Housing boom-bust cycles and asymmetric macroprudential policy

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Abstract

In this paper I argue that occasionally-binding borrowing constraints are a source of non-linearity that warrant an appropriate non-linear macroprudential policy response. Non-linear policy responses likely better capture the spirit of macroprudential policy. I show that an asymmetric macroprudential policy rule, which lowers the borrowing limit more aggressively during credit booms, obtains better economic outcomes compared to an optimized symmetric rule that is typically studied in the literature. An asymmetric policy response reduces output and inflation tail risks, generating not only better economic stabilization but also positive externalities to monetary policy.

Keywords: asymmetric macroprudential policy, news shocks, credit booms, collateral constraint, tail risks

JEL codes: C61, E32, E44, E61, R21

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1. INTRODUCTION

Asset price booms are frequently associated with an increase in credit through collateral (net worth) effects. The literature on debt-fuelled crises shows that highly leveraged economies develop a greater risk of experiencing heavy contractions and slow recoveries, often experienced as 'financial crisis recessions' (Jordà, Schularick, and Taylor 2015, 2017; Reinhart and Rogoff 2009, 2013; Schularick and Taylor 2012). Borrowing constraints and financial frictions matter much more in a recession than in a boom (Guerrieri and Iacoviello 2017). Borrowing constraints that limit credit issuance during a boom may become non-binding if collateral values rise beyond a certain threshold, leading to debt-driven consumption of housing and non-durable goods. Corrections that can follow a boom lead to deep recessions, as households cut back on consumption and deleverage aggressively (Guerrieri and Lorenzoni 2017). Jensen et al. (2020) show that occasionally-binding borrowing constraints coupled with increasing financial deepending can account for the observed increase in business cycle asymmetry in G7 economies since the mid-1980s.

This source of business cycle asymmetry calls for relevant policy responses that address the financial friction. In this paper I study how a macroprudential policy authority can use a maximum loan-to-value (LTV) ratio policy rule to address the distortion that leads to this boom-bust cycle, building on the existing literature (Kannan, Rabanal, and Scott 2012; Lambertini, Mendicino, and Punzi 2013b; Rubio and Carrasco-Gallego 2014). I show that a policy of asymmetric countercyclical LTV ratio movements can tame the rise in credit during a boom, preventing households from building excessive leverage and therefore lowering the severity of the recession that follows. This policy therefore specifically addresses the fact that borrowing constraints can become slack during a boom, and I show that it is superior to the use of a linear optimised LTV rule that has been studied in the literature.[1]

Asymmetric policy stances also tie in with the core purpose of macroprudential policy, since its inherent task is to limit, pre-emptively, the build-up of systemic risk (Bank of England 2009). This is especially the case since high leverage increases the probability of a financial crisis, making policymakers generally averse to credit booms and thus targeting peaks more fervently (Cerutti, Claessens, and Laeven 2017; Lautenschläger 2018; Rogers 2014). Empirical evidence suggests that macroprudential policy is typically more effective during credit booms (Cerutti, Claessens, and Laeven 2017), likely on account of more intense implementation during the build-up phase. Intuitively, a strong reaction to credit booms may represent a willingness to dampen the build-up phase of the credit cycle, so that the economy experiences a more muted correction in the wake of a bursting bubble.

I study asymmetric macroprudential policy using a DSGE model with representative saver and borrower households and housing, as in Iacoviello (2005) and Rubio and Carrasco-Gallego (2014). The financial friction in the model originates from collaterized borrowing, giving rise to a financial accelerator which amplifies the effect of a shock to net worth on economic activity (Bernanke, Gertler, and Gilchrist 1999; Kiyotaki and Moore 1997). This constraint motivates the use and effectiveness of macroprudential policy which controls leverage countercylically through adjustments to the maximum LTV ratio. These adjustments tame credit booms by weakening the financial accelerator, thus dampening boom-bust cycles when these are driven by inefficient or strong house price and credit growth. The driver of boom-bust cycles are unrealized news shocks, which give rise to the formation of house price bubbles through expectations which are ex-ante rational but revealed ex-post to be disconnected from fundamentals.[2] Such shocks have become more popular in models with a housing market as an additional driver of business cycles (Bruneau, Christensen, and Meh 2018; Burlon et al. 2018; Kaplan, Mitman, and Violante 2020; Lambertini, Mendicino, and Punzi 2013b).

I find that conducting macroprudential policy asymmetrically reduces volatility in the economy, by more than when the borrowing limit is revised symmetrically. By tightening collateral constraints more stongly during a boom, the rise in credit and consumption is contained, thereby limiting the fallout during the correction. I show that the resulting lower volatility in credit and output is a function of the degree of asymmetry in the policy response. Moreover, while any macroprudential policy response reduces the skewness of the output distribution, asymmetric policy results in the lowest 'GDP-at-Risk' (Cecchetti 2008). Asymmetric macroprudential policy also generates positive spillovers by reducing the strain on monetary policy during housing booms. Therefore, I also contribute to the discussion on the interaction between monetary and macroprudential policies (Angelini, Neri, and Panetta 2014; Angeloni and Faia 2013; Kannan, Rabanal, and Scott 2012; Lambertini, Mendicino, and Punzi 2013b; Rubio and Carrasco-Gallego 2014).

The rest of the paper is structured as follows. Section 2 describes the model and defines a competitive equilibrium. Section 3 discusses housing bubbles as the main source of aggregate uncertainty, and Section 4 discusses the calibration and solution method used. Section 5 analyzes business cycle stabilization under optimal symmetric and asymmetric macroprudential policies, while Section 6 shows long run outcomes under these different macroprudential policy strategies. Section 7 concludes.

2. THE MODEL

I use a New Keynesian model with financial frictions originating from enforcement constraints. The setup is very similar to that in Rubio and Carrasco-Gallego (2014, 2016) and Kanik and Xiao (2014) who build on Iacoviello (2005). It is also very similar to Liu, Wang, and Zha (2013), apart from the fact that in their model the financial friction is faced by the productive sector. There are six types of infinitely-lived agents in the model: patient households, impatient households, intermediate and final goods firms, the central bank and the financial regulator. The numeraire is the price of the final good, therefore wages and house prices are expressed in units of consumption goods.

Households consume the final good and housing services, hold housing as a durable good and supply labour to intermediate goods firms. Housing is fixed in supply and does not depreciate.[3] Intermediate goods firms use labour to produce differentiated goods, which are packaged and sold as a final homogeneous good by the final good firm.[4] Intermediate goods firms are subject to a price setting friction, which introduces nominal rigidities in the model, giving rise to real effects of monetary disturbances. This allows the study of macroprudential policy in the presence of monetary policy. Impatient households face a borrowing constraint. When this is binding, it introduces amplification of real disturbances via a financial accelerator effect through changes in net wealth (Bernanke, Gertler, and Gilchrist 1999). Given the presence of these two distortions, the central bank and the financial regulator are tasked with maintaining price and financial stability respectively using appropriate policy tools. The economy is perturbed by a single aggregate shock to housing preferences that can be unanticipated, or arrives as news four quarters in advance. Most of the first-order conditions (FOCs) of the model are standard and are provided in the Online Appendix for reference.

2.1 Households

The two household types in the model, each a continuum of size one, have almost identical preferences. The source of heterogeneity between them is the rate at which they discount the future. As is standard in the literature, households with the higher discount factor are termed patient and hence will in equilibrium save and receive interest on resources (Kiyotaki and Moore 1997). On the other hand, households with the lower discount factor will in equilibrium want to consume more than their budget, and hence will borrow and pay interest on resources to finance spending. Both household types derive utility from consumption, housing and leisure, and take wages and the interest rate as given. Let household variables be denoted with $i \in \{s, b\}$ for savers and borrowers respectively. I assume that credit flows from savers to borrowers efficiently, so the presence of a financial intermediary is redundant.[5]

2.1.1 Patient households - savers

Savers aim to maximise lifetime utility subject to their per-period budget constraint, discounting future utility streams at $\beta_s \in (0, 1)$. They choose consumption $C_{s,t}$, housing $H_{s,t}$ and labour supply in hours $N_{s,t}$, and form external habits in consumption governed by the parameter $\varrho \in (0, 1)$. Their objective is

$$\max_{C_s, H_s, N_s, B} \mathbb{E}_0 \left\{ \sum_{t=0}^{\infty} \beta_s^t \left((1 - \varrho) \log \left(C_{s,t} - \varrho C_{s,t-1} \right) + \mathrm{j}_t \log H_{s,t} - \tau \frac{N_{s,t}^{1+\varphi}}{1 + \varphi} \right) \right\}$$

where $\tau > 0$ is a preference parameter which shifts the labour supply schedule, and $\varphi > 0$ is the inverse of the Frisch elasticity of labour supply. The process j_t is a shock to the marginal utility of housing, which is typically referred to as a housing demand shock in the literature.[6] Since this is the key source of uncertainty in this paper, I discuss it at length further below.

