Macroprudential Policies in a Low Interest-Rate Environment*

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Abstract

In this paper, we analyze the use of macroprudential policies in a low interest-rate environment, where an occasionally-binding zero lower bound (ZLB) reenforces financial frictions to give rise to greater economic instability. We calibrate a DSGE model with collateral constraints and a monetary policy rule that is subject to the ZLB for a low interest-rate world. We find that the occasionally binding ZLB creates additional scope for macroprudential intervention. Under perfect coordination between monetary and macroprudential policies, the optimal policy mix calls for independence between the two policies when interest rates are high. However, in the low interest-rate environment, macroprudential policy is more intertwined with monetary policy.

Keywords: Macroprudential, monetary policy, zero lower bound, collateral constraint, financial stability

JEL Classification: E32, E44, E58

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"*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

The post-Global Financial Crisis (GFC) world poses 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). Plausible explanations for these low interest rates include demographic developments and the integration of Chinese savings into global financial markets (See Bean et al, 2015). These low rates are challenging for policymakers 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).

Motivated by the double challenges imposed by the low interest-rate world, in this paper, we study the optimal conduct of monetary and macroprudential policies in a dynamic stochastic general equilibrium (DSGE) model. We argue that the case for using macroprudential policies becomes even stronger in a low interest rate environment.[1] In economic theory, there are two distinct inefficiencies that create scope for macroprudential policy intervention. Firstly, a large body of literature has leveraged pecuniary externalities to justify macroprudential interventions.[2] In models with collateral constraints, for example, negative shocks to house prices tighten the borrowing capacity of borrowers, making house prices fall further. This negative feedback mechanism gives rise to a powerful financial accelerator, amplifying financial shocks. Secondly, aggregate demand externalities, as emphasized in Farhi and Werning (2016), provide a distinct rationale for macroprudential policies. In the context of models with a zero lower bound (ZLB) for nominal interest rates, borrowers fail to internalize the adverse macroeconomic consequences of their over-borrowing to aggregate demand. These types of aggregate demand externalities also create

[1] In policy debates, the use of macroprudential policies to act as a macroeconomic stabilizer is controversial, since these policies are designed to manage financial cycles at its origin. Instead, the use of unconventional monetary policy and/or fiscal policy have been widely discussed in the policy circle. Nevertheless, we view that the optimal implementation of stability policy is still an open question, especially in the rapidly changing economic environment.

[2] See e.g. Caballero and Krishnamurthy (2001); Lorenzoni (2008); Bianchi and Mendoza (2010); Jeane and Korinek (2010, 2013); Woodford (2011); Davilla and Korinek (2017), among others.

the need for macroprodential policy intervention.

In this paper, we build a DSGE model with collateral constraints on borrowers and an occasionally binding ZLB for the interest rate. Our model sets up a stage for both types of externalities to interact and allows us to study the optimal implementation of simple policy rules for both monetary and macroprudential policy. The novel aspect of our paper is that we examine the use of macroprudential policies in a low interest-rate environment, in which an occasionally-binding ZLB gives rise to aggregate demand externalities. We analyze how this distortion interacts with pecuniary externalities from collateral constraints. To study the low interest-rate environment, we set the steady-state interest rate of the model equal to 2%.[3] We then solve the model with the "Occbin" toolkit proposed by Guerrieri and Iacoviello (2015). Using this approach, 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 greater financial and macroeconomic stability and enhance social welfare in the low interest-rate environment?

To address the first question, we simulate the model under two steady-state interest rates. 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 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 demand shocks drive down house prices and tighten the collateral constraint for borrowers. This negatively affects credit. This feedback loop between house prices and credit gives rise to a powerful financial accelerator, emphasized in Iacoviello (2005) and Iacoviello and Neri (2010). 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 a period of time reinforces the effects of the negative demand shock. Inflation falls and pushes up the real cost of borrowing. This, in turn, depresses house prices and credit even further than under the collateral channel (See Neri and Notarpietro, 2014). The interaction of these two frictions in this model provides a rationale for macroprudential policy intervention.

Next, we study the case of active macroprudential policy rules as a supplement to monetary policy.

[3] In this paper, we choose to motivate the change in real interest rate at the steady state as a result of unmodeled slow-moving long-run forces, such as population aging (Eggertsson, Lancastre and Summers, 2018). We view those long-run forces as the primary drivers that change the economic environment in which macro policies are operating. 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.

In particular, we compute optimal simple rules for the LTV by minimizing a welfare-based loss function for the macroprudential regulator. We consider an LTV rule that responds to credit and output. We find that, in the high interest-rate world, allowing macroprudential policy to respond to output does not significantly improve welfare. When the steady-state interest rate is closer to the ZLB, however, the occasionally binding ZLB gives rise to aggregate demand externalities that create additional scope for macroprudential intervention. Our results 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. In this case, the macroprudential policy helps monetary policy by managing the cost of borrowing when monetary policy is binding at the ZLB.

Lastly, we also use the model to study policy coordination, where both policies are optimized jointly. We find that, when the interest rate is high and the two policies can perfectly coordinate, the optimal policy prescription behaves as if policies were independent. Price stability is delegated to monetary policy, while financial stability can be effectively managed by the macroprudential authority. The two policies work more or less independently using different instruments to target different objectives. This is, however, no longer the case when the interest rate is low and/or when the two policies cease to coordinate. In this more complex policy environment, policy coordination brings more welfare gains.

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 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 policy. 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 should 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 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. Wu and Zhang (2016) integrate shadow rates into the Iacoviello model. They find that when the ZLB is reached, alternative policy measures can be used, so that shadow rates are not limited by the ZLB. 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 show how macroprudential policy can simultaneously contribute to financial and macroeconomic stabilities.

Most closely related to our paper is the seminal work by Farhi and Werning (2016), who study the interaction between the ZLB and using macroprudential policy as a stabilization tool. They consider a simple two-period model to show that, when the ZLB is binding, the interest rate fails to stimulate the economy to the optimal allocation. In this situation, macroprudential policy in the form of a tax on borrowing can induce the implicit interest rate to the level that provides economic stability. Our paper complements their study in the sense that we investigate the interaction between monetary policy that is subject to the ZLB and a more plausible macroprudential policy setting with the LTV ratio, in a DSGE model. Our model is arguably more realistic than theirs and includes many features that are relevant for policy. Our quantitative results confirm their finding that, under certain circumstances, the optimal policy mix is featured as independent targeting rules. We extend their analysis to the non-coordination case and the low interest-rate environment, where the two policies appeared to be more intertwined.

The rest of the paper continues as follows. Section 2 describes the model environment and the calibration. Section 3 simulates and studies the dynamics of the model allowing for a ZLB constraint in the low interest-rate environment. In Section 4, we conduct an optimal policy analysis. Section 5 shows the robustness of our main results. 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:

$$\max_{C_{s,t},H_{s,t},N_{s,t}} E_0 \sum_{t=0}^{\infty} \beta_s^t \left[\log C_{s,t} + j \log H_{s,t} - \frac{(N_{s,t})^{1+\eta}}{1+\eta} \right],$$

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. $1/\eta$ is the Frisch elasticity of labor supply, $\eta > 0$. j represents the weight of housing in the utility function.

Savers maximize their utility subject to the following budget constraint:

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

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 constant τ^h is a tax/subsidy on savers' housing that we assume is eliminating the distortion at the steady state in the housing market. The first-order conditions for this optimization problem are as follows:

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

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

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

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:

$$\max_{C_{b,t},H_{b,t},N_{b,t}} E_0 \sum_{t=0}^{\infty} \beta_b^t \left[\log C_{b,t} + j \log H_{b,t} - \frac{(N_{b,t})^{1+\eta}}{1+\eta} \right],$$

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:

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

$$R_t b_t \leq k_t E_t \left[q_{t+1} \pi_{t+1} H_{b,t} \right], \tag{6}$$

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.[4] The borrowing constraint limits borrowing to the present discounted value of their housing holdings.[5] The first-order conditions are as follows:

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

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

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

where λ_t denotes the multiplier on the borrowing constraint.[6] These first-order conditions can be

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

[5] As discussed in Iacoviello (2005), when the model is parameterized with an amount of uncertainty that is sufficient to replicate the volatility which is observed in macroeconomic time series, such uncertainty does not generate a substantial amount of buffer-stock behavior in the model, provided that the borrowing constraint is tight enough, that relative risk aversion is not too large, and that the gap between the interest rate and the discount rate is not too small. The presence of uncertainty implies that in a model of the kind presented below there is precautionary saving. However, we assume that the precautionary forces are weak enough so that borrowers always choose the maximum amount of borrowing possible and so that the model can be analysed as if the constraint was an equality constraint.

[6] 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.

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

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

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

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

The price index is then given by:

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

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:

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

where $\alpha \in [0, 1]$ measures the relative size of savers and borrowers in terms of labor.[7] 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.[8]

A_t represents technology and it follows the following autoregressive process:

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

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

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

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:

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

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

where X_t is the markup, or the inverse of marginal cost.[9]

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

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

where $\varepsilon/\left(\varepsilon-1\right)$ is the steady-state markup and τ is a tax/subsidy equal to ε^{-1}, which corrects the distortion associated with monopolistic competition at the steady state.

The aggregate price level is given by:

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

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 ($\psi \equiv \left(1-\theta\right)\left(1-\beta\theta\right)/\theta$). $u_{\pi t}$ is a normally distributed cost-push shock. In the canonical new Keynesian model, cost-push shocks (also called inflation shocks) and typically introduced. The introduction of these exogenous shocks creates a trade-off between inflation and output stabilization. Variables with a hat denote percent deviations from the steady state.

