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House Price Dynamics, Optimal LTV Limits and the Liquidity Trap

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This paper studies the optimal design of a macro-prudential instrument, a loan-to-value (LTV) limit, and its implications for monetary policy in a model with nominal rigidities and financial frictions. The analysis accounts for both an effective lower bound on the nominal interest rate and an upper bound on the ability of LTV limits to stimulate credit demand. The welfare-based loss function features a role for macro-prudential policy to enhance risk-sharing. Optimal LTV limits are strongly countercyclical. In a house price boom-bust episode, the active use of LTV limits alleviates debt-deleveraging dynamics and prevents the economy from falling into a liquidity trap.

Key words: Monetary and macro-prudential policy, Financial crisis, Zero lower bound

JEL codes: E52, E58, G01, G28

1. INTRODUCTION

A persistent boom in house prices and a large increase in private indebtedness planted the seeds for the 2008 financial crisis (Figure 1). Once house prices collapsed, the turmoil in the financial sector and the ensuing deleveraging process caused the worst US recession since the Great Depression (Hall, 2011). Many other countries, including Ireland, Spain, and the UK, experienced similarly long-lived booms followed by deep recessions.

To prevent the repeat of similar episodes, policy authorities around the world have introduced macro-prudential frameworks that include both "lender-based" policy tools, which primarily influence credit supply, and "borrower-based" tools, which primarily affect credit demand.

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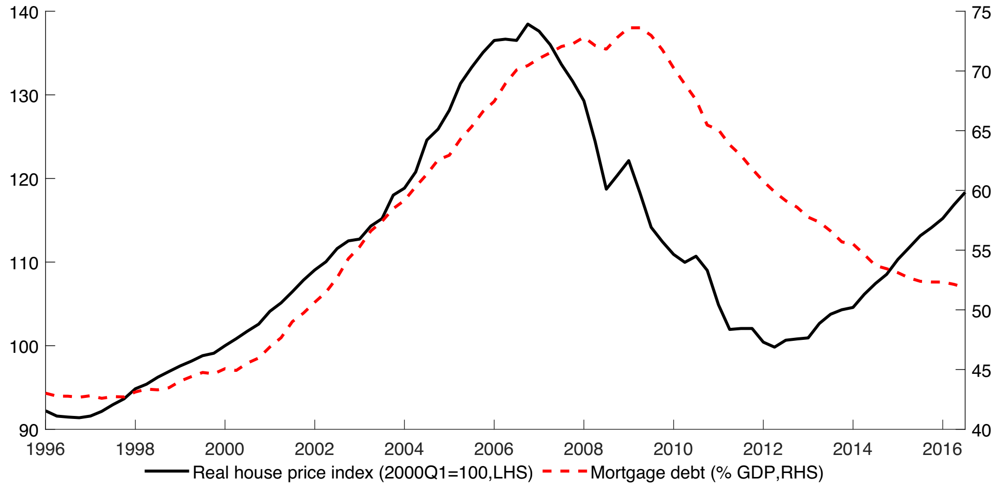

FIGURE 1

Real house prices and mortgage debt in the US

Note: Real house prices correspond to the FHFA index deflated by the CPI (normalized to 100 in 2000q1). Mortgage debt corresponds to "Households and Nonprofit Organizations, One-to-Four-Family Residential Mortgages," expressed as a fraction of GDP in percentage points. All data are from FRED, Federal Reserve Bank of St. Louis.

Motivated by the rapid increase in the use of borrower-based policy instruments in recent years, this paper focuses on one such tool—a loan-to-value (LTV) limit—and its implications for monetary policy. We find that the optimal LTV policy is strongly countercyclical, limiting the build-up of debt during a credit boom and thus reducing the deleveraging pressure in a credit bust. In our simulation experiments, this active use of LTV limits alleviates the burden of macroeconomic stabilization on monetary policy and can avoid a liquidity trap that would otherwise occur in the absence of macro-prudential policy.