Patient households consume the final good and housing services, change their stock of housing at the current market price and save via a one-period loan instrument B_t. They earn labour income, and accrue savings from the previous period with interest. Furthermore, savers are assumed to own the production sector and hence receive lump-sum profits from intermediate goods firms. Their budget constraint is:

$$C_{s,t} + q_t(H_{s,t} - H_{s,t-1}) + B_t = w_{s,t}N_{s,t} + \frac{R_{t-1}B_{t-1}}{\pi_t} + \Pi_t \tag{1}$$

where q_t is the relative price of housing to consumption goods, $w_{s,t}$ is the real hourly wage rate, R_t is the gross nominal interest rate and $\pi_t \equiv P_t/P_{t-1}$ is the gross inflation rate for goods prices. Savers are assumed to lend in real terms in time t and receive back a nominal amount in time $t+1$, such that debt is not indexed, as in Iacoviello (2005).[7] The term Π_t represents profits from intermediate goods producers, defined below.[8]

2.1.2 Impatient households - borrowers

Impatient households have preferences similar to savers, with the exception of the discount factor $\beta_b \in (0,1)$, where by assumption $\beta_b < \beta_s$:

$$\max_{C_b,N_b,H_b,B} \ \mathbb{E}_0 \left\{ \sum_{t=0}^{\infty} \beta_b^t \left((1-\varrho)\log\left(C_{b,t} - \varrho C_{b,t-1}\right) + \mathrm{j}_t \log H_{b,t} - \tau \frac{N_{b,t}^{1+\varphi}}{1+\varphi} \right) \right\}.$$

They receive labour income and supplement their budget by obtaining an amount of borrowing B_t as a one-period loan at the gross rate R_t. These inflows finance the purchase of the consumption good and housing, and the repayment of the previous period's loan:

$$C_{b,t} + q_t(H_{b,t} - H_{b,t-1}) + \frac{R_{t-1}B_{t-1}}{\pi_t} = w_{b,t}N_{b,t} + B_t \tag{2}$$

taking the wage and interest rate as given. Note that the loan is written on the right hand side of the budget constraint. This implies a market clearing condition in every period such that the total saving by patient households through this loan instrument is equal to the total borrowing by impatient households.[9]

Following Kiyotaki and Moore (1997), savers can only enforce repayment of the loans by securing them against collateral. Housing is a durable good which can be pledged as collateral, and the fraction of borrowing relative to housing wealth is the LTV ratio. Therefore the maximum borrowing for impatient households is limited by a collateral constraint, written in terms of a time-varying LTV ratio m_t of their expected nominal housing wealth in the next period:

$$R_t B_t \leq \mathsf{m}_t \, \mathbb{E}_t \left\{ q_{t+1} \pi_{t+1} \right\} H_{b,t} \tag{3}$$

Section (2.4) discusses how the LTV ratio m_t is used as a policy tool by the financial regulator to actively relax or tighten the collateral constraint to boost or reduce credit flows. Since house prices respond to economic conditions, the collateral constraint is endogenous and thus can generate a strong financial accelerator, leading to amplified responses of output to exogenous disturbances.

The FOCs for B and H_b merit some discussion and are:

$$\frac{1-\varrho}{C_{b,t}-\varrho C_{b,t-1}} = \beta_b \, \mathbb{E}_t \left\{ \left(\frac{1-\varrho}{C_{b,t+1}-\varrho C_{b,t}} \right) \frac{R_t}{\pi_{t+1}} \right\} + R_t \mu_t \tag{4}$$

$$q_t \left(\frac{1-\varrho}{C_{b,t}-\varrho C_{b,t-1}} \right) = \frac{\mathsf{j}_t}{H_{b,t}} + \beta_b \, \mathbb{E}_t \left\{ q_{t+1} \left(\frac{1-\varrho}{C_{b,t+1}-\varrho C_{b,t}} \right) \right\} + \mu_t \, \mathbb{E}_t \left\{ \mathsf{m}_t q_{t+1} \pi_{t+1} \right\} \tag{5}$$

where $\mu_t > 0$ is the Lagrange multiplier on the borrowing constraint, and is a key variable for the analysis in this paper. Equations (4)-(5) are the Euler equations over borrowing and housing demand respectively. When (3) binds, borrowers are constrained by their borrowing limit and are not able to fully smoothen consumption, making them unable to adjust fully in the wake of shocks. This implies that they have a higher marginal propensity to consume out of current income than savers. Note that shocks to housing preferences j_t generate an immediate response in housing demand and house prices, for both household types.

2.2 Firms

The supply side of the model is standard as in the New Keynesian model, featuring Dixit-Stiglitz monopolistic competition with price setting frictions. Production of the final consumption good involves two stages: the manufacture of intermediate goods by a continuum of firms and the packaging of all these intermediate goods into a final good by another. Both firms are owned by savers and thus use the corresponding stochastic discount factor in intertemporal decisions.

2.2.1 Final goods firm

The final consumption good is produced by a competitive firm that takes as inputs a continuum of intermediate goods $y_{j,t}$, where $j \in (0,1)$, and aggregates them using Dixit-Stiglitz CES technology with elasticity of substitution between varieties $\sigma > 1$:

$$Y_t = \left[\int_0^1 y_{j,t}^{\frac{\sigma-1}{\sigma}}\, dj\right]^{\frac{\sigma}{\sigma-1}}. \tag{6}$$

The firm aims to minimize the cost of a bundle $\int_0^1 p_{j,t} y_{j,t} dj$ in each period, subject to the technology described above. Demand for intermediate good $y_{j,t}$ is given by:

$$y_{j,t} = \left(\frac{p_{j,t}}{P_t}\right)^{-\sigma} Y_t \tag{7}$$

where the aggregate price P_t for the final good is a weighted average over the set of intermediate goods prices:

$$P_t = \left(\int_0^1 p_{j,t}^{1-\sigma}\, dj\right)^{\frac{1}{1-\sigma}}. \tag{8}$$

2.2.2 Intermediate goods firms

A continuum of intermediate goods firms indexed by $j \in (0,1)$ operate in a monopolistically-competitive market, and each firm faces the downward sloping demand curve (7) with an elasticity depending on the substitutability across goods. Production of each firm is based on constant returns to scale technology using labour from both household types. Each firms' production technology delivers constant returns to scale:

$$y_{j,t} = n_{s,j,t}^{\alpha} n_{b,j,t}^{1-\alpha} \tag{9}$$

where $n_{s,j,t}$ and $n_{b,j,t}$ are labour input from savers and borrowers respectively and $\alpha \in (0,1)$ is the share of income from production of savers. Cobb-Douglas technology has some desirable features; it allows for an analytical solution for the steady state of the model, and yields an interpretation for α and $1-\alpha$ as the relative economic size of saver and borrower households respectively.[10] Each firm j faces two optimization problems; a static choice over labour to minimize production costs in each period, and a dynamic choice for the price which maximises present and future discounted profits. Firms take wages as given in both these problems. Cost minimization by any firm j is given by:

$$\min_{n_{s,j,t}, n_{b,j,t}} \quad w_{s,t} n_{s,j,t} + w_{b,t} n_{b,j,t} + MC_{j,t} \left(y_{j,t} - n_{s,j,t}^{\alpha} n_{b,j,t}^{1-\alpha} \right) \tag{10}$$

where MC_t are real marginal costs. The relevant FOCs are in the Online Appendix . As marginal costs of production do not depend on characteristics of any firm j, and since technology is symmetric across all firms, I drop the subscript j in later parts of the paper to ease notation.

Intermediate goods firms are subject to the Calvo-Yun price setting friction in their profit maximisation. In any given period a random fraction of firms ω are not able to change prices. With this knowledge, the remaining $1-\omega$ of firms set prices such that they maximise present and expected future discounted profits:

$$\max_{p_{j,t}} \; \mathbb{E}_t \left\{ \sum_{i=0}^{\infty} \omega^i \Lambda_{i,t+i} \left[\frac{p_{j,t}}{P_{t+i}} y_{j,t+i} - MC_{t+i} y_{j,t+i} \right] \right\} \tag{11}$$

where $\Lambda_{i,t+i} = \beta_s^i (C_{s,t+i} - \varrho C_{s,t+i-1})/(C_{s,t} - \varrho C_{s,t-1}) = \beta_s \widetilde{C}_{s,t+i}/\widetilde{C}_{s,t}$ is the relevant stochastic discount factor and the term in square brackets is equal to profit in period $t+i$, which is rebated to savers. Using the demand curve faced by each firm $y_{j,t} = (p_{j,t}/P_t)^{-\sigma} Y_t$, we can write the above problem as:

$$\max_{p_{j,t}} \; \mathbb{E}_t \left\{ \sum_{i=0}^{\infty} \omega^i \Lambda_{i,t+i} Y_{t+i} \left[\left(\frac{p_{j,t}}{P_{t+i}} \right)^{1-\sigma} - MC_{t+i} \left(\frac{p_{j,t}}{P_{t+i}} \right)^{-\sigma} \right] \right\}. \tag{12}$$

As shown in Christiano, Trabandt, and Walentin (2011), the solution to this problem leads to a system of equations which characterise the non-linear formulation of the New Keynesian Phillips curve and jointly determine price dynamics. Log-linearization of these conditions around a zero net inflation rate, combined with the dynamics of aggregate prices, yields the familiar New Keynesian Phillips curve:

$$\widehat{\pi}_t = \beta_s \, \mathbb{E}_t\{\widehat{\pi}_{t+1}\} + \frac{(1-\omega)(1-\omega\beta_s)}{\omega} \widehat{MC}_t \tag{13}$$

where variables with a hat denote percentage deviations from steady state.

