-1}}. \tag{12}$$

[7] In standard housing models, the LTV is a parameter. However, in our model, this has a subindex t because it is the macroprudential instrument.

[8] Through simple algebra it can be shown that the Lagrange multiplier is positive in the steady state and thus the collateral constraint holds with equality.

2.3.2 Intermediate Goods Producers

The intermediate goods market is monopolistically competitive. Following Iacoviello (2005), intermediate goods are produced according to the production function:

$$Y_t(z) = A_t N_{s,t}(z)^{\alpha} N_{b,t}(z)^{(1-\alpha)}, \tag{13}$$

where $\alpha \in [0,1]$ measures the relative size of savers and borrowers in terms of labor.[9] This Cobb-Douglas production function implies that labor efforts of constrained and unconstrained consumers are not perfect substitutes. This specification is analytically tractable and allows for closed form solutions for the steady state of the model. This assumption can be economically justified by the fact that savers are the managers of the firms and their wage is higher than the wage received by borrowers.[10]

A_t represents technology and it follows the following autoregressive process:

$$\log(A_t) = \rho_A \log(A_{t-1}) + u_{At}, \tag{14}$$

where ρ_A is the autoregressive coefficient and u_{At} is a normally distributed shock to technology. We normalize the steady-state value of technology to 1.

Labor demand is determined by:

$$w_{s,t} = \frac{1}{X_t}\alpha\frac{Y_t}{N_{s,t}}, \tag{15}$$

$$w_{b,t} = \frac{1}{X_t}(1-\alpha)\frac{Y_t}{N_{b,t}}, \tag{16}$$

where X_t is the markup, or the inverse of marginal cost.[11]

The price-setting problem for the intermediate good producers is a standard Calvo-Yun setting. The intermediate good producer sells its good at price $P_t(z)$, and has a$1-\theta \in [0,1]$, probability of being able to change the sale price in every period. The optimal reset price $P_t^*(z)$ solves:

$$\sum_{k=0}^{\infty}(\theta\beta)^k E_t\left\{\Lambda_{t,k}\left[\frac{P_t^*(z)}{P_{t+k}} - \frac{\varepsilon/(\varepsilon-1)}{X_{t+k}}\right]Y_{t+k}^*(z)\right\} = 0. \tag{17}$$

[9] Notice that the absolute size of each group is one.

[10] It could also be interpreted as the savers being older than the borrowers, therefore more experienced.

[11] Symmetry across firms allows us to write the demands without the index z.

where $\varepsilon/(\varepsilon-1)$ is the steady-state markup.

The aggregate price level is given by:

$$P_t = \left[\theta P_{t-1}^{1-\varepsilon} + (1-\theta)\left(P_t^*\right)^{1-\varepsilon}\right]^{1/(1-\varepsilon)}. \tag{18}$$

Using log-linearized versions of (17) and (18), we can obtain a standard forward-looking New Keynesian Phillips curve $\widehat{\pi}_t = \beta E_t \widehat{\pi}_{t+1} - \psi \widehat{x}_t + u_{\pi t}$, that relates inflation positively to future expected inflation and negatively to the markup ($\psi \equiv (1-\theta)(1-\beta\theta)/\theta$). $u_{\pi t}$ is a normally distributed cost-push shock.[12]

2.4 Equilibrium

The market clearing conditions are as follows:

$$Y_t = C_{s,t} + C_{b,t}. \tag{19}$$

The total supply of housing is fixed and it is normalized to unity:

$$H_{s,t} + H_{b,t} = 1. \tag{20}$$

2.5 Monetary Policy

Monetary policy is set as follows:

$$R_t^{TR} = \left(R_{t-1}^{TR}\right)^{\rho} \left((\pi_t)^{\left(1+\phi_\pi^R\right)} \left(\frac{Y_t}{Y}\right)^{\phi_y^R} R \right)^{1-\rho} \tag{21}$$

$$R_t = \max\left(R_t^{TR}, 1\right) \tag{22}$$

We consider a standard Taylor rule which responds to inflation and output, with interest-rate smoothing, where $\phi_\pi^R \geq 0$, $\phi_y^R \geq 0$ measure the response of interest rates to current inflation and output deviations from the steady state,[13] respectively. R is the steady-state interest rate. However, we impose a ZLB constraint on the interest rate so that it cannot reach negative values when it follows the Taylor

[12] Variables with a hat denote percent deviations from the steady state.

[13] We use deviations of output with respect to the steady state as opposed to output gap because in a model with financial frictions there is no consensus about what the efficient level of output is.

rule. Thus, R_t^{TR} is the policy rate implied by the Taylor rule while R_t is the actual rate, both expressed in gross terms.

2.6 A Macroprudential Rule for the LTV

In standard models, the LTV ratio is a fixed parameter which is not affected by economic conditions. However, we can think of regulations of LTVs as a way to moderate credit booms. When the LTV is high, the collateral constraint is less tight. And, since the constraint is binding, borrowers will borrow as much as they are allowed to. Lowering the LTV tightens the constraint and therefore restricts the loans that borrowers can obtain. Literature on macroprudential policies has proposed rules for the LTV so that it reacts inversely to variables such that the growth rates of GDP, credit, the credit-to-GDP ratio or house prices. These rules provide a simple illustration of how a macroprudential policy could work in practice. We assume that the objective of the macroprudential regulator is to avoid situations that lead to an excessive credit growth; when there is a boom in the economy or house prices increase, agents borrow more. Therefore, we take deviations of credit and output from their respective steady states as leading indicators of credit growth and consequently consider a rule for the LTV, so that it responds to credit and output:

$$k_t = k_{SS} \left(\frac{b_t}{b} \right)^{-\phi_b} \left(\frac{Y_t}{Y} \right)^{-\phi_y}, \tag{23}$$

where k_{SS} is a steady state value for the LTV, and $\phi_b \geq 0$, $\phi_y \geq 0$ measure the response of the LTV to borrowing and output, respectively. This kind of rule delivers a lower LTV in booms, when credit and output are high, therefore restricting the credit in the economy and avoiding a credit boom derived from good economic conditions.[14]

We choose this specific functional form in the spirit of Basel III reports on countercyclical buffers, adapted for the specific context of a low interest-rate environment. The Basel III guide on countercyclical buffers states that credit variables area a useful reference point in taking buffer decisions. Given the guide's close links to the objectives of the buffer and its demonstrated usefulness in many jurisdictions as an indicator of the build-up of system-wide risk in a financial system in the past, it is reasonable that it should be part of the information considered by the authorities. As such, according to the Basel III, the buffer is not meant to be used as an instrument to manage economic cycles or asset prices. However, particularly in the low interest-rate context that we are considering in this paper, monetary policy is

[14] Funke and Paetz (2012) consider a non-linear version of this macroprudential rule for the LTV.

not effective when it hits the ZLB. Therefore, we believe that it is worthwhile to include output in the LTV rule to account for possible complementarities between macroprudential and monetary policy (See Basel Committee on Banking Supervision, 2010).