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

2.4 Equilibrium

The market-clearing condition for consumption goods is as follows:

$$Y_t = \omega C_{s,t} + (1-\omega) C_{b,t}, \tag{19}$$

where ω is the population share of savers.

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

$$\bar{H} = \omega H_{s,t} + (1-\omega) H_{b,t}, \tag{20}$$

where $\bar{H}$ is housing supply, which is assumed to be fixed.

2.5 Monetary Policy

Monetary policy is set as follows:

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

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

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, 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 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 as the growth rate 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:[10]

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

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.[11]

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 are 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 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 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). Note that this type of financial constraint does not arise endogenously within the model but comes exogenously from regulation. This is the difference between market and government-imposed constraints. We choose the latter approach. However, the rationale for macroprudential policy interventions can be justified in terms of the model. On the one hand, the binding collateral constraint introduces a pecuniary externality in the sense that borrowers always choose

[10] We consider that financial regulators cyclically vary the financial constraint but not permanently set the constraint to a permanently looser level. The rationale behind could be that moral hazard problems à-la Kiyotaki-Moore build up over time and do not materialize instantaneously when the constraint is relaxed for a short amount of time.

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

the maximum amount allowed. This creates a distortion that can be corrected by a mechanism such as a macroprudential policy that softens credit cycles. On the other hand, the ZLB constraint creates a demand externality since at those instances, monetary policy cannot stabilize the macroeconomy. This implies an extra motive for macroprudential policy to help monetary policy smooth the macroeconomic cycle. This extra externality explains the presence of output in the macroprudential rule.

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 rate 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.[12] 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 $\eta = 1$, implying a value of the labor-supply elasticity of 1.[13] For the parameter controlling leverage, we set k_{SS} to 0.90, in line with the US data (See Iacoviello, 2005).[14] 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 $\phi_\pi^R = 1.5$ and $\phi_y^R = 0.5$, consistent with the original estimates by Taylor.[15] For ρ we use 0.8, which represents an empirically plausible value.

We simulate the response of the model to a demand and technology shock. For the calibration of the shocks, we use the estimates of Smets and Wouters (2007), for the US economy, as an empirically plausible size and persistence of the shocks. We assume that technology, A_t, follows an autoregressive process with 0.95 persistence and a normally distributed shock of 0.45% size.[16] The persistence of the demand shock is 0.22, with a 0.23% size. Table 1 presents a summary of the parameter values used:

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

[13] 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 these estimates could have a downward bias of 50%.

[14] 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.

[15] 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.

[16] The high persistence of the shocks is also 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
$1/\eta$	1	Frisch elasticity of labor supply
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	0.8	Smoothing parameter in Taylor rule
ϕ_π^R	1.5	Inflation parameter in Taylor rule
ϕ_y^R	0.5	Output parameter in Taylor rule

2.8 Quantitative Properties of the Model

In this subsection, we compare the quantitative properties of the model with the US data under the chosen calibration.

Table 2: Quantitative Properties						
	Y	C	q	b	π	R
US *Data (1950 Q1 - 2007 Q4)*						
Variance (%)	2.49	1.65	5.62	6.56	0.98	2.10
Relative variance to output	1	0.66	2.26	2.63	0.39	0.84
Auto-correlation (1)	0.82	0.79	0.85	0.93	0.81	0.82
Cross-Correlation to output	1	0.78	0.35	0.60	0.15	0.34
Benchmark model						
Variance (%)	2.31	2.31	1.63	8.75	0.40	0.31
Relative variance to output	–	1	0.70	3.82	0.18	0.14
Auto-correlation (1)	0.77	0.77	0.87	0.45	0.97	0.16
Cross-Correlation to output	–	1	0.89	0.69	0.14	0.13

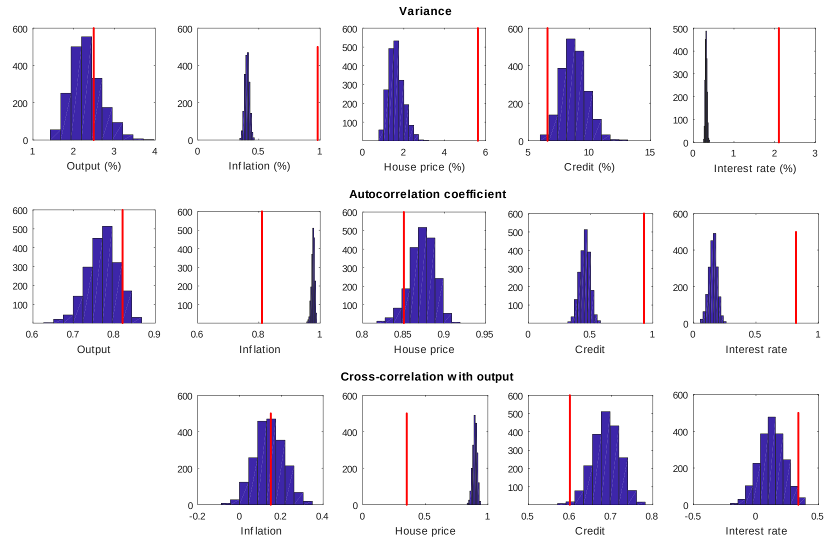

Figure 1: Comparing model simulated moments (2000 runs) with data moments

In Table 2, we compare the actual US data with the simulated data from our benchmark calibration, discussed in the previous section.[17] To simulate the model, we draw different sequences of shocks from the distribution displayed above and solve the model 2000 times. The mean of the simulated moments is reported in this table, while, in figure 1, we also plot the histogram of the simulated model moments (blue bars), compared to the sample moments from the real data (red vertical line).

Data moments represent the typical patterns of business cycles, well documented in the literature. In particular, consumption is less volatile than output, while house prices and credit are much more volatile. All time series are highly persistent. The model, with only demand and technology shocks, replicates the moments of the actual data in several important aspects. First, our model captures the volatility and persistence of output very well. In addition, the model with collateral constraints also matches the volatility of credit and the persistence of house prices. Nonetheless, our model is a very parsimonious representation of the real economy and therefore it misses some features from the US data. For example, consumption in the model is equal to output, because there is no capital or housing investment. In addition, credit in the model is one-period debt, while, in the real world, especially in the US, mortgage debt is long-term loans. As a result, the model simulation cannot match the persistence of household credit in the data. Overall, despite its simplicity, the model does catch some important features of the

[17] The US time series data are taken quarterly from 1950 Q1 to 2007 Q4. We choose the periods, during which the ZLB was not binding. Both inflation and the nominal interest rate are expressed in annualized percentage terms. For the other real variables, we first take the logarithm and then we extract the business cyclical component by using the Hodrick-Prescott (HP) filter, with a smoothing parameter of 1600. Therefore, the units are expressed as percentage deviations from the HP trends of the respective time series.

data before the ZLB periods. Next, we use the model to simulate the counterfactual economy under the low steady-state interest rates.

3 The Low Interest-Rate Environment

The GFC has caused us to re-think about existing models and re-shape them in order to appropriately reflect the changes that are occurring in the economy. 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. Large enough shocks may bring the policy rate to negative levels, violating the ZLB. 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,[18] 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 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. 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 the model, we compute impulse responses to a negative demand shock[19], using both the standard solution method and the "occbin" toolkit. 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.

Figure 2 shows the dynamics of the model following this negative demand shock. In this figure, we

[18] 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.

[19] Similar plot for productivity shocks is available upon request from authors.

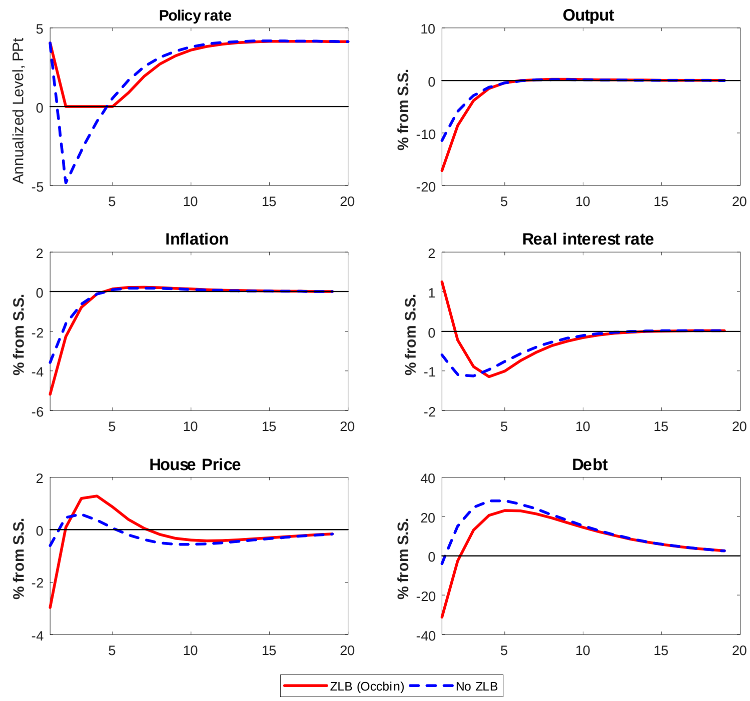

Figure 2: Impulse responses to a negative demand shock

consider 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). The upper- left panel displays the annualized level of the policy rate. It starts 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 some 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 demand 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, as pointed out in Farhi and Werning (2016), when the interest rate is restricted by the occasionally binding ZLB, the economy suffers an even stronger recession because of aggregate demand externalities. 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 decreases more strongly, 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.

The interaction between collateral constraints and an occasionally binding ZLB provides a rationale for macroprudential policy intervention and the need is even greater when the steady-state interest rate is low. In this next subsection, we formally make this point by simulating the model under different steady-state interest rates (high and low).