2.3 The central bank

The central bank implements monetary policy to promote price stability. It steers the nominal interest rate in accordance with a standard Taylor rule, reacting to the deviations of inflation and output from their steady state values. The interest rate response is sluggish, reflecting the central bank's aversion to large rate revisions within a period. The interest rate evolves according to:

$$R_t = \overline{R}^{(1-\rho_R)} \left(\frac{\pi_t}{\overline{\pi}}\right)^{\delta_\pi(1-\rho_R)} \left(\frac{Y_t}{\overline{Y}}\right)^{\delta_Y(1-\rho_R)} R_{t-1}{}^{\rho_R} \tag{14}$$

The parameters δ_π, $\delta_Y > 0$ control the sensitivity of the interest rate to the deviation of gross inflation π_t and output from their steady state values ($\overline{\pi}$ and $\overline{Y}$ respectively). $\overline{R}$ is the interest rate in the steady state and ρ_R controls the smoothness of changes in the interest rate over a given period.

2.4 The financial regulator

Macroprudential policy is the prerogative of the financial regulator, with an objective of maintaining financial stability by taming excessive credit, or by supporting credit when it is anaemic.[11] A macroprudential tool is typically tailored specifically to control leverage countercyclically by reacting to credit growth (Kannan, Rabanal, and Scott 2012; Rubio and Carrasco-Gallego 2014, 2016) or to measures of credit gaps, such as the deviation of the credit to GDP ratio from its long term trend or equilibrium (Angelini, Neri, and Panetta 2014). The latter argue that macroprudential policy can be considered a reaction to abnormal developments in credit, that is, credit growing faster than output. The credit gap has been identified as a good early warning indicator for excessive growth in credit

(Drehmann and Yetman 2018), and is also the reference indicator used in practice to operate the Countercyclical Capital Buffer for banks (Basel Committee 2010).

I first specify a benchmark, symmetric macroprudential policy rule that does not distinguish between credit booms and busts. This negative feedback rule sets a time-varying LTV ratio m_t, which alters impatient households' borrowing constraint (3). The LTV ratio is raised or lowered from its steady state value $\overline{\mathsf{m}}$ countercyclically in response to the deviation of the credit to GDP ratio $\Omega_t \equiv B_t/Y_t$ from its value in the steady state $\overline{\Omega} \equiv \overline{B}/\overline{Y}$. The policymaker's response, as for interest rate, is also potentially sluggish. The benchmark LTV rule is:

$$\mathsf{m}_t = \overline{\mathsf{m}}^{(1-\rho_\mathsf{m})} \left(\frac{\Omega_t}{\overline{\Omega}}\right)^{-\delta_\mathsf{m}(1-\rho_\mathsf{m})} \mathsf{m}_{t-1}^{\rho_\mathsf{m}} \tag{15}$$

where $\overline{\mathsf{m}}$ is the LTV ratio in steady state, $\delta_\mathsf{m} > 0$ is the sensitivity of the LTV ratio to deviations in the credit ratio, and ρ_m is the smoothing parameter over changes to the LTV ratio. These parameters will be optimised in Section 4.

Next is the state-dependent asymmetric rule, which is more aggressive during credit booms. As discussed in the introduction, this response can mitigate a slack borrowing constraint during credit booms and is inherent in the pre-emptive character of macroprudential policy. The asymmetric macroprudential policy function is given by:

$$\mathsf{m}_t = \overline{\mathsf{m}}^{(1-\rho_\mathsf{m})} \left(\frac{\Omega_t}{\overline{\Omega}}\right)^{-\widetilde{\delta}_\mathsf{m}(1-\rho_\mathsf{m})} \mathsf{m}_{t-1}^{\rho_\mathsf{m}} \tag{16}$$

where $\widetilde{\delta}_\mathsf{m} = (1-\mathbb{1}_H)\delta_\mathsf{m} + \mathbb{1}_H\overline{\delta_\mathsf{m}}$, with $\overline{\delta_\mathsf{m}} > \delta_\mathsf{m}$ and $\mathbb{1}_H$ is an indicator function for periods of credit booms:

$$\mathbb{1}_H = \begin{cases} 1 & \text{if } \Omega_t > \overline{\Omega} \\ 0 & \text{otherwise.} \end{cases}$$

This rule yields the same LTV ratio response during a credit bust, as in the symmetric rule, but drives a stronger response during a credit boom.[12] As in the symmetric rule (15), I allow the policymaker to adjust the LTV ratio around its steady state value, subject to the same degree of persistence ρ_m. It is useful to define the strength of the asymmetry, the 'kink', as:

$$\kappa = \frac{\overline{\delta_{\mathsf{m}}}}{\delta_{\mathsf{m}}} \tag{17}$$

where $\kappa \in [1, \infty)$ is a summary measure of how strong the response is during a boom relative to a recession.

2.5 *Market clearing*

The market for labour employed by intermediate goods firms clears:

$$N_{s,t} = \int_0^1 n_{s,j,t}\, dj = \alpha \frac{MC_t Y_t}{w_{s,t}} \tag{18}$$

$$N_{b,t} = \int_0^1 n_{b,j,t}\, dj = (1-\alpha) \frac{MC_t Y_t}{w_{b,t}}. \tag{19}$$

I keep the housing supply (H) fixed and normalized to 1, and the following housing market clearing condition holds in each period:

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

The goods market clearing condition can therefore be written as:

$$Y_t = C_{s,t} + C_{b,t} = \frac{1}{s_t} N_{s,t}^{\alpha} N_{b,t}^{1-\alpha} \tag{21}$$

such that all output produced is consumed, and where $s_t = \int_0^1 \left(\frac{p_{j,t}}{P_t}\right)^{-\sigma} dj > 1$ is the measure of output cost of price dispersion, which reduces aggregate output compared with an economy with flexible prices (Yun 1996).[13]

2.6 *Equilibrium and solution method*

A competitive equilibrium is defined as a sequence of prices and quantities that satisfy the dynamical system listed in the Online Appendix and the shock processes for j, discussed in the next section.[14] The difference in discount factors between savers and borrowers implies that the Lagrange multiplier on the borrowing constraint μ_t is positive and hence the borrowing limit binds both in the steady state and in small deviations from it. Monetary and macroprudential policies are implemented in an uncoordinated fashion, with either authority taking the actions of the other as given.[15]

Although the borrowing constraint (3) is binding in the steady state, it may become slack when the economy is hit by a sequence of shocks. Similarly, the asymmetric macroprudential rule (16) is not differentiable at the kink. The borrowing constraint and the macroprudential rule therefore introduce two occasionally-binding constraints, and standard local solution approaches based on perturbation cannot be used to solve the model. Instead, I use the method proposed by Guerrieri and Iacoviello (2015), who argue that occasionally-binding constraints can be thought of as defining two regimes of the same model. In one regime any given constraint binds, and in the other it is slack. The solution is based on a piecewise linear approximation around the non-stochastic steady state of the model. This approach has also been used to simulate monetary policy at the zero lower bound (Guerrieri and Iacoviello 2017; Rubio and Yao 2020). To the best of my knowledge this paper is the first to use this technique to solve and simulate a model in which one of the occasionally-binding constraints is a macroprudential policy reaction function. Even though the model is approximated at first order, the solution can deliver significant non-linearities as the coefficients of the decision rules are dependent on the time agents believe the economy will be in any particular regime, which in turn is a function of the state variables.[16]

3. GENERATING HOUSING BOOM-BUST CYCLES

The prevalent driving forces in DSGE models are unanticipated shocks hitting technology, preferences or costs, which account for all of the variation in macroeconomic variables. However, *anticipated* shocks – shocks expected to hit at some future period – capture waves of consumer sentiment and are important drivers of house price dynamics (Piazzesi and Schneider 2009). Lambertini, Mendicino, and Punzi (2013a) find that in episodes of housing booms, expectations of rising house prices explain an important share of house price variation.[17] I generate a housing boom-bust cycle through news shocks in housing preferences j_t. Housing preferences shocks can be actual *or perceived* changing attitudes towards housing, such as a drive by government encouraging broader home ownership, or expected demographic pressure such as migration.[18]

Positive *unanticipated* housing preference shocks increase the marginal utility of housing, stimulating demand. Since housing supply is fixed, the increase in demand maps directly into an increase in house prices. This boosts net worth and relaxes borrowers' borrowing constraint, triggering a boom. This is also the case for an *anticipated* future increase in demand which is driven by news, since households are forward-looking and react immediately.[19] In cases when this news turns out to be false, households realise that high house prices are not supported by fundamentals, and therefore housing is overvalued. The 'housing bubble' bursts, house prices revert to their original level, borrowers de-leverage, and consumption and output drop. The fall in households' net worth then further amplifies the contraction, as the borrowing constraint tightens during the bust and consumption falls further, and so on.