2.7 Baseline Parameter Values

For simulations, we create two types of environments; one which we call "normal times," in which the steady-state annual interest is 4% as in the standard RBC models, and a second one called "low interest rate" in which the steady-state interest rate is 2%. For the "normal times" case, the discount factor for savers, β_s, is set to 0.99 to match a 4% interest rate in the steady state. The discount factor for borrowers in this scenario is set to 0.98.[15] For the "low interest rate" environment, we set β_s to 0.995. In order to keep the same difference across agents' discount factors in both scenarios, we set β_b to 0.985 in this case. The steady-state weight of housing in the utility function, j, is set to 0.1 in order for the ratio of housing wealth to GDP to be approximately 1.40 in the steady state, consistent with the US data, as in Iacoviello (2005). We set $\eta = 2$, implying a value of the labor supply elasticity of 1.[16] For the parameter controlling leverage, we set k_{SS} to 0.90, in line with the US data (See Iacoviello, 2005).[17] The labor income share for savers is set to 0.64, following the estimate in Iacoviello (2005). For the Taylor rule, we consider the standard values $\phi_{\pi}^{R} = 0.5$ and $\phi_{y}^{R} = 0.5$.[18] For ρ we use 0 so that we rule out smoothing from the rule and it is comparable to the case in which the economy is hitting the ZLB.

We simulate the response of the model to a technology shock. We assume that technology, A_t, follows an autoregressive process with 0.9 persistence and a normally distributed shock.[19] Table 1 presents a summary of the parameter values used:

[15] Lawrance (1991) estimated discount factors for poor consumers at between 0.95 and 0.98 at quarterly frequency. We take the most conservative value.

[16] Microeconomic estimates usually suggest values in the range of 0 and 0.5 (for males). Domeij and Flodén (2006) show that in the presence of borrowing constraints this estimates could have a downward bias of 50%.

[17] Experimenting with lower values of the LTV ratio weakens the financial accelerator effects and the need for macroprudential policies. A value of the LTV ratio of 90%, which is consistent with values in many countries, gives more powerful results.

[18] We are aware that in a quarterly model, this value should be divided by 4. However, to be consistent with the rest of the literature, we use 0.5 as a baseline. We have experimented with other values of this parameter and results are virtually unchanged.

[19] The persistence of the shocks is consistent with the estimates in Iacoviello and Neri (2010).

Table 1: Parameter Values		
β_s	0.99/0.995	Discount Factor for Savers
β_b	0.98/0.985	Discount Factor for Borrowers
j	0.1	Weight of Housing in Utility Function
η	2	Parameter associated with labor elasticity
k_{SS}	0.9	Loan-to-value ratio
α	0.64	Labor share for Savers
X	1.2	Steady-state markup
θ	0.75	Probability of not changing prices
ρ	0	Smoothing parameter in Taylor rule
ϕ_π^R	0.5	Inflation parameter in Taylor rule
ϕ_y^R	0.5	Output parameter in Taylor rule

3 The Occasionally Binding ZLB

The GFC has made us to re-think about existing models and re-shape them in order to appropriately reflect the changes that are occurring in the economy. For instance, standard solution methods for DSGE models did not take into account the possibility of having the interest rate constrained at the ZLB, which has been proven to be a crucial feature of the economy, especially after the recent financial crisis. Large enough shocks, under these traditional methods, bring the policy rate to negative levels, violating the ZLB. However, we now know that the ZLB constraint for the interest rate is not just a theoretical curiosity, partly due to falling neutral interest rates. Even absent of large shocks, we have seen many economies across the world interest rates hitting their lower bounds. Therefore, it is important to be able to introduce this constraint in monetary policy models.

Considering occasionally binding lower bounds poses a technical challenge to solving DSGE models. In this paper, we use the solution method proposed by Guerrieri and Iacoviello (2015), namely the "occbin" toolbox,[20] which implements a piecewise-linear approximation to solve DSGE models with occasionally binding constraints. The key advantage of the toolbox is to solve for the rational expectations solution with unknown durations of each regime. For instance, in this method, the duration of

[20] There are alternative solution methods in the literature. For example, Jones (2015) shows that if the Blanchard-Kahn conditions are satisfied for the linearized model under the non-zero lower bound regime, then the "occbin" method developed by Guerrieri and Iacoviello (2015) yields the same path for the endogenous variables as his approach. This is the case of our model.