3.1 Simulations

In this subsection, we simulate our model with the productivity and demand shocks under two levels of steady-state interest rates. In the first setting, we set the annualized steady-state interest rate to be 4%, as in the standard real business cycle literature.[20] As an alternative, to reflect post-crisis times, we construct a scenario, which we call the "low interest-rate" environment, in which the interest rate in the steady state is 2%. 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.

In figure 3, the black solid line corresponds to the low 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 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.

[20] 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).

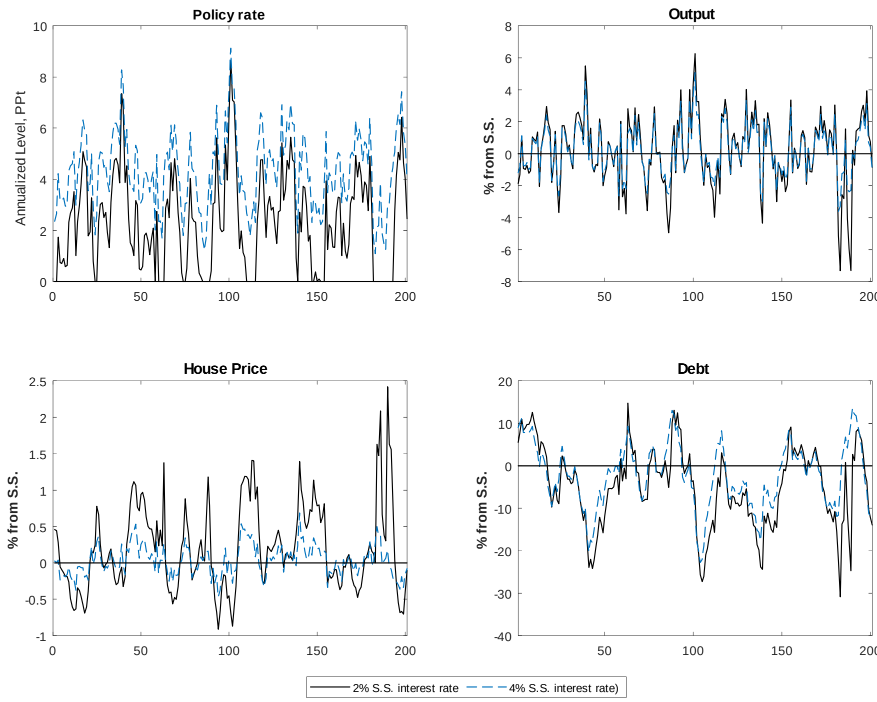

Figure 3: Simulated economy for productivity and demand shocks. "Normal times" vs. "Low interest rate"

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 prices increase 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.

Table 3: Low Interest rate Economies

Models	ZLB		Output		Credit	
	Prob.(%)	*Duration* (*Qtr*)	*Volatility* (%)	*Autocorr.*	*Volatility* (%)	*Autocorr.*
$i_{SS} = 4\%$	0	0	2.31	0.77	8.75	0.45
$i_{SS} = 2\%$	0.02	1.03	2.34	0.76	16.38	0.40
$i_{SS} = 1.2\%$	1.58	1.11	2.35	0.74	24.36	0.37
$i_{SS} = 0.4\%$	26.1	1.87	4.18	0.71	183.68	0.32

To complement the analysis, in Table 3, we report the statistics of the simulated economy under different levels of steady-state interest rates, compared to the benchmark case. We simulate 1000 periods each time to derive the statistics, and repeat this exercise for 2000 simulations. In the table, we report the average values over all simulations. When the steady-state interest rate is equal to 4%, small business cycle shocks will not trigger any binding ZLB incidences. When the interest rate decreases toward zero, however, the probability of a binding ZLB becomes larger and the average duration of each binding case also becomes longer. As a result, both business cycles and financial cycles become more volatile, but slightly less persistent.

4 Can Macroprudential Policy Help?

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. In this paper, we explore the role of macroprudential policy as a supplementary stability policy.[21] Macroprudential policy is a natural candidate for alternative stabilization policy in low-interest rate environment, as, firstly, it is a targeted tool for addressing issues of financial instability, and, secondly, macroprudential policy affects the cost of borrowing, so it can be used as a complement (or substitute) to monetary policy when it is restricted by the ZLB to stabilize the real economy. 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.

For the following analysis, we simplify the macroprudential policy setting to a set of simple LTV

[21] 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.

rules. The most basic LTV rule for macroprudential policy can be specified as the LTV responding negatively to the deviation of credit from its steady state:[22]

$$k_t = k_{SS} \left(\frac{b_t}{b} \right)^{-\phi_b}, \tag{24}$$

where ϕ_b is the policy parameter set by the macroprudential authority. Similarly, LTV rules can be extended to respond to other variables, such as the credit-to-GDP ratio, credit growth or output. We perform several robustness checks on this respect.

To get some intuition, if we substitute equation (24) into (6), it yields

$$b_t = \frac{k_{SS}}{b^{-\phi_b}} E_t \left[\frac{q_{t+1} \pi_{t+1} H_{b,t}}{R_t} \right]^{\frac{1}{1+\phi_b}}. \tag{25}$$

From equation (25), we see that, when the LTV rule parameter (ϕ_b) is set to be high, credit is less affected by shocks to asset prices or interest rates.

4.1 Welfare-based Loss Function

In this section, we assess the optimal combination of the parameters in the LTV rules, which minimizes a welfare-based loss function. 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 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 availability subject to collateral constraints. The latter creates conflicts and trade-offs between borrowers and savers. Savers may prefer policies that reduce the price stickiness distortion, while borrowers who operate in a second-best situation may prefer a scenario in which the pervasive effect of the collateral constraint is softened. A more stable financial system would provide them a setting in which their consumption pattern is smoother because their consumption is directly linked to credit through the collateral constraint. As a result, to evaluate different policy rules, we need to derive a welfare-based policy loss function that takes into account this heterogeneity between savers and borrowers.

To obtain the welfare-based loss function, we derive the second-order approximation of the social

[22] In the robustness section, we check the sensitivity of our main results using other financial indicators for the LTV rule.

welfare function as follows:[23]

$$W_0 \simeq -\frac{1}{2} E_0 \sum_{t=0}^{\infty} \beta_s^t \left[\widetilde{y}_t^2 + \lambda_\pi \pi_t^2 + \lambda_c \widetilde{c}_t^2 + \lambda_h \widetilde{h}_t^2 \right], \tag{26}$$

where $\widetilde{y}_t = y_t - y_t^n$, $\widetilde{c}_t = c_{b,t} - c_{s,t}$ and $\widetilde{h}_t = h_{b,t} - h_{s,t}$, are the output gap, consumption gap and housing gap between borrowers and savers, respectively. π_t is the inflation deviation from the steady-state inflation. The relative policy weights are $\lambda_\pi = \frac{\theta\varepsilon}{(1-\theta)(1-\beta\theta)(1+\eta)}$; $\lambda_c = \frac{\alpha(1-\alpha)(2+\eta)}{(1+\eta)^2}$; $\lambda_h = \frac{\alpha(1-\alpha)}{1+\eta}$.

The welfare-based loss function (26) has a clear economic interpretation in each of its components in terms of wedges to the efficient steady state. The first two include the efficient output gap and inflation. These are the standard variables that appear in the welfare-based loss function of a large class of new Keynesian models. Their presence in the loss function reflects the two distortions associated with price rigidities. First, monopolistic competition introduce a "labor wedge" into the model, causing the level of output to deviate from its efficient level. Second, the staggered price setting implies an inefficient dispersion in prices, which is proportional to the rate of inflation. The second set of terms in (26) comprises the consumption and the housing gap. They arise from the heterogeneity between the two types of agents in terms of their access to finance. In fact, one group of households are credit constrained while the other is not. Savers could insure each other against the variation in their housing and consumption bundles, while borrowers in the model are limited by the amount of housing collateral. The gaps of consumption and housing between optimizing savers and constrained borrowers give policymakers a measure of the welfare loss associated with the financial friction.

We make a further assumption that the policymaker takes unconditional expectations on the periodic loss function, instead of conditional expectations period by period when evaluating it.[24] This gives the

[23]Detailed derivations are shown in the Appendix.

[24]Taking unconditional expectations on the loss function can be theoretically justified as an "unconditional continuation policy" by Jensen and McCallum (2002, 2010).

final policy loss function as follows:

$$
\begin{aligned}
W &\simeq -\frac{1}{2} E \sum_{t=0}^{\infty} \beta_s^t \left[\widetilde{y}_t^2 + \lambda_\pi \pi_t^2 + \lambda_c \widetilde{c}_t^2 + \lambda_h \widetilde{h}_t^2 \right] \\
&= -\frac{1}{2} \sum_{t=0}^{\infty} \beta_s^t \left[E\left(\widetilde{y}_t^2\right) + \lambda_\pi E\left(\pi_t^2\right) + \lambda_c E\left(\widetilde{c}_t^2\right) + \lambda_h E\left(\widetilde{h}_t^2\right) \right], \\
&= -\frac{1}{2} \sum_{t=0}^{\infty} \beta_s^t \left[Var\left(\widetilde{y}\right) + \lambda_\pi Var\left(\pi\right) + \lambda_c Var\left(\widetilde{c}\right) + \lambda_h Var\left(\widetilde{h}\right) \right], \\
&\simeq -\frac{1}{2} \left[Var\left(\widetilde{y}\right) + \lambda_\pi Var\left(\pi\right) + \lambda_c Var\left(\widetilde{c}\right) + \lambda_h Var\left(\widetilde{h}\right) \right]. \qquad (27)
\end{aligned}
$$

The last step of algebra is based on the fact that the unconditional variance of the gap variables is independent of time, so that we can take them out of the summation operator. We use this loss function to evaluate different combinations of the policy parameters. The solution of this problem is represented by the following expression:

$$
\phi^* = \arg\min W\left(\phi\right),
$$

subject to the model equations.