The process j_t follows a first-order autoregressive process in logs around the steady state value $\bar{\mathrm{j}}$, with mean zero i.i.d shocks. In addition to unanticipated housing demand shocks $\epsilon_{\mathrm{j},t}$, households are hit with news about a housing demand shock n periods in advance $\widetilde{\epsilon}_{\mathrm{j},t-n}$:

$$\log(\mathrm{j}_t) = (1-\rho_{\mathrm{j}})\log(\bar{\mathrm{j}}) + \rho_{\mathrm{j}}\log(\mathrm{j}_{t-1}) + \epsilon_{\mathrm{j},t} + \widetilde{\epsilon}_{\mathrm{j},t-n} \tag{22}$$

where $\epsilon_{\mathrm{j},t} \sim N(0,\sigma_{\mathrm{j}}^2)$ and $\widetilde{\epsilon}_{\mathrm{j},t-n} \sim N(0,\sigma_{\mathrm{j}}^2)$ are uncorrelated i.i.d. shocks. The shock $\widetilde{\epsilon}_{\mathrm{j},t-n}$ represents a news (belief) shock, received at time $t-n$, about an event happening at t. If this news shock, which is an expectation, turns out to be unfounded, then $\epsilon_{\mathrm{j},t} = -\widetilde{\epsilon}_{\mathrm{j},t-n}$ and the housing demand term j_t never actually moves. This mechanism captures the expectations-driven cycle described above, and is similar to shock processes used in other recent studies on macroprudential policies (Ferrero, Harrison, and Nelson 2018; Lozej, Onorante, and Rannenberg 2018). I assume that any news that arrives is about events 1 year into the future, so $n = 4$, as in Lambertini, Mendicino, and Punzi (2013b, 2017).

Following Lorenzoni (2009, 2010) and Lambertini, Mendicino, and Punzi (2013b), households, firms, the central bank and the financial regulator cannot distinguish between a true shock to fundamentals and a non-fundamental expectations shock. This also follows views shared by policymakers, as discussed by Trichet (2005). News about the future arrives exogenously, and there is no way ex-ante to verify the reliability of such news. From the point of view of policy, the non-fundamental housing demand shock is a distortion as it gives rise to an inefficient boom and bust cycle. In this context, there is a strong scope for active macroprudential policy (Burlon et al. 2018; Lambertini, Mendicino, and Punzi 2013b). In the stochastic simulations I run below, unless otherwise stated, housing demand shocks can be unanticipated, anticipated, and unrealized news (a bubble).

4. CALIBRATION

A period in the model is a quarter. Most of the parameters are set at values typically used or estimated in the literature, and are summarized in Table 1. I set the discount factor β_s at 0.9901, such that in the steady state the annualised net interest rate is 4%, and β_b at 0.985. The latter choice implies that the collateral constraint can become slack when the economy is perturbed by a housing preference shock. I set both the inverse of the Frisch labour supply elasticity and the external habit persistence parameter ϱ at 0.5, as estimated in Iacoviello and Neri (2010).[20] The preference parameter on labour τ is set at 0.844 such that steady state output is normalized at 1.

I set $\bar{\mathsf{j}}$ at 0.06 such that the steady state level of total housing wealth to annual output is around 1.6, close to the value targeted in (Iacoviello and Neri 2010), and $\overline{\mathsf{m}}$ to 0.9, which is the same value used by Rubio and Carrasco-Gallego (2014) and Iacoviello (2015). This LTV ratio reflects borrower household leverage which is high but within ranges observed in the data.[21] The share of income from production accruing to savers α is set at 0.64, as estimated in Iacoviello (2005). This implies that savers own about 75% of housing wealth. This calibration ensures that the collateral effect is strong enough to generate a positive response of output to a house price increase.

The parameters involving price setting are standard. I set the elasticity of substitution between intermediate good varieties σ at 6, which implies a steady state mark-up over marginal costs of 20%, and the Calvo parameter ω at 0.75, which implies that on average intermediate goods firms can reset prices once every four quarters. The shock variance for the unanticipated and news shocks is calibrated at 0.054 such that the borrowing constraint is slack around half of the time in stochastic simulations when macroprudential policy is passive ($\mathsf{m}_t = \overline{\mathsf{m}}, \quad \forall t$). The persistence parameter for the housing shock ρ_{j} is the same as the estimate in Iacoviello and Neri (2010) at 0.96.[22]

[INSERT TABLE 1 HERE]

Turning to the monetary policy reaction function, the calibration of the Taylor rule parameters is standard and δ_π is set at 1.5, while δ_Y at 0.125 (a response of 0.5 to annualised output). The inertia in the Taylor rule on the interest rate ρ_R is set at 0.8 as in McCallum (2001), which reflects a strong preference for small changes in the policy rate from one period to another.

The reaction and persistence parameters $\{\delta_{\mathsf{m}}, \rho_{\mathsf{m}}\}$ in the symmetric LTV rule (15) are set by following the Optimal Simple Rule (OSR) literature, and therefore deserve some discussion. The objective of macroprudential policy is to reduce systemic risk, but the latter is unobservable. Following Kannan, Rabanal, and Scott (2012), Angelini, Neri, and Panetta (2014) and Rubio and Yao (2020), I assume that a suitable proxy for systemic risk is the variability of the credit to output ratio. Lower variability in this ratio would then be synonymous with reduced systemic risk. In principle it is possible to meet this objective quickly and effectively by triggering large movements in the LTV ratio, that is, setting a very high δ_{m}. Yet in practice this behaviour is hardly observed and any regulatory authority in general would want to avoid drastic and unpalatable policy measures, so I assume that the second objective of policy concerns the variability of the instrument.

I therefore specify the macroprudential loss function as the sum of the variability in both the credit to output ratio and the LTV ratio:

$$L = \sigma_\Omega^2 + \omega_{\mathsf{m}} \sigma_{\mathsf{m}}^2. \tag{23}$$

This welfare criterion follows the 'revealed-preferences' approach of Kannan, Rabanal, and Scott (2012) and Angelini, Neri, and Panetta (2014) and is not microfounded but modelled on policy experience.[23] In contrast with the studies listed above, I do not include the variability of output as this could create some overlap between the goals of monetary and macroprudential policy, as discussed in Section 2.4. I assume the financial authority cares more about the volatility in the credit ratio than that in the LTV ratio, and I set ω_{m} to 0.50. The OSR solution is the tuple $\{\delta^*_{\mathsf{m}}, \rho^*_{\mathsf{m}}\}$ which minimizes this loss:

$$\{\delta^*_{\mathsf{m}}, \rho^*_{\mathsf{m}}\} = \arg\min L(\delta_{\mathsf{m}}, \rho_{\mathsf{m}}). \tag{24}$$

This minimization is subject to the structure of the economy as described above. The solution to (24), obtained while taking monetary policy as given and fixed at the benchmark calibration, yields $\delta^*_{\mathsf{m}} = 0.75$ and $\rho^*_{\mathsf{m}} = 0$. Refer to the Online Appendix for more details. Given the structure and calibration of the rest of the economy, it is optimal for the financial authority operating under the symmetric rule to respond to credit conditions without being tied to the LTV ratio it set in the previous period. I solve for the optimal asymmetric rule in the next section.

It is instructive to see how an asymmetric LTV rule performs relative to alternative policies. In Figure 1 I show the dynamic responses of output, the credit to GDP ratio, house prices and the LTV ratio to an expectations-driven housing bubble shock as described above. This shock generates a boom-bust cycle in which housing demand, credit and output rise and then collapse. The alternative rules I consider are passive policy, which keeps the LTV ratio fixed throughout, and the optimised symmetric policy rule described above. For the purpose of this illustration, the asymmetric rule is arbitrarily calibrated to deliver an LTV response that is twice as strong as the symmetric rule during credit booms, and the same response otherwise ($\kappa = 2, \overline{\delta_{\mathsf{m}}} = 1.5$).

In the absence of an active macroprudential policy, optimism about future housing demand generates a strong boom that lasts for four quarters, in which credit and output rise strongly. In all four periods the collateral constraint becomes slack, and the fixed maximum LTV ratio is not binding on households. The boom is followed by a correction when households do not observe an actual rise in housing demand at $t + 4$, realise that housing is overvalued and delever. House prices fall sharply, triggering a drop in impatient households' borrowing, consumption and housing investment via the collateral effect, tipping the economy into a recession.[24] The rise in credit and output is dampened when the optimal symmetric LTV rule is active, as the macroprudential authority lowers the LTV ratio to stem the rise in borrowing. Subsequently, the correction is not as severe. The countercyclical LTV response keeps the borrowing constraint binding in the first period of the boom, however it is not enough to keep borrowing constrained in subsequent periods. The macroprudential authority can dampen the rise in credit and output further by using an asymmetric rule that lowers the maximum LTV ratio more aggressively, reducing the periods in which households are not bound by the limit. Therefore, asymmetric policy has the potential to address the occasionally-binding borrowing constraint, leading to more stable credit and output dynamics in the wake of shocks.