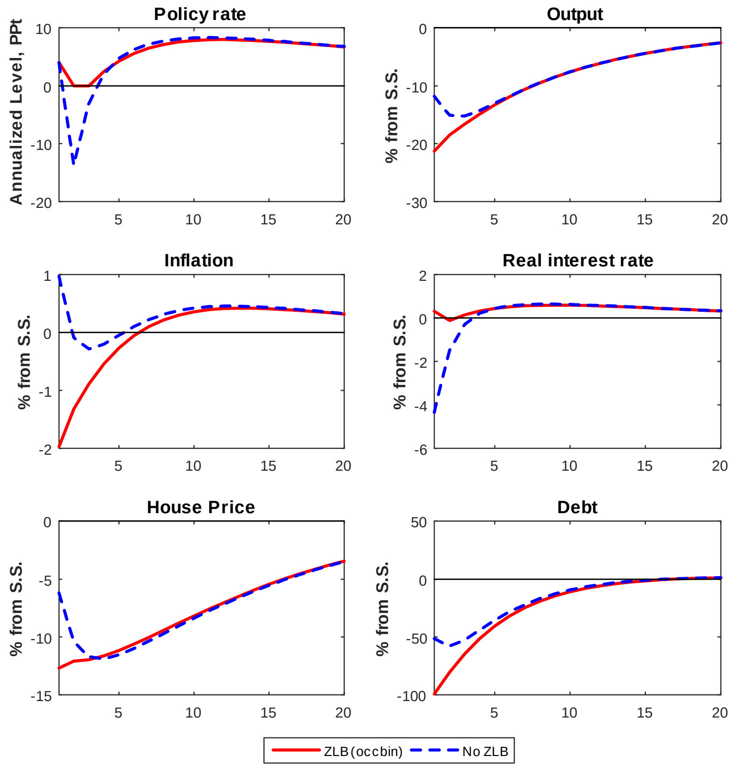

Figure 1: Impulse responses to a negative productivity shock

the binding regime does not need to be fixed at a predetermined value but depends on the realization of shocks. In fact, how long a regime is expected to last affects the value of the endogenous variables contemporaneously. The "occbin" toolbox uses a guess-and-verify procedure to generate time-varying policy functions depending on the expected duration of regimes at each period.[21] In our case, the constraint that binds occasionally is the ZLB. Under one regime, the ZLB constraint is slack. Under the other regime, the constraint binds. Using this toolkit, we linearize the model under each regime around the non-binding steady state.

To illustrate how the occasionally binding ZLB affects the dynamics in our model, we compute impulse responses to a productivity shock, using both the standard solution method and the "occbin" toolkit. In this case, the LTV is set to its steady state value of 0.9 and no active rule is allowed.

Figure 1 presents impulse responses to a negative productivity shock for the case in which the economy is not constrained by the ZLB (blue dashed line) as opposed to the occasionally binding ZLB case (red solid line).[22] The upper- left panel displays the annualized level of the policy rate. It starts

[21] See Guerrieri and Iacoviello (2015) for further explanation on the "occbin" toolkit and the solution method.

[22] For illustrative purposes, we consider a size of the shock large enough to make the ZLB bind.

from the steady state level of 4%. We see that, when there are occasionally binding constraints for the interest rate, the policy rate reaches the zero lower bound and stays there for a couple of periods before converging to the Taylor rule interest rate. The non-constrained interest rate, however, becomes negative. This discrepancy between the two rates makes the rest of the variables also behave differently. In particular, both output and inflation respond in a much stronger manner in the world in which the interest rate is constrained. The deeper output recession in the occasionally binding model is driven by two channels. Firstly, the negative impact of the productivity shock is amplified by the collateral channel of borrowers, even without a ZLB. As shown in blue dashed lines, when the negative shock hits, house prices fall and tighten the collateral constraint for borrowers. This, in turn, negatively affects credit via the collateral constraint. This feedback loop between house prices and credit gives rise to a powerful financial accelerator, emphasized in Iacoviello (2005). Even though, in this case, the central bank can support the economy by cutting the interest rate dramatically, the economy suffers an output recession. Secondly, when the interest rate is restricted by the occasionally binding ZLB, the latter provides an additional amplification of the shock. In this case, the occasionally binding ZLB economy suffers an even stronger recession, because the combination of deflation and the binding ZLB of the nominal interest rate pushes up the real cost of borrowing. The rise in the real interest rate depresses house prices and credit further, triggering the collateral effect on the real economy. As shown by the red solid lines, in the occasionally binding economy, the interest rate falls to zero and stays there for a few periods. In the meantime, inflation falls sharply, pushing up the real interest rate. As a result, house prices, credit and output decrease by more than in the case where the ZLB is ignored.

With this example, we show that explicitly modelling the occasionally binding ZLB delivers an enhanced propagation mechanism via the collateral channel for both real and financial variables. The importance of the collateral channel is much greater when the steady-state interest rate is low. In the next section, we illustrate this point formally by simulating the model under different steady-state interest rates (high and low).

To check robustness with respect to other shock, we also consider a demand shock, defined as a direct additive shock in the Euler equation for savers, equation (2) .

Figure 2 shows that the dynamics of the model are consistent to the choice of the shock. The dynamics of the model following a negative demand shock are very similar to Figure 1. Without considering the possibility of a binding ZLB, the policy rate can be cut deep enough to support the real economy. As a result, the economy suffers a less severe recession. House prices and real credit go up because the interest

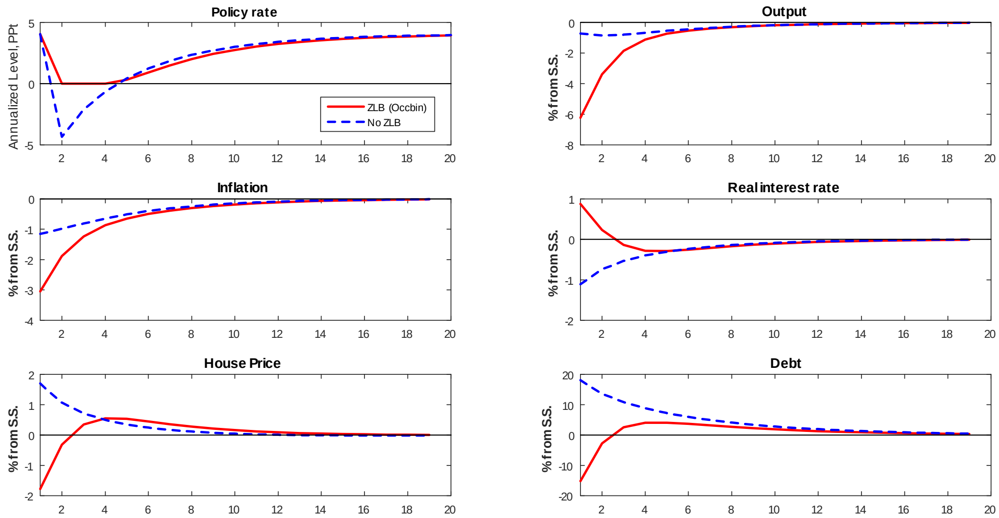

Figure 2: Impulse responses to a negative demand shock

rate goes down strongly. By contrast, when the ZLB is allowed to be binding, the policy rate gets stuck at zero, and the real interest rate rises. This puts more pressure on house prices and credit, additionally to the effect of the collateral channel. In this case, the economy suffers an even deeper recession. Overall, in both the productivity and the demand shock scenarios, the same mechanisms are at work. Based on this impulse response analysis, in the rest of the paper, we use productivity shocks in our simulations.