Our findings contribute to a growing literature exploring the conduct of macro-prudential policy and its interaction with monetary policy. From a theoretical perspective, Farhi and Werning (2016) and Korinek and Simsek (2016) present detailed analyses of the financial market distortions that macro-prudential policy can address in the presence of aggregate demand externalities, such as nominal rigidities and the zero lower bound (ZLB) on the nominal interest rate, while Davila and Korinek (2018) emphasize the pecuniary externalities due to an endogenous collateral constraint.

We obtain our results in a simple model that builds on Cúrdia and Woodford (2016) and combines both types of externality. As is standard in the New Keynesian literature, nominal rigidities arise because of staggered price setting (Calvo, 1983), so that monetary policy has real effects. The key financial friction is a collateral requirement on borrowers. As in Kiyotaki and Moore (1997), an underlying moral hazard problem implies that lenders are only willing to lend up to a given fraction of the value of housing collateral. We allow the macro-prudential authority to impose an LTV limit on mortgage borrowing that is no greater than this fraction.

The model also features a second financial friction. Borrowers obtain loans through perfectly competitive financial intermediaries (banks), which raise equity and deposits from savers. Banks seek to minimize equity issuance, which is costly as in Justiniano *et al.* (2019), but an equity requirement places an upper bound on their leverage. Exogenous changes in this requirement map into movements of the spread between borrowing and deposit rates. These financial disturbances, which we label "credit spread shocks", are the exogenous source of fluctuations in our model.

The resulting framework is rich enough to generate meaningful policy trade-offs, but sufficiently tractable that, up to a second-order approximation, the welfare-based loss function clearly identifies how the inefficiencies in the economy map into four policy objectives. Two of the terms in the welfare-based loss function, inflation and the output gap, stem from nominal rigidities and are standard in the New Keynesian literature (*e.g.*Clarida *et al.*, 1999, and Woodford, 2003). The remaining two terms are due to imperfect risk sharing between borrowers and savers. In particular, the policymaker seeks to stabilize the differences (or "gaps") in the marginal utility of non-durable consumption and housing between the two types of household.

The welfare-based loss function shares a number of similarities with those derived in Andres *et al.* (2013), Benigno *et al.* (2020), and Cúrdia and Woodford (2016). While those papers focus on optimal monetary policy, our contribution is to explore its interaction with the optimal setting of LTV limits. When the collateral constraint is always binding and the nominal interest rate never hits the ZLB, the jointly optimal monetary and macro-prudential plan in a linear-quadratic (LQ) approximation of the model satisfies a pair of targeting rules. The optimal targeting rule for monetary policy manages the standard trade-off between inflation and the output gap. The optimal targeting rule for macro-prudential policy prescribes that the marginal utility gap and the output gap co-move. Thus, LTV limits are countercyclical, limiting consumption of borrowers relative to that of savers in a boom (and vice versa in a recession).

Our quantitative experiments allow for occasionally binding constraints, as in Guerrieri and Iacoviello (2017). In addition to the ZLB on the nominal interest rate, we also account for occasionally binding constraints on macro-prudential policy. If the collateral constraint is slack, the policymaker cannot force borrowers to hold more debt than the amount demanded at market prices (a "credit demand" constraint). At the same time, the policymaker cannot force lenders to extend credit at an LTV ratio that is higher than the level required to avoid the underlying moral hazard problem, which creates an upper bound on the LTV limit (a "credit supply" constraint).

A slow and persistent decline in credit spreads, followed by a sharp tightening, drives our quantitative experiments. The model generates a boom-bust cycle in house prices which captures the salient features of the data in the US and other advanced economies before and after the 2008 financial crisis. We compare a baseline scenario characterized by a standard interest rate rule for monetary policy and a fixed LTV limit with a regime in which the policymaker optimally sets the nominal interest rate and the LTV limit to minimize the welfare-based loss function. In the baseline scenario, the collateral constraint remains slack during the boom and becomes binding in the bust, during which the economy experiences a liquidity trap and a deep recession. Conversely, under optimal policy, the LTV limit declines markedly during the boom, such that the collateral constraint binds tightly, and rises at the time of the crisis, relaxing the collateral constraint. The countercyclical LTV policy avoids a large build-up in private debt during the expansion so that, when house prices fall, the recessionary consequences of the deleveraging process are limited. As a result, the nominal interest rate remains above the ZLB, and the economy avoids the recession. In this sense, the optimal setting of the LTV limit is indeed prudential, at least as far as macroeconomic objectives are concerned.