[INSERT FIGURE 1 HERE]

5. OPTIMAL POLICY ASYMMETRY

What is the optimal level of macroprudential policy asymmetry? Given policymakers' preferences reflected by the arguments and parameters in loss function (23), I search for the value of $\overline{\delta_{\mathsf{m}}}$, keeping δ_{m} fixed at 0.75, to find the optimal value of policy asymmetry κ.[25] I simulate the model when it is hit by housing demand shocks over a range for κ and plot the variance of consumption, output, inflation and the credit to output ratio relative to the benchmark case of symmetry ($\kappa = 1$). For comparability, I feed in the same sequence of shocks used over the iterations for each value of κ.[26] The results, shown in Figure 2, display a monotone relationship between the degree of asymmetry in macroprudential policy and the relative variance of key variables. Stronger asymmetry as prescribed by equation (16) on average leads to lower output, inflation and credit volatility, at the cost of more volatile LTV ratios. The relationship between asymmetry and relative volatility is not linear. Slight departures from symmetric policy yield relatively large improvement in macro-stabilization, yet the policy runs into diminishing returns and at higher levels of asymmetry it becomes progressively harder to reduce volatility further.

[INSERT FIGURE 2 HERE]

Asymmetric policy also induces a trade-off between less volatility in macroeconomic indicators and a more volatile policy tool. Under the assumed parameters in the loss function, this trade-off is minimized at $\overline{\delta_{\mathsf{m}}^*} = 32.5$, which implies $\kappa = 43.3$. As Figure 3 shows, the solution for the optimal asymmetric policy response is unique and obtains at the point at which the gains in loss from reduced credit variability is equal to the increase in loss from increased LTV ratio volatility. A secondary but important consideration is the lower induced volatility in inflation, which generates positive spillovers to monetary policy.

[INSERT FIGURE 3 HERE]

[INSERT FIGURE 4 HERE]

To explore the link between how frequently the constraint binds with a rise in asymmetry, I track the average number of periods in which the borrowing constraint is binding in each case. The economy can in principle be in any one of the four regimes at any point in time; credit boom and credit bust, with the borrowing constraint either binding or slack. However, it is unlikely for households to be off their constraint during a credit bust, since collateral values are typically low in this regime. Figure 4 shows the proportion of the time the economy spends in each of the four regimes over rising values of κ. As discussed, rising LTV rule asymmetry lowers the probability that the economy experiences a slack constraint during a boom (Regime 2), and therefore spends more time in the regime in which the constraint binds (Regime 1). Moreover, by taming the boom phase of the cycle, the policy also reduces the fraction of the time that the economy spends in a credit bust (Regime 3), and this also contributes to a higher probability of being in Regime 1. Meanwhile, the economy spends a trivial share of the time in Regime 4, which barely changes over κ, and likely reflects numerical error in the solution method rather than any economic channel.

5.1 Decision rules

The decision rules of the economy are significantly non-linear owing to the borrowing constraint and the asymmetric LTV rule. Figure 5 shows the decision rules for output, credit, the LTV ratio and the Lagrange multiplier on the borrowing constraint as a function of the housing preference term. I express the latter in deviations from steady state, $\widehat{\mathsf{j}} = \mathsf{j} - \bar{\mathsf{j}}$. When $\widehat{\mathsf{j}} \leq 0$ the decision rules are linear, as expected. However, the policy rules experience a kink when $\widehat{\mathsf{j}} > 0$, due to the asymmetric LTV rule. I also show, for comparison, the resulting optimal responses under the case of a symmetric LTV rule. In this case, the decision rules become kinked once – at the point at which the borrowing constraint becomes slack. The circular marker in Figure 5 highlights this point. The lower slope of the decision rules from that point on implies relatively muted behaviour since the propensity of borrower households to consume out of rising housing wealth is lower, dampening the financial accelerator. Asymmetric macroprudential policy generates decision rules for credit and output with a much lower slope than in the symmetric case when $\widehat{\mathrm{j}} > 0$, since households' borrowing capacity is constrained relatively more than in the symmetric case. As the borrowing constraint is tightened more aggressively during booms, the Lagrange multiplier falls at a much slower rate. Consequently, the collateral constraint remains binding far off from the vicinity of the steady state. This summarizes the effectiveness of the strategy behind the asymmetric rule.

[INSERT FIGURE 5 HERE]

5.2 Managing a boom-bust cycle

In Figure 6 I show the behaviour of the economy following a housing bubble shock as shown in Section 4 under the optimised asymmetric rule, comparing its performance with passive and the optimal symmetric rule. Under a symmetric macroprudential policy rule the collateral constraint becomes slack for three periods even though the maximum LTV ratio is lowered, as shown above. In the case of the asymmetric rule the LTV ratio is lowered significantly more, such that the constraint now remains binding throughout the cycle. The key outcome under asymmetric macroprudential policy as in equation (16) is a significantly dampened boom and a much shallower recession, leading to reduced volatility in the economy. This policy also generates positive spillovers to monetary policy, since inflation rises by much less, necessitating a much smaller interest rate hike by the central bank.

[INSERT FIGURE 6 HERE]

To emphasise that the role of the asymmetric LTV rule is to prevent an excessive build-up of credit during booms, but is otherwise no different from a symmetric rule during other times, I show the responses to a pessimistic news shock in Figure 7. The scenario here is reversed; expectations of a decrease in future demand for housing lead to an immediate drop in house prices which drags down the borrowing limit. Under passive LTV policy credit and output fall significantly, but recover strongly when the pessimism proves to be unfounded. The recovery is strong enough to turn the borrowing constraint slack for several periods. The implementation of a countercyclical LTV rule limits the fallout from this shock and the subsequent recovery by first raising the borrowing limit and then unwinding it, and as a result the borrowing constraint remains binding in all periods. The symmetric and asymmetric rules deliver practically the same outcomes under this scenario, since the latter rule offers an improvement in macroeconomic stabilisation only during a credit build-up phase. This is primarily what policymakers aim for in the practical implementation of macroprudential policy.

[INSERT FIGURE 7 HERE]

6. OUTCOMES UNDER AN ASYMMETRIC LTV RULE

A useful way to characterise the gains from an asymmetric macroprudential policy is to look at the distribution of output, which has recently gained more prominence in policymaking. The primary objective of financial stability is to minimize the sources of risk that can lead to a financial crisis, which can ultimately be proxied via the concept of 'GDP-at-Risk' (Adrian, Boyarchenko, and Giannone 2019; Cecchetti 2008). This is typically measured as the 5^{th} percentile of some measure of output, and therefore places emphasis on the left tail of the distribution.[27] In Figure 8 I plot the ergodic distribution of output when the LTV is kept fixed over the business cycle, under the use of the optimized symmetric LTV rule and under the optimized asymmetric rule. In the absence of any active macroprudential policy response, the economy experiences an upward bias in output driven by debt-fuelled consumption when collateral constraints become slack. The distribution of output also has a fat left tail, reflecting the deep recessions that follow debt-fuelled consumption booms. Consequently, the 5^{th} percentile of output (vertical line) is very low. This is in line with the findings in Galán (2020), who shows that countries without any active macroprudential policies had thick left tails in output growth irrespective of the stage of the business cycle.

[INSERT FIGURE 8 HERE]

The introduction of a symmetric LTV rule greatly reduces the skewness in the distribution, and centers mean output much closer to the steady state level. However, under this policy output still deviates considerably above steady state, as the LTV ratio is not lowered enough since the optimised symmetric rule deals with both credit booms and busts in the same way. The asymmetric rule achieves the best outcome in terms of minimizing fluctuations in output. It centers the distribution of output much more around its steady state value and eliminates the upward bias. Therefore, active LTV policy signficantly reduces tail risks in output, with asymmetric policy leading to marginally lower left tail risk than symmetric policy. Asymmetric policy also materially reduces the *right* tail. The increase in the lower 5^{th} percentile *and* the reduction in the 95^{th} percentile of output following the use of LTV policy (symmetric or otherwise) is consistent with the empirical evidence presented in Franta and Gambacorta (2020).[28]

Very similar outcomes apply to the distribution of inflation (Figure 9), which inherits the upward bias and a fat left tail due to movements in output when macroprudential policy is passive and only monetary policy is active. Symmetric and asymmetric macroprudential policies progressively lower the upward bias in inflation during booms while at the same time improving the level of 'Inflation-at-Risk' (López-Salido and Loria 2020) during recessions. This translates to a lower risk of monetary policy hitting the zero lower bound. By taming credit booms and the associated rise in inflationary pressures, LTV policy generates positive spillovers for monetary policy. Out of the scenarios I analyse, asymmetric macroprudential policy generates the best outcomes; both directly by avoiding strong house price and credit pro-cyclicality and strong boom-bust cycles, and indirectly by easing the pressure on monetary policy to stabilize the economy.