4 A Low Interest-Rate Environment

In recent years, and especially in the post-crisis period, long-term interest rates have trended downwards persistently. The decline in interest rates has implications both for financial stability and the implementation of monetary policy. In this section, we explore the consequences of a low steady-state interest rate, when an occasionally binding ZLB is explicitly considered. To address this question, we simulate our model with the same productivity shock process under two levels of steady-state interest rates (high and low). The LTV in these experiments is fixed at the steady-state level.

In the first setting, which we call "normal times," we set the annualized steady-state interest rate to be 4%, as in the standard real business cycle literature.[23] As an alternative, to reflect post-crisis times, we construct a scenario, which we call the "low interest-rate" environment, in which the interest

[23] Since the seminal paper by Kydland and Prescott (1982), the literature on DSGE models had traditionally considered a calibrated value of the discount factor of 0.99, to pick up the value of the interest rate in the steady state. It was considered that a reasonable value of the steady-state interest rate was 1% in a quarterly model (4% annualized).

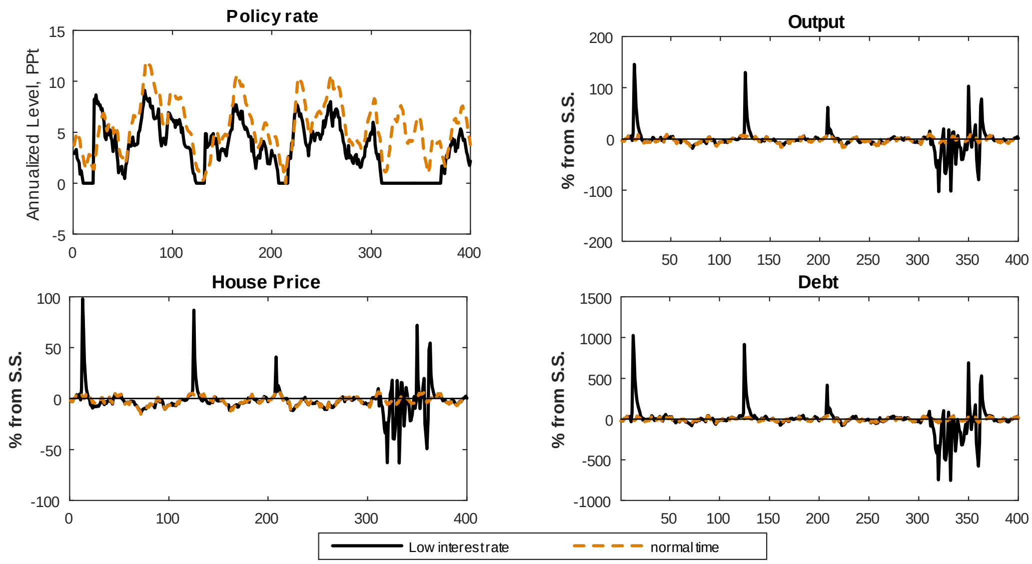

Figure 3: Simulated economy for productivity shocks. "Normal times" (4% SS interest rate) vs. "Low interest rate" (2% SS interest rate).

rate in the steady state is 2%. Both simulations are done using the "occbin" toolkit in order to allow for occasionally binding ZLB constraints, which is crucial for the propagation mechanism in the low interest-rate economy. Given the same size of shocks, we show that, in a low interest-rate environment, the interest rate is more likely to hit the ZLB and the economy is more volatile than the economy with a high interest rate.

Figure 3 shows the simulated economy under a productivity shock.[24] We consider the two scenarios; "normal times" and "low interest rate," and plot them together for comparison. The black solid line corresponds to the 2% steady-state interest rate, while the red dashed line indicates the 4% steady-state interest rate economy. We can observe that in "normal times" the economy never hits the ZLB, while in the "low interest-rate" setting, the constraint binds several times and for extensive periods. Furthermore, in "normal times" the economy is less volatile than in a "low interest-rate" environment. Having interest rates permanently low, as it is currently the case in many economies, has important implications for economic dynamics. First of all, when we are in a "low interest-rate" environment, even small business cycle shocks can make the interest rate hit the ZLB frequently. As a result, monetary policy becomes less effective, because it loses its ability to further stimulate the economy, when the interest rate reaches zero. In this case, it results in a more volatile macroeconomy, as we can see in the upper-right panel of figure 3.

[24] We consider a 0.03% shock to technology for simulations.

Furthermore, low interest rates create an environment of amplified financial cycles. This can be clearly seen in the lower panels of figure 3, in which we observe that the volatility of debt and house prices is much higher for the "low interest-rate" economy as compared to the "normal time" economy. This is a consequence of the financial accelerator mechanism built into the model, interacting with constrained monetary policy. A model with collateral constraints presents a powerful financial accelerator, which allows for feedback loops between asset prices and credit. High house price increases the collateral value and relaxes the borrowing constraint for borrowers. This, in turn, creates aggregate demand effects from both borrowers and savers through both collateral and wealth effects. Such an environment, combined with less effective monetary policy which is occasionally binding at the ZLB, can produce both substantial financial expansions and catastrophic meltdowns.

As the previous simulations show, economies with financial frictions and low interest rates are particularly vulnerable when the conventional monetary policy is subject to the ZLB constraint. This circumstance calls for the need of other policies to stabilize the economy. A natural candidate that could help monetary policy in this situation is macroprudential policy.[25] Thus, a conclusion that we could extract from the simulation exercise is that, in a low interest-rate world, the case for using macroprudential policies is even stronger: first, it can be used to deal with financial instability, which is an important problem in this case. Second, it can act as a complement to monetary policy when it hits the ZLB to stabilize the real economy. Indeed, we find that macroprudential policies are more needed in a "low interest-rate" economy than in "normal times."

For the rest of the paper, we use the "low interest-rate" environment as the benchmark calibration and study how active LTV rules can help monetary policy to stabilize the economy.