4.2 Optimal Simple Rules for LTV Policy

In this section, we study how the macroprudential rule could be used as a supplement to monetary policy for macroeconomic stabilization. In particular, we first consider a rule in which the macroprudential regulator only responds to credit deviations from the steady state. Then, we extend the rule to allow the macroprudential instrument to also respond to output.

In Table 4, we report the optimized values of the LTV rule coefficients and the volatilities of the key variables that drive the welfare-based loss function (27). For comparison, we first report results that are generated from the economy without LTV rules, which we take as a benchmark. Next, we compare them with the values that are produced by two rules responding to different variables. In the upper panels of the table, we describe the economy in the high interest-rate environment (4% steady-state interest rate), while in the lower panels, results are generated in the low interest-rate scenario (2% steady-state interest rate).

Table 4: Optimal Macroprudential Rules

	LTV rule		Welf-Loss	σ^2_{y-gap}	$\sigma^2_{\pi-gap}$	σ^2_{c-gap}	σ^2_{h-gap}
High interest-rate environment	ϕ^*_b	ϕ^*_y			%		
Benchmark (No LTV)	-	-	-11.45	1.6	0.16	9.6	121
LTV Rule with Credit	0.43	-	-9.96	2.1	0.25	17.3	50.6
LTV Rule with Credit and Output	0.43	0.24	-9.83	2.0	0.25	16.4	51.7
Low interest-rate environment							
Benchmark (No LTV)	-	-	-27.97	3.5	0.45	24.8	279
LTV Rule with Credit	0.46	-	-15.56	3.3	0.43	34.5	58.9
LTV Rule with Credit and Output	0.76	0.35	-14.97	3.2	0.44	35.1	45.4

Note: In this table, all policy scenarios are based on monetary policy using a Taylor rule with $\phi^R_\pi = 1.5$ and $\phi^R_y = 0.5$.
All volatilities and values of the loss function are reported in the unit of percentage points.

First of all, driven by the same shocks, the economy in the high interest-rate environment is significantly less volatile than that in the low interest-rate environment. This leads to a significant increase in the welfare loss in the low interest-rate economy. As we discussed before, in the low interest-rate world, the ZLB is binding more frequently. Lacking an effective stabilization policy, the economy becomes more volatile in both the real and financial sectors. This has severe welfare consequences for the agents in the economy, especially for credit-constrained borrowers. Decomposing the drivers of the welfare loss reveals that the housing gap between savers and borrowers is the main contributor of the welfare loss in the economy. This finding motivates the need for using a macroprudential policy to enhance welfare, especially in the low interest-rate environment.

When introducing an active LTV rule responding to credit, we see that the welfare loss is improved in both economies substantially. Interestingly, in the high interest-rate world, the credit-focused macroprudential rule faces a trade-off between financial and macroeconomic stability. Optimal response to credit significantly reduces the welfare loss caused by the consumption gap and the housing gap, but the volatility of the output gap and the inflation gap are slightly increased. On the other hand, in the low interest-rate world, the credit-only-LTV rule dampens both the volatility of the inequality gap and macroeconomic fluctuations. Compared to the high interest rate economy, the LTV rule needs to respond more strongly to credit than in the low interest-rate environment.

In the next experiment, we extend the LTV rule to a version that responds to both credit and output.

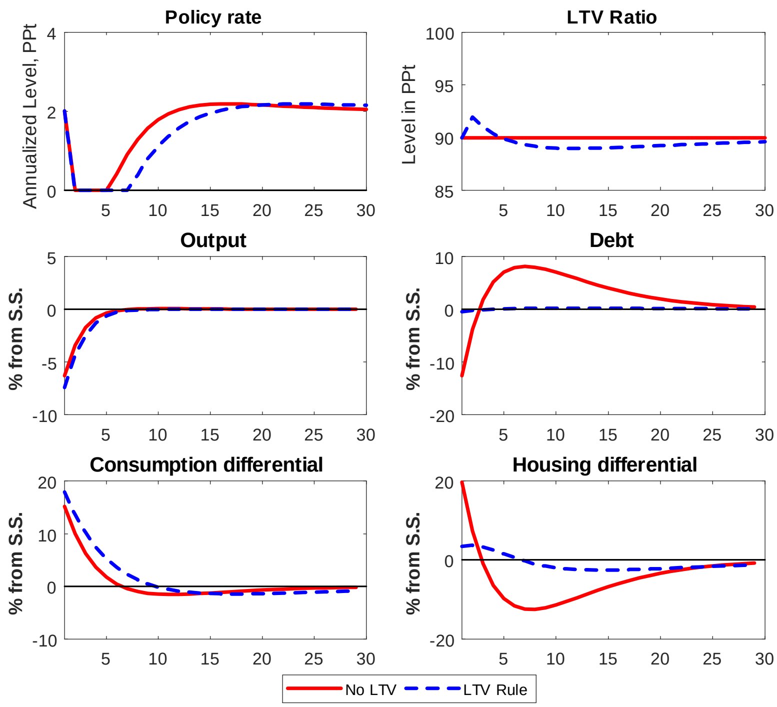

Figure 4: The effect of an active LTV rule with ZLB

Results show that, in the high interest-rate world, allowing macroprudential policy to respond to output does not significantly improve the welfare loss. Macroeconomic stability is effectively managed by the monetary authority through the Taylor rule. When the steady-state interest rate is closer to the ZLB, however, the optimized rule responds strongly both to credit and to output. As discussed above, the binding ZLB becomes the major distortion in the economy that affects welfare, both by amplifying macroeconomic fluctuations and the inequality of the economy through financial frictions. In this case, the macroprudential policy helps monetary policy to improve social welfare both in terms of containing macroeconomic volatility and economic inequality.

Figure 4 presents impulse responses to a negative demand 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. Even though, in both cases, policy rates are restricted by the ZLB, having an active LTV policy largely isolates borrowing from the demand shock. As shown in the figure, the negative demand shock leads monetary policy to cut the interest rate to zero, but the countercyclical LTV influences implicitly the borrowing cost by relaxing the borrowing constraint for credit-limited agents in the economy. As a result, the economy with a countercyclical LTV policy suffers from a smaller welfare loss in terms of the housing gap between savers and borrowers.

4.3 Optimal policy coordination

In this section, we set the optimal monetary and macroprudential policy rules jointly. In particular, we differentiate between two cases: the perfect coordination policy and the non-coordination policy. The perfect coordination policy considers the situation where monetary policy and macroprudential policy are set simultaneously and optimally to minimize the joint welfare loss function (27):

$$\left(\phi_\pi^{R*}, \phi_y^{R*}, \phi_b^*\right) = \arg\min W\left(\phi_\pi^R, \phi_y^R, \phi_b\right).$$

The non-coordination policy, on the other hand, assumes that monetary policy and macroprudential policy are set independently to achieve their own policy objectives. For this experiment, we split the welfare-based loss function (27) into two parts:

$$W^{MP} \simeq -\frac{1}{2}\left[Var\left(\widetilde{y}\right) + \lambda_\pi Var\left(\pi\right)\right], \tag{28}$$

$$W^{LTV} \simeq -\frac{1}{2}\left[\lambda_c Var\left(\widetilde{c}\right) + \lambda_h Var\left(\widetilde{h}\right)\right], \tag{29}$$

where the loss function of monetary policy (28) reflects the monetary policy's objective of mitigating the welfare costs of business cycles, while the loss function of macroprudential policy (29) represents the goal of the macroprudential authority of reducing the negative consequences of financial frictions on economic inequality. We assume that monetary policy tries to minimize its loss function by choosing the Taylor rule parameters $\left(\phi_\pi^R, \phi_y^R\right)$, while the macroprudential authority does it by choosing the LTV rule parameter associated with the deviation of credit.

$$\left(\phi_\pi^{R*}, \phi_y^{R*}\right) = \arg\min W^{MP}\left(\phi_\pi^R, \phi_y^R\right)$$
$$\left(\phi_b^*\right) = \arg\min W^{LTV}\left(\phi_b\right).$$

Table 5 summarizes the optimal policy coordination results under both the high interest-rate environment (upper panel) and the low interest-rate scenario (lower panel). In the high interest-rate environment, as shown in Section (3.1), the ZLB is very rarely binding, so that the main distortions in the economy comes from sticky prices and collateral constraints. In this case, the perfect coordination policy mix features a strong response to inflation, and a strong response to credit by the LTV rule. This set of policies achieves a lower welfare loss compared to the case where only LTV policy is optimized in Table 4. Interestingly, when two policies are perfectly coordinated, the optimal policy prescription behaves as if they were working "independently".[25] Monetary policy is featured by a strict inflation targeting, addressing frictions from sticky prices,[26] while the macroprudential authority is delegated to manage imbalances between savers and borrowers, resulting from financial frictions. When optimal policies are conducted independently, however, monetary policy is found to be optimal to respond to output too. This is because, without the coordination with the macroprudential policy, monetary policy is "distracted" from focusing on price stability. Instead, monetary policy also tries to smooth business cycles to help borrowers in the economy, even though more effective and targeted tool (macroprudential policy) is available. As a result, non-coordination leads to a slightly greater welfare loss.

Table 5: Optimal Policy Coordination

	Taylor rule		LTV rule	Welf-Loss	σ^2_{y-gap}	$\sigma^2_{\pi-gap}$	σ^2_{c-gap}	σ^2_{h-gap}
High interest-rate environment	ϕ_π^{R*}	ϕ_y^{R*}	ϕ_b^*			%		
Perfect coordination	5	0	5	-5.13	0.50	0.04	19.6	43.6
Non-coordination	5	0.45	5	-5.24	0.46	0.04	19.3	46.2
Low interest-rate environment								
Perfect coordination	5	0.4	5	-7.81	0.80	0.07	34.3	56.6
Non-coordination	5	0.6	5	-8.08	0.84	0.07	34.9	58.0

Note: * not optimized policy parameters.