[INSERT FIGURE 9 HERE]

7. CONCLUDING REMARKS

In this paper I argue that borrowing constraints that become slack in a credit-driven boom warrant an asymmetric macroprudential policy response. Moreover, non-linear policy responses likely better represent the pre-emptive nature of macroprudential policy. I use a New Keynesian DSGE model with borrowing that is tied to the use of housing as collateral, up to an LTV ratio. A housing bubble generates a boom-bust cycle in the real economy, due to the financial accelerator that is introduced by the financial friction. Policymakers intervene by varying the LTV ratio as a macroprudential policy tool to stabilize the cycle.

While an optimized symmetric LTV rule manages the business cycle much better than in the case of no intervention, an asymmetric policy that addresses the occasionally-binding constraint during a boom obtains the best economic outcomes. The policy significantly reduces the likelihood of a deep contraction following a debt-driven boom, reducing 'GDP-at-Risk', a policy-relevant measure of output tail risks. Besides improved performance along the financial stability domain, asymmetric macroprudential policy also generates positive externalities to monetary policy, by reducing volatility in output and inflation and therefore the need for large interest rate movements by the central bank. This paper therefore also contributes to the discussion on the unintended interplay between macroprudential and monetary policy.

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FOOTNOTES

1. However, most studies focus on the case when the collateral constraint is always binding. In that case, absent any other sources of non-linearity, symmetric policy responses are optimal.

2. The reaction to the news shock follows the literature on herd behaviour and information cascades in financial markets (Banerjee 1992; Bikhchandani, Hirshleifer, and Welch 1992; Shiller 2000: p. 151).

3. This is a simplification; see Iacoviello and Neri (2010) who allow for depreciation and model investment in the housing supply.

4. To simplify the model I abstract from capital accumulation in the economy.

5. See Gerali et al. (2010) and Iacoviello (2015) for models with frictions in the banking sector.

6. See Iacoviello and Neri (2010) and Liu, Wang, and Zha (2019) for a discussion and possible interpretations of this shock.

7. This implies that an increase in prices between period $t-1$ and t lowers the real return on saving.

8. Profits in real terms are equal to the difference between price and marginal cost of output; $\Pi_t = (1 - MC_t)Y_t$.

9. I use the terms loan, borrowing, credit and mortgage debt interchangeably in this paper since the latter is the only liability that borrowers hold.

10. Iacoviello and Neri (2010) find that changing the substitutability between saver and borrower labour hours yields similar results but complicates the analysis unnecessarily, since it introduces a feedback loop between labour supply decisions and borrowing constraints.

11. Some authors adopt a 'hybrid' approach to meet this objective, where a single institution implements monetary policy to maintain both price and financial stability (Gelain, Lansing, and Mendicino 2013; Notarpietro and Siviero 2015). However, using monetary policy to address financial stability concerns has been questioned by Svensson (2012, 2017) and goes against the Tinbergen principle of using one tool to meet one policy objective (Galati and Moessner 2013; Rubio and Carrasco-Gallego 2014).

12. See Funke and Paetz (2018) for similar specification of an asymmetric LTV rule, which lowers the LTV ratio only when the indicator variable breaches a certain threshold.

13. Note that this variable drops out from any linear approximations of the model around a point, as the variance of prices has only second-order effects on output.

14. Explosive paths in credit and house prices are ruled out through relevant transversality conditions.

15. For a discussion and comparison of the performance of coordinated and uncoordinated policy actions see Rubio and Carrasco-Gallego (2014).

16. Consistent with the temporary nature of a bubble in this model, the solution assumes a return to the reference regime in finite time.

17. Schmitt-Grohé and Uribe (2012) find that anticipated shocks not only to productivity, but also to government spending, the wage markup and preferences explain about half the variance in output, consumption, labour hours and inflation.

18. The 'buy-to-let' phenomenon, which took off in the mid-1990s in the UK due to regulatory changes to the mortgage market, is one such driver of housing preferences, formed under the belief of a positive net return from such investment.

19. The model is based on representative saver (s) and borrower (b) households since there is no idiosyncratic risk within each household type. Yet there is a continuum of households within each type. Expectations about future housing demand movements that each individual household of type $i \in \{s, b\}$ forms relate in turn to beliefs it forms about the beliefs of all other households. Intuitively this is similar to the 'higher-order beliefs' framework as in Angeletos, Collard, and Dellas (2018).

20. Their estimates for ϱ differ between savers (0.33) and borrowers (0.58). I use a figure close to the latter for both households to limit differences between them.

21. As at 2007, LTV ratios varied between 0.63 and 1.01 across 15 countries in the euro area, whereas at the beginning of 2016 this ratio amongst 8 such countries varied between 0.7 and 1.01 (ECB 2009, 2016). In the US, Iacoviello and Neri (2010) report that in 2004 a significant share of new home buyers took loans with high LTV ratios, at an average of 0.94. More recently, Zabai (2017) documents a range of maximum LTV ratios between a minimum of 70% and a maximum of 125%.

22. The corresponding estimate in Liu, Wang, and Zha (2013) is 0.9987, since land prices are very persistent. This is in line with the discussion in Drehmann, Borio, and Tsatsaronis (2014), who find that financial cycles, which are driven by credit and asset prices, are longer than typical business cycles.

23. See the discussion in Paez-Farrell (2014) and Wieland and Wolters (2013) on the use of ad-hoc loss functions in analysis of policy.

24. The dynamics of house prices are very similar across all three policy rules since the policy intervention does not prevent the bubble from occuring.

25. The result from the optimal symmetric rule on the optimum persistence parameter $\rho_{\mathsf{m}} = 0$ also applies here, so I do not comment on this further.

26. I simulate the model 50 times, for 100 years in each simulation for a given value of κ. This allows me to reasonably sample the average volatility of some variables. The number of iterations, simulation length and increment in κ are influenced by the computational time required to complete one full round. I check that these numerical parameters are sufficient to infer a clear pattern in the variance ratio. Setting more iterations for a given calibaration has very minor effects on the results.

27. See Aikman, Bluwstein, and Karmakar (2021) for a recent model-based decomposition of the evolution of GDP-at-Risk around the financial crisis of 2008 in the UK.

28. Galán (2020) also presents similar evidence based on an array of macroprudential policy tools.

TABLES

Table 1: Parameter values

Parameter	**Value**	**Description**
β_s	0.9901	Discount factor – savers
β_b	0.985	Discount factor – borrowers
φ	0.5	Inverse of Frisch labour supply elasticity
τ	0.844	Preference parameter on leisure
$\bar{\mathsf{j}}$	0.06	Preference parameter on housing
ϱ	0.5	Habit persistence
$\overline{\mathsf{m}}$	0.9	LTV ratio
σ	6	Elasticity of substitution
α	0.64	Share of labour income (savers)
ω	0.75	Calvo parameter
ρ_{j}	0.96	Persistence parameter for housing preference shock
σ_{j}	0.054	Standard deviation of housing preference shock
δ_π	1.5	Taylor rule coefficient on inflation
δ_Y	0.125	Taylor rule coefficient on output growth
ρ_R	0.8	Smoothness parameter for monetary policy
δ_{m}	0.75	Symmetric LTV rule coefficient on credit to output (OSR)
ρ_{m}	0	Smoothness parameter for LTV rules (OSR)

Note: OSR – optimal simple rule.

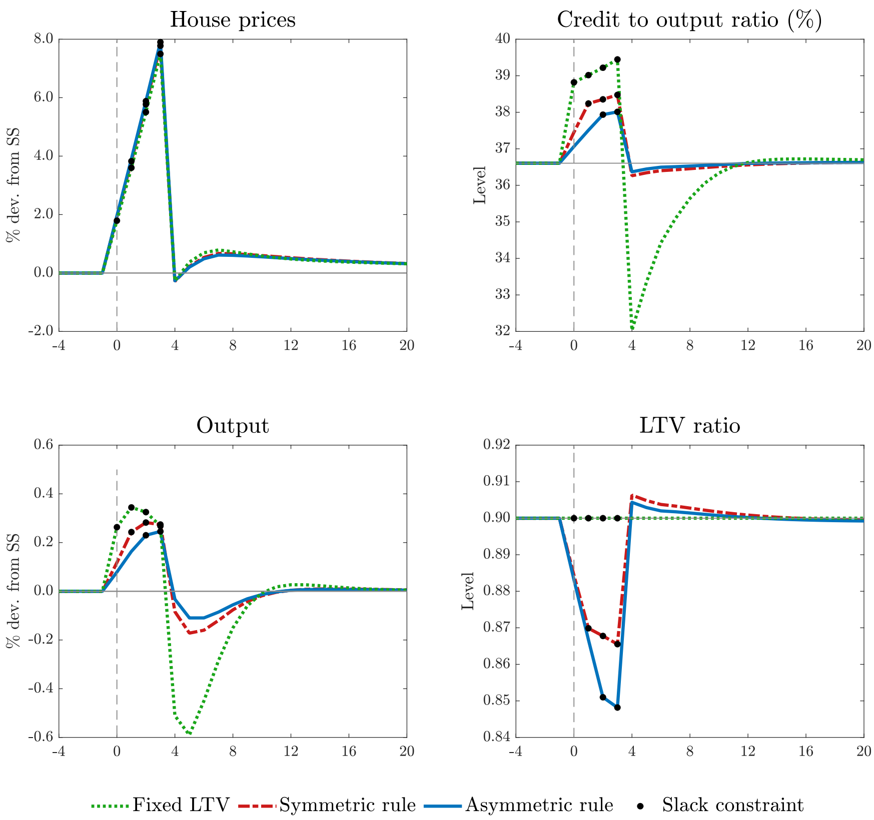

Figure 1: Dynamic responses to a housing bubble shock

Notes: Values on the x-axis are time in quarters, the y-axis denotes percentage deviations from steady state or levels. The dots denote periods in which the borrowing constraint is slack, and the dashed vertical lines at time 0 denote the first period of the shock.