5 How Can Macroprudential Policy Help?

We have seen in the previous section that a "low interest-rate" environment calls for the use of macroprudential policy. In this paper, as in Angelini et al. (2014), we take the presence of the macroprudential regulator as given and study the effect of this policy on the economy and its interaction with monetary policy. As a first step, we demonstrate the effectiveness of macroprudential policy by studying the impulse responses with and without an active LTV policy rule responding only to credit. Then, we extend

[25] In the policy debate, other policy measures, such as unconventional monetary policy and fiscal policy, are also frequently mentioned. In this study, for the sake of scope and focus of the paper, we abstract the model from those alternative policies, even though they could also be interesting subjects in the low interest-rate environment.

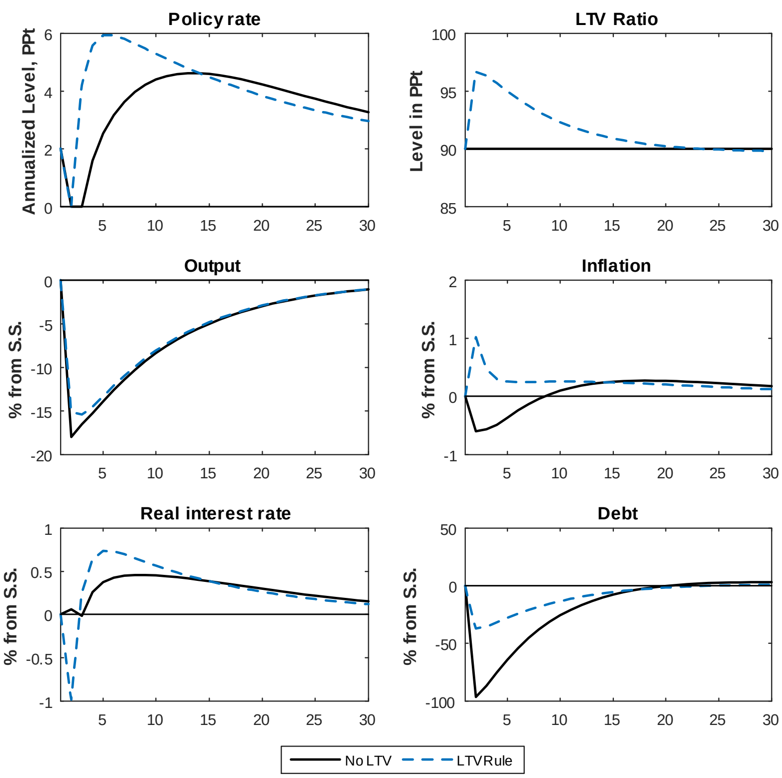

Figure 4: The effect of an active LTV rule with ZLB

the class of the LTV rules to more variables and identify the optimal policy coefficients that minimize a loss function for the macroprudential regulator.

5.1 An LTV Rule responding to Credit

To develop some intuition, we first compare the impulse responses of the model with and without an active LTV rule. We take the monetary policy rule as given. We first study a simple LTV rule that responds only to credit:

$$k_t = k_{SS} \left(\frac{b_t}{b}\right)^{-\phi_b},$$

where we tentatively set the reaction parameter ϕ_b to 0.2.

Figure 4 presents impulse responses to a negative productivity shock in the model with a 2% steady-state interest rate. We compare the benchmark scenario in which there is no active LTV policy versus the case where the LTV responds countercyclically to credit. In both cases, interest rates are restricted by the occasionally binding ZLB.

First of all, without an active LTV policy, the interest rate immediately drops to the ZLB and stays there for a few periods. The economy suffers a deep recession, where both output and inflation fall. As discussed above, the effect of a negative productivity shock is amplified by the collateral channel and the rising real interest rate due to the binding ZLB. By contrast, when a countercyclical LTV rule can be used to help the economy, it relaxes the LTV by about 10 percentage points. As a result, the provision of credit is supported by the LTV loosening. Interestingly, under the LTV policy, the ZLB binds just for one period. This comes from the general equilibrium effect on inflation. With the support of macroprudential policy, inflation increases instead of falling, which lifts the interest rate out of the ZLB more quickly. As a result, the real interest rate falls, providing the real economy with the kind of support that would have been achieved by monetary policy, should an occasionally binding ZLB not exist.

The main message that we obtain is that, when monetary policy is limited by an occasionally binding ZLB, a countercyclical LTV rule can help to stabilize the economy by both mitigating the collateral effect and lifting the interest rate out of the ZLB.[26] Next, we study the optimal setting of the LTV rule by minimizing a loss function of the macroprudential authority.

5.2 Volatilities

In this subsection, to check for the effectiveness of macroprudential policies under the two scenarios, we compute volatilities in the credit and output space, for the high and the low interest-rate environment. This experiment resembles the computation of output and inflation volatility frontiers for monetary policy.

Figure 5 displays a scatter plot of the volatility of output and credit, given different LTV rule parameter values.[27] The black crosses correspond to volatilities obtained in the high interest-rate environment, while the blue circles represent the low interest-rate simulations. The point corresponding to simulations without LTV policy is shown in red.. From the plot, two observations stand out. First, the volatility frontier in each steady-state interest-rate scenario presents a clear trade-off between output and credit volatility. This is similar to the traditional output-inflation volatility frontier for monetary policy under the presence of cost-push shocks. A stronger use of macroprudential policy would decrease the financial volatility, but increase the volatility of the real economy, and vice versa. Second, the low steady-state

[26] Wu and Zhang (2016) integrate shadow rates into Iacoviello model. They find that when the ZLB is reached, alternative policy measures can be used, so that shadow rates are not limited by ZLB.

[27] This figure is based on the rule only responding to credit.