In the low interest-rate world, because monetary policy is more frequently restricted by the binding ZLB, aggregate demand externalities, as emphasized in Farhi and Werning (2016), play an important role in optimal policy. Under perfect coordination, monetary policy is also used to smooth business cycles. Optimal LTV policy is again set to strongly respond to credit countercyclically. The non-coordinated policy setting makes monetary policy respond to output even more strongly, which leads to a bigger welfare loss compared to the perfect coordination setting.

In summary, in a low interest-rate environment, there are two reasons that strengthen the role of macroprudential policy intervention. First, the low interest-rate world is more prone to pecuniary externalities, that calls for the use of macroprudential policies to bring a more stable financial system.

[25] It echoes the "Tinbergen principle", in which two policies use different instruments to target different objective variables.

[26] This reflects the fact that the driving force of inefficient economic fluctuations in our model is a demand shock, so that the "divine coincidence" applies.

Second, monetary policy not only loses its effectiveness in bringing macroeconomic stability, but also becomes a source of aggregate demand externalities when it is constrained by the ZLB. In this case, macroprudential policy can lend a helping hand to monetary policy in managing the cost of borrowing. We find that, when the interest rate is high and the two policies can perfectly coordinate, the optimal policy prescription behave as if they were independent. There are no conflicts between them. This is, however, no more the case, when the interest rate is low and/or when monetary policy and macroprudential policy cannot be perfectly coordinating. This more complex policy environment calls for more policy coordination.

5 Robustness

In this section, we check the robustness of our key results in alternative settings of macroprudential policy rules and more practical macroprudential loss functions.

5.1 Alternative LTV rules

We consider alternative LTV rules, which respond to the credit-to-GDP ratio, the output gap and an LTV with a smoothing term. These rules are motivated by either practical or theoretical reasons. For example, an LTV rule with smoothing captures the idea that macroprudential tools are adjusted very gradually in practice. In addition, we also experiment with rules including the credit-to-GDP gap and the output gap. The former is shown in empirical studies (see, e.g.: Drehmann and Juselius, 2014) as a good early warning indicator of banking crises. The output gap captures precisely the welfare loss caused by macro fluctuations associated with sticky prices.

Table 6: Optimized Parameters of Alternative Rules							
	$\phi^*_{b/y}$	ϕ^*_{y-gap}	Welf-Loss	σ^2_{y-gap}	$\sigma^2_{\pi-gap}$	σ^2_{c-gap}	σ^2_{h-gap}
High interest-rate environment					%		
LTV Rule with credit-to-GDP	0.3	-	-10.34	2.1	0.24	17.5	61.8
LTV Rule with credit and output gap	0.5	0.6	-9.60	1.9	0.25	16.3	49.8
LTV Rule with smoothing	0.45	0	-9.72	2.0	0.24	16.8	52.9
Low interest-rate environment							
LTV Rule with credit-to-GDP	0.7	-	-16.68	3.6	0.47	39.6	55.1
LTV Rule with credit and output gap	0.8	0.6	-15.07	3.2	0.44	35.7	42.9
LTV Rule with smoothing	0.58	0	-15.96	3.4	0.44	36.4	59.1

Note: All volatilities and values of the loss function are reported in the unit of percentage points.

Results are shown in Table 6. Intuitively, an LTV rule responding to credit-to-GDP amounts to a restricted version of the rule reacting to credit and output separately. In particular, we restrict the LTV rule to respond to credit and output equally, but with opposite signs. Overall, the policy rule responding to the credit-to-GDP ratio performs slightly worse than the LTV rule responding to credit and output separately. On the other hand, when allowing the LTV rule to respond to both the credit-to-GDP ratio and the output gap, we find that responding to the more precise measure of the welfare loss leads to a strong response of the rule, but the welfare gains are very small. Conversely, introducing smoothness into the LTV rule reduces the effectiveness of the LTV policy in stabilizing the economy. This leads to a weaker response to inflation and the output gap, which results again in a small welfare loss.

5.2 Alternative loss functions

In Table 7, we report our results based on alternative loss functions, which take the volatility of output, the LTV ratio, the credit-to-GDP ratio, and the change in the LTV ratio into account. These alternatives are chosen based on practical reasons for conducting macroprudential policy. In practice, the macroprudential authority does not know the true model of the economy, and hence the welfare-based loss function is unknown to them. To conduct macroprudential policy, policymakers choose loss functions evaluated by some observable economic variables and hope they can capture the welfare of the economy to a large degree, based on theoretical models.

In this section, we report the optimal simple rules derived under four 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 and fourth variations reflect the practical concern of the macroprudential regulator on the stability of the policy instrument itself. These versions take the volatility of the LTV (and the changes) into account. We derive the optimal simple rules and the associated values of the loss function for each case. We also consider both the high and the low interest-rate environment.

Table 7: Alternative Loss Functions

	$\sigma_b^2 + \Lambda\sigma_y^2$			$\sigma_b^2 + \Lambda\sigma_{b/y}^2$			$\sigma_b^2 + \Lambda\sigma_{LTV}^2$			$\sigma_b^2 + \Lambda\sigma_{\Delta LTV}^2$		
	ϕ_b^*	ϕ_y^*	Loss	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	-	-	12.7
LTV with Credit	0.55	-	5.4	0.55	-	2.4	0.55	-	3.39	0.55	-	2.1
LTV with Credit and Output	0.55	0	5.4	0.75	0.1	2.3	0.55	0	3.39	0.55	0	2.1
Low interest-rate environment												
No LTV Rule	-	-	155.2	-	-	327.9	-	-	76.5	-	-	85.2
LTV with Credit	0.65	-	28.4	0.85	-	11.1	0.65	-	26.2	0.65	-	16.1
LTV with Credit and Output	0.55	0.9	22.6	0.65	0.3	8.1	0.55	0.5	21.1	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 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 responds 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 three key results drawn from the previous section pass robustness tests with alternative loss functions.

6 Concluding Remarks

This paper investigates stabilization policies in a low interest-rate environment. We use a DSGE model with financial frictions, 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? Our quantitative results suggest that a low interest-rate environment poses new challenges to conventional monetary policy, because of the occasionally binding ZLB. As a result, monetary policy not only loses its efficacy in stabilizing the economy, but also becomes a source of instability. In this case, monetary policy is in real need of a helping hand from alternative policies. We focus in this paper on the role of macroprudential policy as a supplement for monetary policy in the low interest-rate environment. We show with numerical simulation results that, if macroprudential policy is available, it can serve as an alternative stabilizing mechanism. In addition, optimal coordination between monetary and macroprudential policies is welfare enhancing, especially in the low interest-rate scenario.

Appendix

Summary of Model Equations

$$
\begin{aligned}
\frac{1}{C_{s,t}} &= \beta_s E_t \left(\frac{R_t}{\pi_{t+1} C_{s,t+1}} \right) \\
w_{s,t} &= \left(N_{s,t}\right)^{\eta} C_{s,t} \\
w_{b,t} &= \left(N_{b,t}\right)^{\eta} C_{b,t} \\
\frac{j}{H_{s,t}} &= \frac{1+\tau^h}{C_{s,t}} q_t - \beta_s E_t \frac{1}{C_{s,t+1}} q_{t+1} \\
E_t \frac{R_t}{\pi_{t+1}} b_t &= k_t E_t q_{t+1} H_{b,t} \\
C_{b,t} + \frac{R_{t-1} b_{t-1}}{\pi_t} &= b_t + w_{b,t} N_{b,t} - q_t \left(H_{b,t} - H_{b,t-1}\right) \\
\frac{j}{H_{b,t}} + \lambda_t k_t E_t \left(q_{t+1} \pi_{t+1}\right) &= \frac{1}{C_{b,t}} q_t - \beta_b E_t \left(\frac{1}{C_{b,t+1}} q_{t+1} \right) \\
\frac{1}{C_{b,t}} &= \beta_b E_t \left(\frac{R_t}{\pi_{t+1} C_{b,t+1}} \right) + \lambda_t R_t \\
Y_t &= \omega C_{s,t} + (1-\omega) C_{b,t} \\
\bar{H} &= \omega H_{s,t} + (1-\omega) H_{b,t} \\
Y_t &= A_t N_{s,t}^{\alpha} {N_{b,t}}^{(1-\alpha)} \\
w_{s,t} &= \alpha \frac{1}{X_t} \frac{Y_t}{N_{s,t}} \\
w_{b,t} &= (1-\alpha) \frac{1}{X_t} \frac{Y_t}{N_{b,t}} \\
0 &= \sum_{k=0}^{\infty} (\theta\beta)^k E_t \left\{ \Lambda_{t,k} \left[\frac{P_t^*(z)}{P_{t+k}} - \frac{\varepsilon/(\varepsilon-1)}{X_{t+k}} \right] Y_{t+k}^*(z) \right\} \\
P_t &= \left[\theta P_{t-1}^{1-\varepsilon} + (1-\theta) \left(P_t^*\right)^{1-\varepsilon} \right]^{1/(1-\varepsilon)} \\
&\text{+policy rules and shock processes}
\end{aligned}
$$

Steady-State Relationships

Here we derive the efficient steady state, where we use three assumptions to eliminate distortions in the model. First of all, we assume a steady state with zero inflation $\pi = 1$. This assumption eliminates the distortion due to sticky prices. Second, we impose a tax $(\tau = \varepsilon^{-1})$ to intermediate goods firms to eliminate the distortion due to monopolistic competition. Third, we assume that there is a tax on savers' housing demand, which closes the gap between housing holdings between savers and borrowers. Given those assumptions, real marginal costs (markup) at the steady state are equal to one and the steady state is symmetric across savers and borrowers.