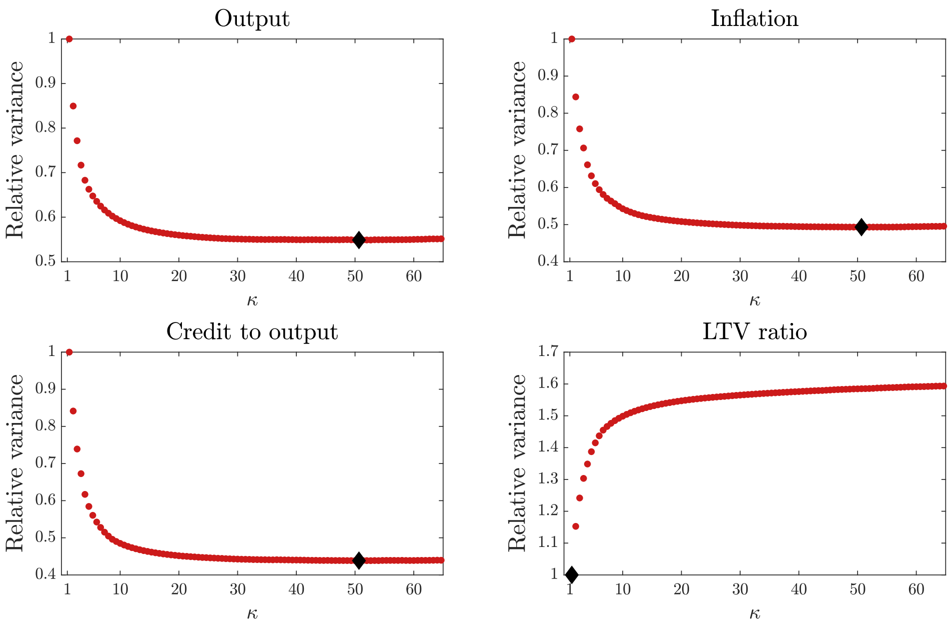

Figure 2: Relative volatility over policy asymmetry ($\kappa = \overline{\delta_m}/\delta_m$)

Note: The figure shows the variance of the model variables under different macroprudential policy asymmetry relative to the symmetric LTV rule. The diamond marks the minimum relative variance for each variable.

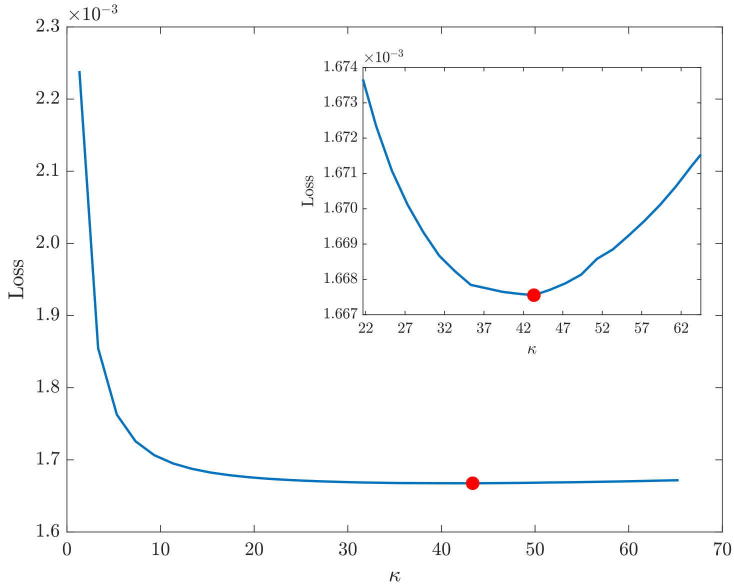

Figure 3: Loss over policy asymmetry ($\kappa = \overline{\delta_{\mathsf{m}}}/\delta_{\mathsf{m}}$)

Notes: The figure shows the macroprudential policymaker's loss as a function of the asymmetry in the LTV rule, and the dot marks the minimum. The insert zooms in on the neighbourhood of this minimum.

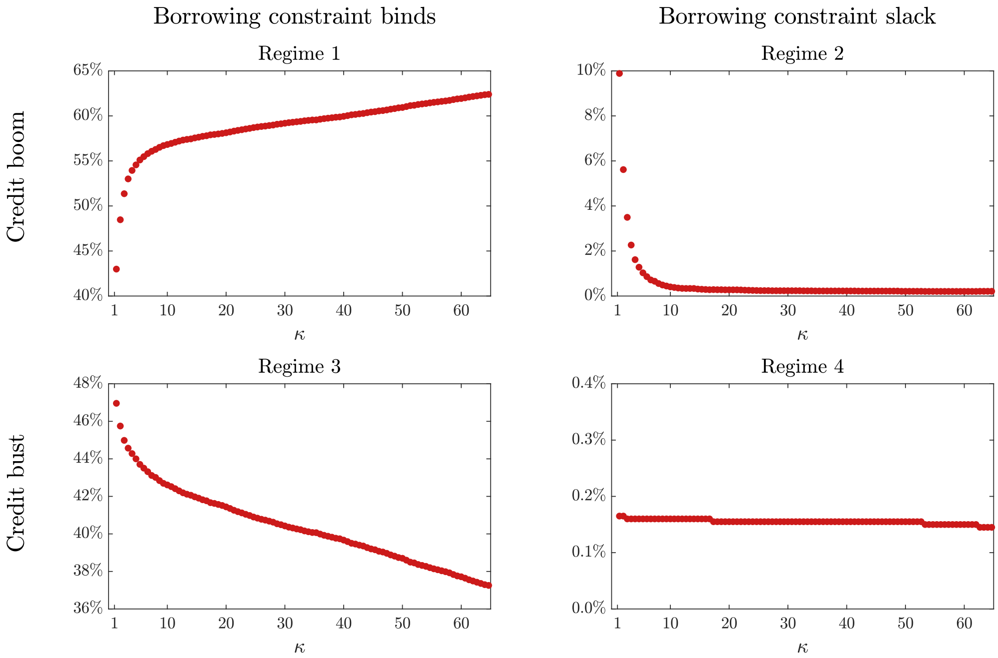

Figure 4: Frequency in each regime over policy asymmetry ($\kappa = \overline{\delta_{\mathsf{m}}}/\delta_{\mathsf{m}}$)

Note: The figure shows the share of the time the economy spends on average in each of the four possible regimes, as the LTV policy rule switches from symmetric ($\kappa = 1$) to highly asymmetric.

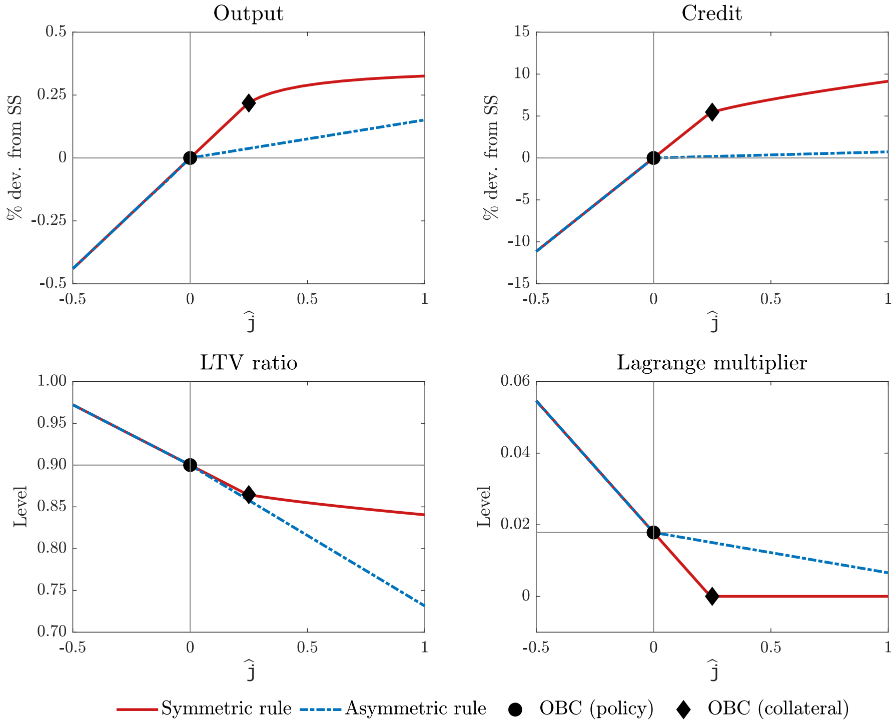

Figure 5: Non-linear decision rules under different macroprudential policy regimes

Notes: Values on the x-axis are deviations from steady state, the y-axis denotes percentage deviations from steady state, or levels. The horizontal and vertical lines denote the steady state, while the diamond and circle markers denote the point at which the policy functions experience a kink due to the asymmetric rule and the borrowing constraint, respectively.