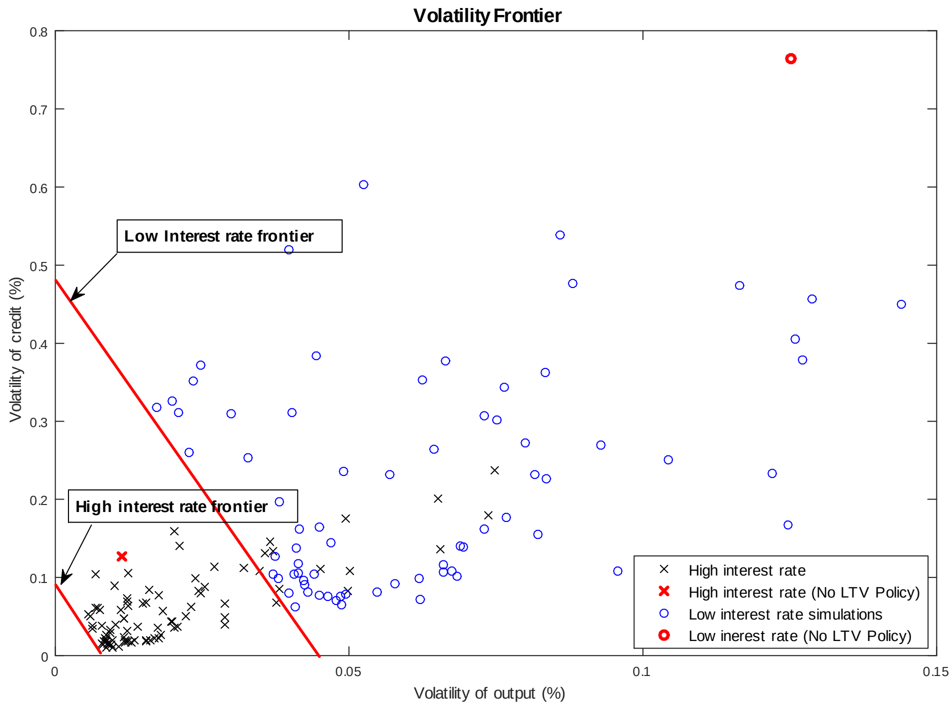

Figure 5: Volatility frontier

interest-rate environment worsens the policy trade-off, because of the occasionally binding ZLB. It is clear from the picture that, in the low interest rate environment, the economy becomes generally more volatile, and macroprudential policy can only achieve the same level of volatility of one variable at a greater expense in the volatility of the other one. Given that the volatilities without the LTV policy are not on the frontier (scatter point in red), macroprudential policy still contributes to greater macroeconomic stability under both interest-rate scenarios, especially for the lower interest-rate environment.

5.3 Optimal Simple Rules for LTV Policy

In the following section, we assess the optimal combination of parameters in the LTV rule, which minimizes a loss function of the macroprudential authority. In our search for optimized LTV policy parameters, we take monetary policy as given.[28] The optimal policy analysis, in models with financial frictions, deserves some discussion. In the standard new Keynesian model, the central bank aims at minimizing the variability of output and inflation to reduce the distortion introduced by nominal rigidities and monopolistic competition. However, in models with collateral constraints, welfare analysis and the design

[28] In this paper, we do not address the optimal coordination between macroprudential policy and monetary policy, as in Angelini et al (2014).

of optimal policies involves a number of issues not considered in standard sticky-price models. In models with constrained individuals, there are two types of distortions: price rigidities and credit frictions. This creates conflicts and trade-offs between borrowers and savers. Savers may prefer policies that reduce the price stickiness distortion. However, borrowers may prefer a scenario in which the pervasive effect of the collateral constraint is softened. Borrowers operate in a second-best situation. They consume according to the borrowing constraint as opposed to savers that follow an Euler equation for consumption. Borrowers cannot smooth consumption by themselves, but a more stable financial system would provide them a setting in which their consumption pattern is smoother. Therefore, in order to assess the optimality of policies, factors that help borrowers smooth their consumption should be included. Studies show that, in these kind of models, financial variables should be included in the loss function that the policy maker aims at minimizing.[29] The macroprudential regulator would be in charge of minimizing the distortion associated with financial frictions.[30]

As in Angelini et al. (2014), we assume that the macroprudential authority cares about the variability of credit, as a proxy for financial stability. However, we also consider that, as a side-effect, the macroprudential authority also takes into account the variability of the instrument. As in Angelini et al. (2014), the rationale for this specification of the loss function is a "revealed-preferences" approach: the objectives of macroprudential policy are to minimize systemic risk and to enhance the resilience of the financial system. However, as discussed in the introduction, financial stability is hard to measure in a DSGE model. In the model, we proxy financial stability by the variability of credit. Therefore, it makes sense, within the model, to define the objective of the macroprudential regulator as achieving a low credit variance (or credit-to-GDP, with which we experiment as a robustness check). We also assume that, as in monetary policy, the regulator cares about the variability of the instrument. We need to take into account that in the case of the LTV, changes in the instrument cannot be too abrupt because, unlike the nominal interest rate, adjusting LTV involves significant changes in bank's lending operation, and it would be difficult to implement sudden changes.

For the benchmark case, we consider a simple loss function in the following form:[31]

[29] Andres et al. (2013) find that optimal monetary policy may involve a trade-off between the stabilization of inflation, output gap, consumption gap and the distribution of the collateral asset between constrained and unconstrained consumers.

[30] The solution method that we use does not allow second order approximations and therefore welfare analysis is difficult to implement. Then, we use loss function minimization for our optimal policy analysis.

[31] Throughout OSR exercises, we choose policy preference parameter Λ, such that it makes the volatilities of variables in the loss function on a roughly same magnitude.

$$L = \sigma_b^2 + \Lambda \sigma_{LTV}^2, \tag{24}$$

where σ_b^2 and σ_{LTV}^2 are variances of credit and the LTV, respectively. Λ is the relative weight that the macroprudential authority assigns to the targets. We use $\Lambda = 5$ in our policy experiences.[32] We use the loss function of the macroprudential regulator to evaluate different combinations of the policy coefficients in the simple rule described by equation (23). Then, searching over a grid of parameters, the solution of this problem is represented by the following expression:

$$\left(\phi_b^*, \phi_y^*\right) = \arg\min L\left(\phi_b, \phi_y\right),$$

subject to the model equations.

As a first approach, we consider a rule in which the macroprudential regulator only responds to credit deviations from the steady state, that is, we impose $\phi_y = 0$. Then, we extend the rule to allow the macroprudential instrument to also respond to output. The motivation for the extension of the rule is that when the economy reaches the ZLB, monetary policy loses its effectiveness to stabilize the economy. Thus, we study whether macroprudential policies could be used as a complement to monetary policy for macroeconomic stabilization.