Consider a social planner who maximizes a weighted average of borrowers' and savers' period utility function, subject to the resource and housing constraints:

$$U = \omega_p U\left(C_s, H_s, N_s\right) + \left(1 - \omega_p\right) U\left(C_b, H_b, N_b\right)$$

$s.t.$:

$$N_s^{\alpha} N_b^{(1-\alpha)} = \alpha C_s + (1-\alpha)\, C_b$$

$$0 = \alpha H_s + (1-\alpha)\, H_b,$$

where ω_p is an arbitrary weight assigned to each individual by the social planner. Let η_1 and η_2 be the Lagrange multipliers on the resource and housing constraints, respectively. The first order conditions are

$$\omega_p U'_{c^s} = \alpha \mu_1 \tag{A1}$$

$$\left(1-\omega_p\right) U'_{c^b} = (1-\alpha)\, \mu_1 \tag{A2}$$

$$\omega_p U'_{h^s} = \alpha \mu_2 \tag{A3}$$

$$\left(1-\omega_p\right) U'_{h^b} = (1-\alpha)\, \mu_2 \tag{A4}$$

$$\omega_p U'_{n^s} = -\mu_1 \alpha Y / N_s \tag{A5}$$

$$\left(1-\omega_p\right) U'_{n^b} = -\mu_1 (1-\alpha)\, Y / N_b \tag{A6}$$

When the social planner sets the policy weights to be equal to population shares ($\omega_p = \alpha$), we obtain

$$\frac{U'_{c^s}}{U'_{h^s}} = \frac{U'_{c^b}}{U'_{h^b}} = \frac{\mu_1}{\mu_2} \tag{A7}$$

Further, at the efficient symmetric steady state, we have

$$X = 1 \tag{A8}$$

$$C_s = C_b = C \tag{A9}$$

$$H_s = H_b = H \tag{A10}$$

$$Y = C \tag{A11}$$

we have the following efficient steady state equation:

$$R = \frac{1}{\beta_s} \tag{A12}$$

$$\frac{N_s w_s}{Y} = \alpha \tag{A13}$$

$$\frac{N_b w_b}{Y} = 1 - \alpha \tag{A14}$$

Evaluated borrower's Euler equation at the steady state, we have

$$\frac{1}{C_b} = \beta_b \frac{R}{C_b} + \lambda R,$$

$$\Downarrow$$

$$\lambda R C_b = \frac{\beta_s - \beta_b}{\beta_s} \tag{A15}$$

The Lagrange multiplier on the collateral constraint is positive as long as our initial assumption $\beta_s > \beta_b$ is satisfied (that is, borrowers are relatively more impatient than savers).

$$\begin{aligned} \frac{C_b}{H_b} &= \frac{(1 - \beta_b - \lambda C_b k)\, q}{j_b} \\ &= \frac{(1 - \beta_b - k\,(\beta_s - \beta_b))\, q}{j_b} \end{aligned} \tag{A16}$$

Further, we get the consumption-to-housing ratio of savers

$$\frac{C_s}{H_s} = \frac{\left(1 + \tau^h - \beta_s\right) q}{j_s} \tag{A17}$$

At the symmetric steady state, where $\frac{C_b}{H_b} = \frac{C_s}{H_s}$, the housing tax should be equal to

$$\frac{C}{H} = \frac{\left(1+\tau^h-\beta_s\right)q}{j_s} = \frac{\left(1-\beta_b-k\left(\beta_s-\beta_b\right)\right)q}{j_b} \tag{A18}$$

$$\tau^h = \left(\frac{j_s}{j_b}\right)\left(1-\beta_b-k\left(\beta_s-\beta_b\right)\right)-\left(1-\beta_s\right) \tag{A19}$$

$$\tau^h = \left(\beta_s-\beta_b\right)\left(1-k\right) \tag{A20}$$

From the collateral constraint equation, we obtain

$$\frac{b}{C} = \frac{k}{R}\frac{H}{C} \tag{A21}$$

Log-Linearized Model

The model can be reduced to the following linearized system, around the efficient steady state, in which all lower-case variables denote percent changes from the steady state and steady-state levels are denoted by dropping the time index (also dropping the expectations operator, for simplicity):

Aggregate Demand

Savers

$$c_{s,t} = c_{s,t+1} - \left(r_t - \pi_{t+1}\right) \tag{A22}$$

$$w_{s,t} = \eta n_{s,t} + c_{s,t} \tag{A23}$$

Borrowers

$$\lambda_t = \frac{\beta_b}{\beta_s-\beta_b}\left(\pi_{t+1}+c_{b,t+1}\right) - \frac{\beta_s}{\beta_s-\beta_b}\left(r_t+c_{b,t}\right) \tag{A24}$$

$$c_{b,t} + \frac{Rb}{C}\left(r_{t-1}+b_{t-1}-\pi_t\right) + \frac{QH}{C}\left(h_{b,t}-h_{b,t-1}\right) = \frac{b}{C}b_t + \frac{w_b N_b}{C}\left(w_{b,t}+n_{b,t}\right) \tag{A25}$$

$$b_t = k_t + q_{t+1} + h_{b,t} + \pi_{t+1} - r_t. \tag{A26}$$

$$w_{b,t} = \eta n_{b,t} + c_{b,t} \tag{A27}$$

Housing Equations

Savers

$$\frac{j_s C}{H}\left(c_{s,t}-h_{s,t}\right)=Qq_t-\beta_s Q\left(q_{t+1}+c_{s,t}-c_{s,t+1}\right) \tag{A28}$$

Borrowers

$$j_b\frac{C}{H}\left(c_{b,t}-h_{b,t}\right)=Qq_t-\beta_b Q\left(c_{b,t}-c_{b,t+1}+q_{t+1}\right)-\lambda CkQ\left(\lambda_t+k_t+q_{t+1}+\pi_{t+1}+c_{b,t}\right) \tag{A29}$$

Aggregate Supply

$$y_t=a_t+\alpha n_{s,t}+\left(1-\alpha\right)n_{b,t} \tag{A30}$$

$$\pi_t=\beta_s E_t\pi_{t+1}-\widetilde{k}x_t \tag{A31}$$

Savers

$$w_{s,t}=y_t-x_t-n_{s,t} \tag{A32}$$

Borrowers

$$w_{b,t}=y_t-x_t-n_{b,t} \tag{A33}$$

Policy Rules

$$r_t=\rho r_{t-1+}\left(1-\rho\right)\left[\left(1+\phi_\pi\right)\pi_t+\phi_y y_t\right] \tag{A34}$$

$$k_t=-\phi_b b_t-\phi_y y_t \tag{A35}$$

Equilibrium

$$y_t=\omega c_{s,t}+\left(1-\omega\right)c_{b,t} \tag{A36}$$

$$\omega h_{s,t}+\left(1-\omega\right)h_{b,t}=0 \tag{A37}$$

Welfare Loss Function Derivation

Following Ferrero et al. (2018), we define the welfare objective of the policymaker as the present discounted value of the utility of the two individuals. We assume that the policymaker discounts the future at the saver's discount rate.

$$W_0 = E_0 \sum_{t=0}^{\infty} \beta_s^t U_t,$$

where $U_t = \omega_p U_{s,t} + (1-\omega_p) U_{b,t}$, and ω_p is an arbitrary weight assigned to each individual by the social planner. Given our functional forms:

$$U_{s,t} = \log C_{s,t} + j \log H_{s,t} - \frac{(N_{s,t})^{1+\eta}}{1+\eta},$$

$$U_{b,t} = \log C_{b,t} + j \log H_{b,t} - \frac{(N_{b,t})^{1+\eta}}{1+\eta},$$

We take a second-order approximation of U_t around the efficient steady state:

$$\begin{aligned} U_t - U \simeq\ & \omega_p U_c \left[(C_{s,t} - C) + \frac{1}{2}\frac{U_{cc}}{U_c} (C_{s,t} - C)^2 \right] + (1-\omega_p) U_c \left[(C_{b,t} - C) + \frac{1}{2}\frac{U_{cc}}{U_c} (C_{b,t} - C)^2 \right] \\ & + \omega_p U_h \left[(H_{s,t} - H) + \frac{1}{2}\frac{U_{hh}}{U_h} (H_{s,t} - H)^2 \right] + (1-\omega_p) U_h \left[(H_{b,t} - H) + \frac{1}{2}\frac{U_{hh}}{U_h} (H_{b,t} - H)^2 \right] \\ & + \omega_p U_n \left[(N_{s,t} - N_s) + \frac{1}{2}\frac{U_{nn}}{U_n} (N_{s,t} - N_s)^2 \right] + (1-\omega_p) U_n \left[(N_{b,t} - N_b) + \frac{1}{2}\frac{U_{nn}}{U_n} (N_{b,t} - N_b)^2 \right] \end{aligned} \tag{A38}$$

Using Pareto efficient steady-state relationships derived in the previous subsection:

$$\omega_p U'_{c^s} = \alpha \mu_1 \tag{A39}$$

$$(1-\omega_p) U'_{c^b} = (1-\alpha) \mu_1 \tag{A40}$$

$$\omega_p U'_{h^s} = \alpha\mu_2 \tag{A41}$$

$$\left(1-\omega_p\right) U'_{h^b} = \left(1-\alpha\right)\mu_2 \tag{A42}$$

$$\omega_p U'_{n^s} = -\mu_1 \alpha Y/N_s \tag{A43}$$

$$\left(1-\omega_p\right) U'_{n^b} = -\mu_1 \left(1-\alpha\right) Y/N_b \tag{A44}$$