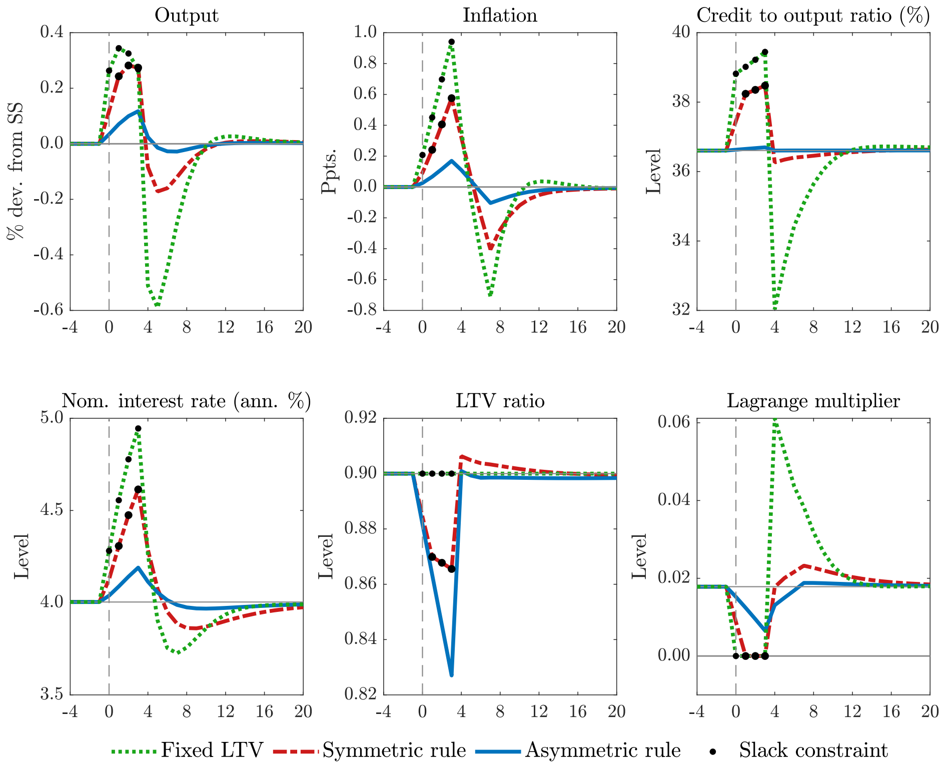

Figure 6: Dynamic responses to a housing bubble shock

Notes: Values on the x-axis are time in quarters, the y-axis denotes percentage deviations from steady state or levels. The dots denote periods in which the borrowing constraint is slack, and the dashed vertical lines at time 0 denote the first period of the shock.

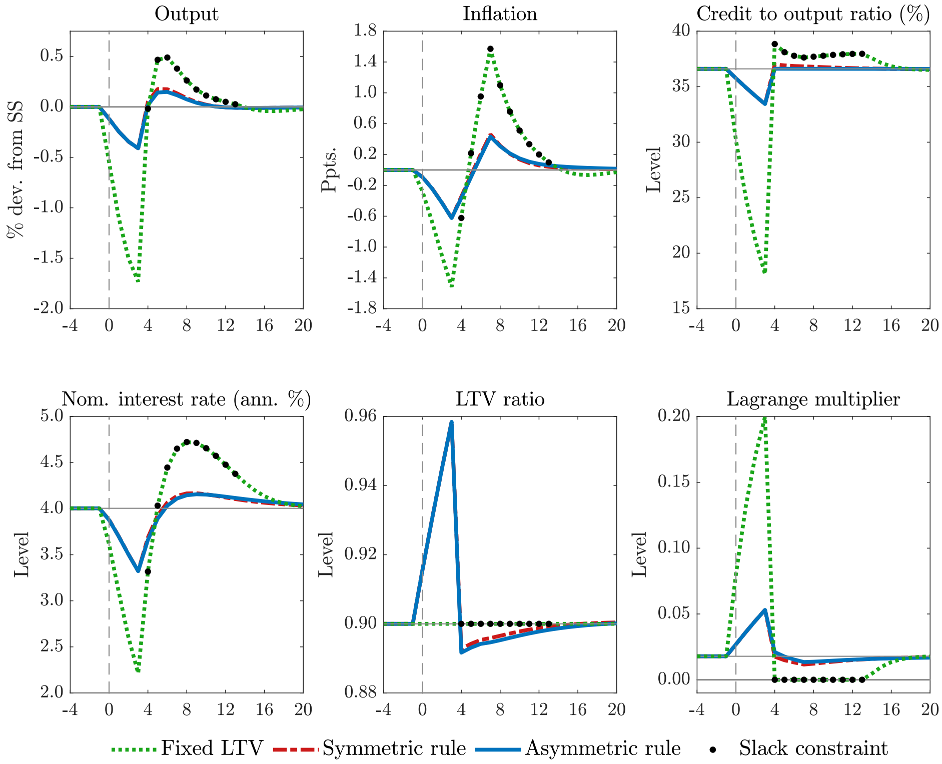

Figure 7: Dynamic responses to a negative news shock

Notes: Values on the x-axis are time in quarters, the y-axis denotes percentage deviations from steady state or levels. The dots denote periods in which the borrowing constraint is slack, and the dashed vertical lines at time 0 denote the first period of the shock.

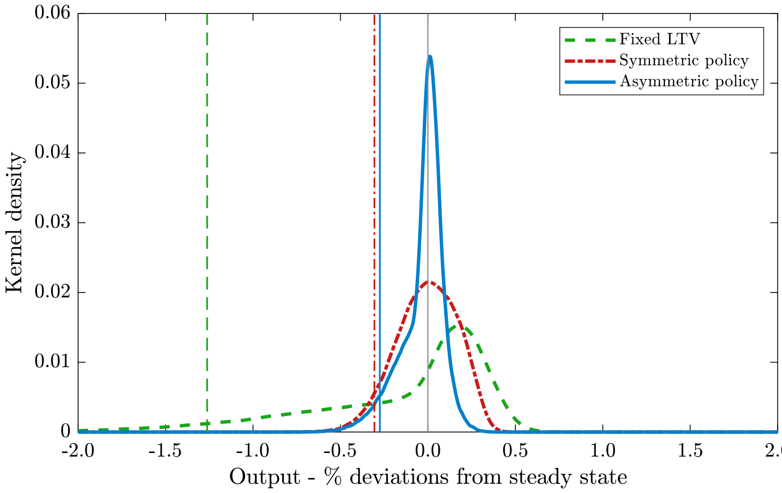

Figure 8: The ergodic distribution of output over macroprudential policies

Notes: The distribution of output is from 300 simulations each of 100 years from the model economy under each policy regime. The vertical lines mark the 5th percentile under each scenario.

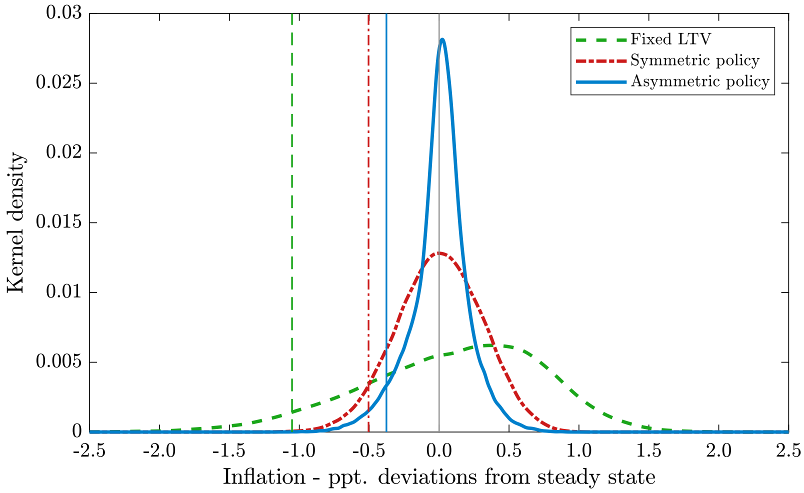

Figure 9: The ergodic distribution of inflation over macroprudential policies

Notes: The distribution of inflation is from 300 simulations each of 100 years from the model economy under each policy regime. The vertical lines mark the 5$^{\text{th}}$ percentile under each scenario.