Table 2 displays the optimized parameters for the proposed macroprudential rules and the corresponding variances of key variables. We take the case when there are no macroprudential policies as a benchmark, and compare it with the model in which the active LTV rules is at work. We do these exercises for both the "normal times" (4% steady-state interest rate) and the "low interest-rate" environment (2% steady-state interest rate). Comparing these two environments helps us to make the point that the macroprudential policy implementation should be different in a world in which long-term interest rates are low and the economy hits the ZLB frequently.

[32] Given credit is much more volatile than the LTV, in order to obtain an internal solution of the minimisation, we set a large weight to the LTV. The value doesn't drive our results in Table 2. We show the robustness in an Appendix.

Table 2: Optimized Parameters						
	ϕ_b^*	ϕ_y^*	σ_b^2	σ_y^2	σ_{LTV}^2	Loss
High interest-rate environment						
Benchmark (No LTV)	-	-	12.69	1.13	-	12.7
LTV Rule with Credit	0.55	-	1.35	0.81	0.41	3.39
LTV Rule with Credit and Output	0.55	0	1.35	0.81	0.41	3.39
Low interest-rate environment						
Benchmark (No LTV)	-	-	76.45	12.52	-	76.5
LTV Rule with Credit	0.65	-	8.36	4.01	3.57	26.2
LTV Rule with Credit and Output	0.55	0.5	3.15	3.91	3.58	21.1

In this table, we report the optimized values of the LTV rule coefficients, and the volatilities associated to the optimized rules, along with the value of the loss function. All volatilities and values of the loss function are reported in the unit of percentage points. For comparison, we first report results that are generated from the economy without LTV rules, which we take as benchmark. Then, we compare them with values that are produced by two rules responding to different variables. In the upper panel of the table, the economy in the high interest-rate environment is described, while in the lower panel, results are generated in the low interest-rate scenario.

First of all, driven by same productivity shocks, the economy in the high interest-rate environment is significantly less volatile than that in the low interest-rate environment. As we discussed before, in the low interest-rate world, the ZLB is binding more frequently. Lacking of an effective stabilization policy, the economy becomes more volatile in both the real and financial sectors. This finding motivates the need for macroprudential policies to enhance economic stability, especially in the low interest-rate environment.

When we introduce an active LTV rule responding to credit only, we see that financial stability is improved dramatically without compromising macroeconomic stability. In the high interest-rate state, the macroprudential policy achieves a much lower variability of credit and it also helps with macroeconomic stability. Similarly, in the low interest-rate world, the optimized LTV rule also dampens mostly the volatility of credit, and to a less extent the output volatility. The drawback from this rule is that it has to respond to credit more aggressively than in the high interest-rate environment, and the volatility of the LTV becomes alleviated as a result.

In the next experiment, we extend the LTV rule to a version that responds to both credit and output. Results show that, in the high interest-rate world, since monetary policy is adequate to do its job, there is no need for the LTV rule to respond to output directly. The optimized rule is the same as the one responding only to the credit. In this case, the so-called "Tinbergen principle" applies. Macroeconomic stability would be effectively managed by the monetary authority, while the macroprudential authority only needs to worry about financial volatility. The two policies work independently with different instruments, achieving separate objectives. When the economy is closer to the ZLB, however, the optimized rule also responds to output, because monetary policy is often constrained by the binding ZLB. As discussed above, the binding ZLB becomes a more important distortion in the economy than the financial accelerator. In this case,the macroprudential policy has to lend helping hands to monetary policy in terms of macroeconomic stabilization. As a result, the whole economy further improves in terms of volatility in both the macroeconomic and the financial sector.

In summary, in a low interest-rate environment, there are two reasons that strengthen the role of macroprudential policies. First, the low interest-rate world is more prone to financial volatility, and that calls for the use of macroprudential policies to bring a more stable financial system. Second, monetary policy not only loses its effectiveness in bringing macroeconomic stability, but also becomes an additional source of destabilization, when it is constrained by the ZLB. In this case, macroprudential policies can act as a complement to monetary policy by not only responding to credit but also to output.

5.3.1 Robustness

For the sake of completeness, we check the robustness of our key results. Throughout the paper, all our results are driven based on a policy loss function that only includes the volatilities of credit and the LTV ratio. The key findings are as follows: first, in a low interest-rate environment, the binding ZLB occurs frequently, leading to greater macroeconomic and financial volatilities. Second, in a low interest-rate environment, macroprudential policies need to be more aggressive in responding to credit. Third, in terms of minimizing the macroprudential authority's loss function, it is also desirable to let the LTV respond to output directly. In the next subsections, we will check the robustness of those results in alternative settings of the macroprudential loss function and under different macroprudential and monetary policy rules.

LTV with Credit-to-GDP As a robustness, we also consider a rule responding to the credit-to-GDP ratio, presented in Table 3. Intuitively, an LTV rule responding to credit-to-GDP amounts to a restricted version of the rule reacting to credit and output separately and freely. In particular, we restrict the LTV rule to respond to credit and output equally, but with opposite signs. Interestingly, in the high interest-rate environment, the LTV rule with the credit-to-GDP ratio outperforms the rule with credit and output. This is in part due to the fact that, in the latter case, we restrict the policy parameters to be positive. In the low interest-rate world, however, the LTV rule with credit-to-GDP is more effective in stabilizing output than credit volatility, but overall it performs worse than the LTV rule responding to credit and output freely.

Table 3: Optimized Parameters (Credit-to-GDP)

	ϕ_b^*	ϕ_y^*	σ_b^2	σ_y^2	σ_{LTV}^2	Loss
High interest-rate environment						
Benchmark (No LTV)	-	-	12.69	1.13	-	12.7
LTV Rule with Credit-to-GDP	0.85	-0.85	1.66	0.64	0.21	2.73
Low interest rate environment						
Benchmark (No LTV)	-	-	76.45	12.52	-	76.5
LTV Rule with Credit-to-GDP	0.5	-0.5	14.41	2.92	1.45	21.6

Alternative loss functions In Table 4, we report our results based on alternative loss functions, which take the volatility of output, the credit-to-GDP ratio, and the change in the LTV ratio into account. In particular, we report the optimal simple rules derived under three variations of the policy loss function. First, we consider a loss function based on the volatilities of credit and output. This version of the loss function reflects a more balanced objective of the macroprudential authority towards balancing the volatility of the financial and the real sector. The second loss function takes the credit-to-GDP ratio into account in addition to the volatility of credit. This is a more financial-stability focused policy objective. The third variation reflects the practical concern of the macroprudential regulator on the stability of the policy instrument. This version takes the volatility of the change in the LTV into account. We derive the optimal simple rules and associated values of the loss function for each case. We also consider both the high and the low interest-rate environment.