Given our functional forms:

$$\frac{U_{cc}}{U_c} = -\frac{1}{C} \tag{A45}$$

$$\frac{U_{hh}}{U_h} = -\frac{1}{H} \tag{A46}$$

$$\frac{U_{nn}}{U_n} = \frac{\eta}{N} \tag{A47}$$

Substituting out the functional forms:

$$\begin{aligned} U_t - U \simeq{}& \alpha\mu_1 \left[\left(C_{s,t} - C\right) - \frac{1}{2}\frac{1}{C}\left(C_{s,t} - C\right)^2 \right] + \left(1-\alpha\right)\mu_1 \left[\left(C_{b,t} - C\right) - \frac{1}{2}\frac{1}{C}\left(C_{b,t} - C\right)^2 \right] \\ &+ \alpha\mu_2 \left[\left(H_{s,t} - H\right) - \frac{1}{2}\frac{1}{H}\left(H_{s,t} - H\right)^2 \right] + \left(1-\alpha\right)\mu_2 \left[\left(H_{b,t} - H\right) - \frac{1}{2}\frac{1}{H}\left(H_{b,t} - H\right)^2 \right] \\ &- \alpha\mu_1 \frac{Y}{N_s} \left[\left(N_{s,t} - N_s\right) + \frac{1}{2}\frac{\eta}{N_s}\left(N_{s,t} - N_s\right)^2 \right] - \left(1-\alpha\right)\mu_1 \frac{Y}{N_b} \left[\left(N_{b,t} - N_b\right) + \frac{1}{2}\frac{\eta}{N_b}\left(N_{b,t} - N_b\right)^2 \right] \end{aligned} \tag{A48}$$

To eliminate first-order terms, we make use of the resource constraint and the housing market equilibrium (equations 19 and 20):

$$Y_t = \alpha C_{s,t} + (1-\alpha)C_{b,t},$$

$$\bar{H} = \alpha H_{s,t} + (1-\alpha)H_{b,t},$$

For algebraic convenience, we assign the arbitrary weights equal to labor income weights, so that $\omega_p = \alpha$:

We also use the approximation equation for Y_t

$$Y_t \simeq Y\left(1 + z_t + \frac{1}{2}z_t^2\right)$$

and obtain

$$\begin{aligned}
\alpha\left(C_{s,t} - C\right) + (1-\alpha)\left(C_{b,t} - C\right) = \left(Y_t - Y\right) \simeq Y\left(y_t + \frac{1}{2}y_t^2\right) \\
\alpha\frac{1}{C}\left(C_{s,t} - C\right) + (1-\alpha)\frac{1}{C}\left(C_{b,t} - C\right) \simeq y_t + \frac{1}{2}y_t^2
\end{aligned} \tag{A49}$$

Similarly, we eliminate first-order terms in housing by using

$$\alpha\left(H_{s,t} - H\right) + (1-\alpha)\left(H_{b,t} - H\right) = 0$$

to get

$$\begin{aligned}
U_t - U \simeq\ & \mu_1\left[Y\left(y_t + \frac{1}{2}y_t^2\right)\right] \\
& - \mu_1 Y\left[\alpha\left(\frac{N_{s,t} - N_s}{N_s}\right) + (1-\alpha)\left(\frac{N_{b,t} - N_b}{N_b}\right)\right] \\
& - \frac{\eta}{2}Y\mu_1\left[\alpha\frac{\left(N_{s,t} - N_s\right)^2}{N_s^2} + (1-\alpha)\frac{\left(N_{b,t} - N_b\right)^2}{N_b^2}\right] \\
& - \mu_1\frac{1}{2}\frac{1}{C}\left[\alpha\left(C_{s,t} - C\right)^2 + (1-\alpha)\left(C_{b,t} - C\right)^2\right] \\
& - \mu_2\frac{1}{2}\frac{1}{H}\left[\alpha\left(H_{s,t} - H\right)^2 + (1-\alpha)\left(H_{b,t} - H\right)^2\right]
\end{aligned} \tag{A50}$$

To eliminate the first-order terms, we express variables in deviations from their respective steady states.

We work with each line in turn.

$$
\begin{aligned}
&\alpha\left(\frac{N_{s,t}-N_s}{N_s}\right)+(1-\alpha)\left(\frac{N_{b,t}-N_b}{N_b}\right)\\
&\simeq \alpha\left(n_{st}+\frac{1}{2}n_{st}^2\right)+(1-\alpha)\left(n_{bt}+\frac{1}{2}n_{bt}^2\right)\\
&=\alpha n_{st}+(1-\alpha)\,n_{bt}+\frac{1}{2}\alpha n_{st}^2+\frac{1}{2}\,(1-\alpha)\,n_{bt}^2
\end{aligned}
$$

$$
\begin{aligned}
&\alpha\frac{(N_{s,t}-N_s)^2}{N_s^2}+(1-\alpha)\,\frac{(N_{b,t}-N_b)^2}{N_b^2}\\
&\simeq \alpha\left(n_{st}+\frac{1}{2}n_{st}^2\right)^2+(1-\alpha)\left(n_{bt}+\frac{1}{2}n_{bt}^2\right)^2\\
&=\alpha\left(n_{st}^2+n_{st}^3+\frac{1}{4}n_{st}^4\right)+(1-\alpha)\left(n_{bt}^2+n_{bt}^3+\frac{1}{4}n_{bt}^4\right)\\
&=\alpha n_{st}^2+(1-\alpha)\,n_{bt}^2+\text{ higher order terms.}
\end{aligned}
$$

$$
\begin{aligned}
&-\mu_1\frac{1}{2}\frac{1}{C}\left[\alpha\,(C_{s,t}-C)^2+(1-\alpha)\,(C_{b,t}-C)^2\right]\\
&=-\mu_1\frac{1}{2}C\left[\alpha\left(\frac{C_{s,t}-C}{C}\right)^2+(1-\alpha)\left(\frac{C_{b,t}-C}{C}\right)^2\right]\\
&\simeq-\mu_1\frac{1}{2}C\left[\alpha\left(c_{st}+\frac{1}{2}c_{st}^2\right)^2+(1-\alpha)\left(c_{st}+\frac{1}{2}c_{st}^2\right)^2\right]\\
&=-\mu_1\frac{1}{2}C\left[\alpha c_{st}^2+(1-\alpha)\,c_{bt}^2\right]\;+\;\text{higher order terms}
\end{aligned}
$$

$$
\begin{aligned}
&-\mu_2\frac{1}{2}\frac{1}{H}\left[\alpha\,(H_{s,t}-H)^2+(1-\alpha)\,(H_{b,t}-H)^2\right]\\
&=-\mu_2\frac{1}{2}H\left[\alpha\left(\frac{H_{s,t}-H}{H}\right)^2+(1-\alpha)\left(\frac{H_{b,t}-H}{H}\right)^2\right]\\
&\simeq-\mu_2\frac{1}{2}H\left[\alpha\left(h_{st}+\frac{1}{2}h_{st}^2\right)^2+(1-\alpha)\left(h_{st}+\frac{1}{2}h_{st}^2\right)^2\right]\\
&=-\mu_2\frac{1}{2}H\left[\alpha h_{st}^2+(1-\alpha)\,h_{bt}^2\right]+\text{ higher order terms}
\end{aligned}
$$

Putting all together, we obtain

$$
\begin{aligned}
U_t - U \simeq\ & \mu_1 Y \left[y_t - \alpha n_{st} - (1-\alpha)\, n_{bt}\right] + \mu_1 Y \frac{1}{2} y_t^2 \\
& - \mu_1 \frac{1}{2} Y (1+\eta) \left[\alpha n_{st}^2 + (1-\alpha)\, n_{bt}^2\right] \\
& - \mu_1 \frac{1}{2} C \left[\alpha c_{st}^2 + (1-\alpha)\, c_{bt}^2\right] \\
& - \mu_2 \frac{1}{2} H \left[\alpha h_{st}^2 + (1-\alpha)\, h_{bt}^2\right] \\
& + \text{higher order terms}
\end{aligned} \tag{A51}
$$

Using the production function log-linearized around the efficient steady state, we have:

$$
y_t = \alpha n_{s,t} + (1-\alpha)\, n_{b,t} - \widehat{\Delta}_t,
$$

where $\widehat{\Delta}_t$ is an index of price dispersion coming from the aggregation of the production function, which is equal to $\widehat{\Delta}_t = \frac{1}{2} \frac{\theta\varepsilon}{(1-\theta)(1-\beta\theta)} \pi_t^2$. [27]

We get:

$$
\begin{aligned}
U_t - U \simeq\ & \frac{1}{2} \mu_1 Y y_t^2 - \frac{1}{2} \mu_1 Y \frac{\theta\varepsilon}{(1-\theta)(1-\beta\theta)} \pi_t^2 \\
& - \frac{1}{2} \mu_1 Y (1+\eta) \left[\alpha n_{st}^2 + (1-\alpha)\, n_{bt}^2\right] \\
& - \frac{1}{2} \mu_1 Y \left[\alpha c_{st}^2 + (1-\alpha)\, c_{bt}^2\right] \\
& - \frac{1}{2} \mu_2 H \left[\alpha h_{st}^2 + (1-\alpha)\, h_{bt}^2\right] \\
& + \text{higher order terms}
\end{aligned} \tag{A52}
$$

At this point, the welfare objective is fully quadratic. To gain more economic intuition, we derive further the welfare function as follows.

Using the housing market equilibrium we have:

$$
h_{b,t} = \alpha \left(h_{b,t} - h_{s,t}\right)
$$

$$
h_{s,t} = -\left(1-\alpha\right)\left(h_{b,t} - h_{s,t}\right)
$$

[27] We also dropped the aggregate productivity shock from the production function, because it is independent from policy.