Table 4: Alternative Loss Functions	$\sigma_b^2 + \Lambda\sigma_y^2$			$\sigma_b^2 + \Lambda\sigma_{b/y}^2$			$\sigma_b^2 + \Lambda\sigma_{\Delta LTV}^2$		
	ϕ_b^*	ϕ_y^*	Loss	ϕ_b^*	ϕ_y^*	Loss	ϕ_b^*	ϕ_y^*	Loss
High interest-rate environment									
No LTV Rule	-	-	18.4	-	-	50.5	-	-	12.7
LTV Rule with Credit	0.55	-	5.4	0.55	-	2.4	0.55	-	2.1
LTV Rule with Credit and Output	0.55	0	5.4	0.75	0.1	2.3	0.55	0	2.1
Low interest rate environment									
No LTV Rule	-	-	155.2	-	-	327.9	-	-	85.2
LTV Rule with Credit	0.65	-	28.4	0.85	-	11.1	0.65	-	16.1
LTV Rule with Credit and Output	0.55	0.9	22.6	0.65	0.3	8.1	0.55	0.5	11.3

Overall, we find that our key results hold in all three variations of the loss function. First of all, in a low interest-rate environment, macroprudential policies need to be more aggressive than in the high interest-rate world. This is especially true for the second case, where the loss function takes both the volatility of the credit-to-GDP ratio and the volatility of credit into account. This loss function makes the volatility of credit very important for the macroprudential authority. As a result, the LTV policy rule responds very strongly to credit in the low interest-rate environment, compared to the high interest-rate world. Next, our conclusion about an independent role of output in the LTV policy function in the low interest-rate environment is also supported by all the three loss functions. We can see that, in the high interest-rate scenario, the LTV rule responding to both credit and output does not make a huge difference, as compared to the rule that reacts only to credit. It changes, however, when the steady-state interest rate decreases. When the loss function puts more weight on output volatility, the optimized LTV rule also respond strongly to output, but less to credit. Even when the loss function puts strong emphasis on financial volatility, the optimal rule still reacts to output. Overall, we find that all the three key results that we draw from the previous section pass robustness tests with alternative loss functions.

Other robustness tests This subsection tests the robustness of our key results under two alternative policy regimes.[33] First, we consider LTV rules with smoothing. This is to capture the idea that macroprudential tools are adjusted very gradually in practice. This result is shown in the mid columns of Table 5. Overall, our key results are unchanged. In a low interest-rate environment, macroprudential policies need to be more aggressive in responding to credit than in the high interest rate environment. And

[33] We still use the loss function in the benchmark case to evaluate those scenarios.

adding output to the rule does not change the optimal simple rule. In addition, in the low interest-rate world, it is desirable to let the LTV respond to output directly. Note that, in this case, the LTV rule with smoothing responds to credit stronger, because the lagged LTV ratio mutes the response to some degree.

Table 5: Other robustness checks	Benchmark			LTV rule with lagged LTV (0.8)			Taylor rule with weaker response to inflation		
	ϕ_b^*	ϕ_y^*	Loss	ϕ_b^*	ϕ_y^*	Loss	ϕ_b^*	ϕ_y^*	Loss
High interest-rate environment									
No LTV Rule	-	-	12.7	-	-	12.7	-	-	104.5
LTV with Credit	0.55	-	3.39	0.35	-	4.99	0.5	-	15.3
LTV with Credit and output	0.55	0	3.39	0.35	0	4.99	0	0.7	13.9
Low interest-rate environment									
No LTV Rule	-	-	76.5	-	-	76.5	-	-	191.2
LTV with Credit	0.65	-	26.2	0.85	-	16.9	0.25	-	33.4
LTV with Credit and Output	0.55	0.5	21.1	0.9	0.3	13.9	0.25	0.1	29.4

Next, we study the optimal simple rules under a monetary policy Taylor rule that responds weakly to inflation. Blanchard et al. (2010) raise the point that, given that large adverse shocks can and do happen, policymakers might should aim for a higher target inflation rate in order to increase the room for monetary policy to react to such shocks. In our model, it is not easy to change the target of inflation, but we use a weaker response in the monetary policy Taylor rule to represent the situation where the central bank weakens the inflation targeting in the low interest-rate environment. Results are shown in the far right columns in Table 5. Interestingly, in normal times, if the central bank loses control for inflation, it will lead to more volatile economic cycles. We find that, even in this situation, macroprudential policy becomes a substitute for monetary policy. The optimized LTV rule responds strongly to output instead of credit. In the low interest-rate environment, we do find the trade-off between the costs of high inflation and the benefits, in terms of avoiding the zero interest-rate bound. In this case, the optimized LTV rule reacts in a weaker manner to credit and output, reflecting that when the interest rate is less frequently restricted by the ZLB, there is less need for macroprudential policy to stabilize the real economy.

6 Concluding Remarks

In this paper, we build a DSGE model in which interest rates are permanently low and monetary policy is constrained by the ZLB. In this context, we study the implementation of macroprudential policies, represented by an LTV rule. In particular we answer the following research questions: Are macroprudential policies more relevant in a low interest-rate environment? Can macroprudential policies complement monetary policy when the latter binds at the ZLB occasionally?

In order to address these issues we first simulate the economy both for "normal times" and for a "low interest-rate" environment. We find that when interest rates are persistently low, the ZLB occurs frequently, leading to greater macroeconomic volatility and financial instability. In this context, the economy calls for the use of active macroprudential policies to contain financial stability and to act as a complement to the less effective monetary policy. Then, we study what would be the best way to implement a countercyclical LTV rule, which minimizes the loss function of the macroprudential regulator. We find that in a low interest-rate environment, macroprudential policies need to be more aggressive in responding to credit. Furthermore, when the LTV is allowed to respond to output, it will respond to output more strongly than to credit, because a binding ZLB not only makes monetary policy less effective in economic stabilization, but also presents an additional amplification mechanism on top of the collateral channel. Therefore, in this environment, macroprudential policies can act as a complement to monetary policy.

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