Then, the housing term becomes:

$$\alpha h_{s,t}^2 + (1-\alpha)\, h_{b,t}^2 = \alpha\,(1-\alpha)\,(h_{b,t} - h_{s,t})^2$$

We can now substitute the housing term back and combine together the output, consumption and labor terms:

$$\begin{aligned} U_t - U \simeq & -\frac{1}{2}\mu_1 Y \left\{\alpha c_{s,t}^2 + (1-\alpha)\, c_{b,t}^2 - y_t^2 + (1+\eta)\left[\alpha n_{s,t}^2 + (1-\alpha)\, n_{b,t}^2\right]\right\} \\ & -\frac{1}{2}\mu_2 H \left[\alpha\,(1-\alpha)\,(h_{b,t} - h_{s,t})^2\right] - \frac{1}{2}\mu_1 Y \frac{\theta\varepsilon}{(1-\theta)(1-\beta\theta)}\pi_t^2 \end{aligned} \tag{A53}$$

Next, we work out the consumption and output terms:

$$\begin{aligned} \alpha c_{s,t}^2 + (1-\alpha)\, c_{b,t}^2 - y_t^2 &= \alpha\left[c_{s,t}^2 - y_t^2\right] + (1-\alpha)\left[c_{b,t}^2 - y_t^2\right] \\ &= \alpha\,(c_{s,t} + y_t)\,(c_{s,t} - y_t) + (1-\alpha)\,(c_{b,t} + y_t)\,(c_{b,t} - y_t) \\ &= \alpha\,(c_{s,t} + y_t)\,(1-\alpha)\,(c_{s,t} - c_{b,t}) - (1-\alpha)\,(c_{b,t} + y_t)\,\alpha\,(c_{s,t} - c_{b,t}) \\ &= \alpha\,(1-\alpha)\,(c_{s,t} - c_{b,t})^2 . \end{aligned} \tag{A54}$$

We can substitute back into the welfare objective:

$$\begin{aligned} U_t - U \simeq & -\frac{1}{2}\mu_1 Y \left\{\alpha\,(1-\alpha)\,(c_{s,t} - c_{b,t})^2 + (1+\eta)\left[\alpha n_{s,t}^2 + (1-\alpha)\, n_{b,t}^2\right]\right\} \\ & -\frac{1}{2}\mu_2 H \left[\alpha\,(1-\alpha)\,(h_{b,t} - h_{s,t})^2\right] - \frac{1}{2}\mu_1 Y \frac{\theta\varepsilon}{(1-\theta)(1-\beta\theta)}\pi_t^2 \end{aligned} \tag{A55}$$

Next, we add and subtract $(1+\eta)\, y_t^2$ from the welfare function:

$$\begin{aligned} U_t - U \simeq & -\frac{1}{2}\mu_1 Y \left\{\alpha\,(1-\alpha)\,(c_{s,t} - c_{b,t})^2 + (1+\eta)\, y_t^2 + (1+\eta)\left[\alpha n_{s,t}^2 + (1-\alpha)\, n_{b,t}^2 - y_t^2\right]\right\} \\ & -\frac{1}{2}\mu_2 H \left[\alpha\,(1-\alpha)\,(h_{b,t} - h_{s,t})^2\right] - \frac{1}{2}\mu_1 Y \frac{\theta\varepsilon}{(1-\theta)(1-\beta\theta)}\pi_t^2 \end{aligned} \tag{A56}$$

Now, we make use of the labor-supply conditions:

$$w_{s,t}N_{s,t} = (N_{s,t})^{1+\eta} C_{s,t}$$

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

We can aggregate the two labor supply conditions and make the assumption that labor supply is equal across agents in the aggregate. Using the aggregate production function, we obtain:

$$w_t N_t = \left(\frac{\Delta_t Y_t}{A_t}\right)^{1+\eta} Y_t = (N_{s,t})^{1+\eta} C_{s,t} = (N_{b,t})^{1+\eta} C_{b,t}$$

Log-linearizing, we obtain an expression for each type of labor:

$$n_{s,t} = \widehat{\Delta}_t + y_t - a_t - \frac{1}{1+\eta} (c_{s,t} - y_t)$$

$$n_{b,t} = \widehat{\Delta}_t + y_t - a_t - \frac{1}{1+\eta} (c_{b,t} - y_t)$$

Using the first-order approximation of the resource constraint:

$$n_{s,t} = \widehat{\Delta}_t + y_t - a_t + \frac{1}{1+\eta} (1-\alpha) (c_{b,t} - c_{s,t})$$

$$n_{b,t} = \widehat{\Delta}_t + y_t - a_t - \frac{1}{1+\eta} \alpha (c_{b,t} - c_{s,t})$$

Then, substituting each labor type into the labor term in the welfare function:

$$\alpha n_{s,t}^2 + (1-\alpha) n_{b,t}^2 - y_t^2 = \alpha \left[\widehat{\Delta}_t + y_t - a_t + \frac{1}{1+\eta} (1-\alpha) (c_{b,t} - c_{s,t})\right]^2$$
$$+ (1-\alpha) \left[\widehat{\Delta}_t + y_t - a_t - \frac{1}{1+\eta} \alpha (c_{b,t} - c_{s,t})\right]^2 - y_t^2$$

Now, expanding the squared terms and dropping higher order terms, we obtain:

$$\alpha n_{s,t}^2 + (1-\alpha) n_{b,t}^2 - y_t^2 \simeq \alpha (y_t - a_t)^2 + \alpha \left[\frac{1}{1+\eta} (1-\alpha)(c_{b,t} - c_{s,t}) \right]^2$$
$$+2\alpha(1-\alpha) \frac{1}{1+\eta} (y_t - a_t)(c_{b,t} - c_{s,t}) + (1-\alpha)(y_t - a_t)^2 + (1-\alpha) \left[\frac{1}{1+\eta} \alpha (c_{b,t} - c_{s,t}) \right]^2$$
$$-2\alpha(1-\alpha) \frac{1}{1+\eta} (y_t - a_t)(c_{b,t} - c_{s,t}) - y_t^2$$

Rearranging:

$$\alpha n_{s,t}^2 + (1-\alpha) n_{b,t}^2 - y_t^2 \simeq (y_t - a_t)^2 + \alpha(1-\alpha) \left[\frac{1}{1+\eta} (c_{b,t} - c_{s,t}) \right]^2 - y_t^2$$

Substituting this expression back into the welfare function:

$$U_t - U \simeq -\frac{1}{2}\mu_1 Y \left\{ \frac{2+\eta}{1+\eta} \alpha (1-\alpha)(c_{b,t} - c_{s,t})^2 + (1+\eta)(y_t - a_t)^2 \right\}$$
$$-\frac{1}{2}\mu_2 H \left[\alpha(1-\alpha)(h_{b,t} - h_{s,t})^2 \right] - \frac{1}{2}\mu_1 Y \frac{\theta\varepsilon}{(1-\theta)(1-\beta\theta)} \pi_t^2 \tag{A57}$$

In a flexible price setting and given our assumption of log-utility, we know that the natural level of output can be expressed in terms of technology:

$y_t^n = a_t$

Replacing this expression into the welfare function, we obtain:

$$U_t - U \simeq -\frac{1}{2}\mu_1 Y \left\{ \frac{2+\eta}{1+\eta} \alpha (1-\alpha)(c_{b,t} - c_{s,t})^2 + (1+\eta)\left(y_t^2 - 2 y_t y_t^n\right) \right\}$$
$$-\frac{1}{2}\mu_2 H \left[\alpha(1-\alpha)(h_{b,t} - h_{s,t})^2 \right] - \frac{1}{2}\mu_1 Y \frac{\theta\varepsilon}{(1-\theta)(1-\beta\theta)} \pi_t^2 \tag{A58}$$

Adding and subtracting the square of natural output, since it is independent from policy, we obtain:

$$U_t - U \simeq -\frac{1}{2}\mu_1 Y \left\{ \alpha(1-\alpha) \frac{2+\eta}{1+\eta} (c_{b,t} - c_{s,t})^2 + (1+\eta)(y_t - y_t^n)^2 \right\}$$
$$-\frac{1}{2}\mu_2 H \left[\alpha(1-\alpha)(h_{b,t} - h_{s,t})^2 \right] - \frac{1}{2}\mu_1 Y \frac{\theta\varepsilon}{(1-\theta)(1-\beta\theta)} \pi_t^2 \tag{A59}$$

Finally, the steady state coefficient $(\mu_2 H)$ of the housing term can be expressed in the terms of $(\mu_1 Y)$, using the first order conditions for the efficient steady state:

$$\mu_2 H = \mu_1 Y \frac{\mu_2 H}{\mu_1 Y} = \mu_1 Y \frac{U'_{h^s} H}{U'_{c^s} Y} = \mu_1 Y \frac{jCH}{HY} = \mu_1 Y,$$

where we choose the housing utility parameter (j) to be one, then, we can express the welfare function in terms of quadratic and gap variables as:

$$W_0 \simeq -\frac{1}{2} E_0 \sum_{t=0}^{\infty} \beta_s^t \left[\widetilde{y}_t^2 + \lambda_\pi \pi_t^2 + \lambda_c \widetilde{c}_t^2 + \lambda_h \widetilde{h}_t^2 \right], \tag{A60}$$

where $\widetilde{y}$, $\widetilde{c}$ and $\widetilde{h}$ are the output, consumption and housing gaps, respectively. The relative policy weights are $\lambda_\pi = \frac{\theta\varepsilon}{(1-\theta)(1-\beta\theta)(1+\eta)}$; $\lambda_c = \frac{\alpha(1-\alpha)(2+\eta)}{(1+\eta)^2}$; $\lambda_h = \frac{\alpha(1-\alpha)}{1+\eta}$.

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