Finally, we present two experiments that demonstrate how the efficacy of macro-prudential policies may depend on prevailing macroeconomic conditions. The first shows that, in line with the existing empirical evidence, the sign of the effect of an LTV limit tightening on house prices depends on whether or not monetary policy is constrained. The second experiment shows that the benefits of setting the LTV limit optimally only once the bust occurs are much smaller than if macro-prudential policy is active also during the boom. The high level of debt built up during the boom limits the space for macro-prudential policy, so that the credit supply constraint becomes binding during the bust.

Our paper contributes to a growing literature studying borrower-based macro-prudential policy tools and their interaction with monetary policy. Rubio and Carrasco-Gallego (2014) postulate a simple rule for LTVs while Lambertini *et al.* (2013) study optimized simple rules for monetary policy and LTV limits in the context of boom-bust cycles generated by news shocks. Angelini *et al.* (2012) consider optimal monetary and macro-prudential policies (including both capital requirements and LTV limits) using an ad-hoc loss function as the policymaker's objective. Gelain *et al.* (2013) evaluate the effects of tighter LTV restrictions on household debt and output in a model that generates excess volatility by relaxing the assumption of rational expectations.[1] A distinguishing feature of our work is the combination of the normative analysis with a welfare-based loss function and the explicit consideration of occasionally binding constraints, including on policy instruments.

The focus on LTV limits in this paper complements a number of contributions that examine lender-based policy tools, in particular the role of capital requirements.[2] Several papers extend the analysis to the interaction between capital requirements and monetary policy. For example, Bean *et al.* (2010) study the optimal setting of capital requirements with ad-hoc loss functions in a simplified version of Gertler and Karadi (2011). In models with bank runs, Angeloni and Faia (2013) compare alternative properties of capital requirements that mimic the Basel I, II, and III accords, while Gertler *et al.* (2020a, 2020b) study a simple capital requirement linked to the net worth of financial intermediaries. Quint and Rabanal (2014) specify rules for the leverage ratio that banks can afford as a function of credit aggregates in an estimated model of the Euro Area. Collard *et al.* (2017) and Van der Ghote (2021) study the jointly optimal setting of interest rates and capital requirements in environments with moral hazard frictions. Finally, Mendicino *et al.* (2020) evaluate the trade-offs associated with increasing capital requirements depending on the state of the business cycle.

The rest of the paper is organized as follows. Section 2 documents the use of LTV limits as a macro-prudential tool, showing the increasing use of this type of borrower-based policy instrument in recent years. Section 3 introduces the model, focusing on the key innovations to the treatment of the household sector. Section 4 presents the LQ framework for optimal policy analysis and derives the targeting rules abstracting from occasionally binding constraints. Section 5 illustrates the optimal joint conduct of monetary and macro-prudential policy with occasionally binding constraints via numerical simulations. Section 6 concludes. The online appendix contains additional results and the computational details.

2. LTV LIMITS AS A POLICY TOOL

The use of LTV limits as a policy tool has a fairly long history. For example, Hong Kong introduced LTV restrictions in 1991. Wong *et al.* (2011) argue that this innovation cushioned the aggregate effects of the 1997 Asian financial crisis on lenders' resilience in the face of a 40% decline in property prices. Similarly, the macro-prudential authority in South Korea set the maximum LTV to 60% in 2002, subsequently tightening the limit to as low as 40%. Crowe *et al.* (2013) document the notable moderation in house price appreciation that followed those policy changes. Together with other measures, regulators in Canada lowered LTV limits four times

1. Our analysis also shares some similarities with De Paoli and Paustian (2017), though their model emphasizes a different credit relationship (between entrepreneurs and households) and focuses on a different macro-prudential policy instrument (a tax/subsidy on the cost of borrowing for entrepreneurs).

2. A non-exhaustive list includes Van den Heuvel (2008), Gertler *et al.* (2012), Miles *et al.* (2013), Admati and Hellwig (2014), Clerc *et al.* (2015), Christiano and Ikeda (2016), and Corbae and D'Erasmo (2021).

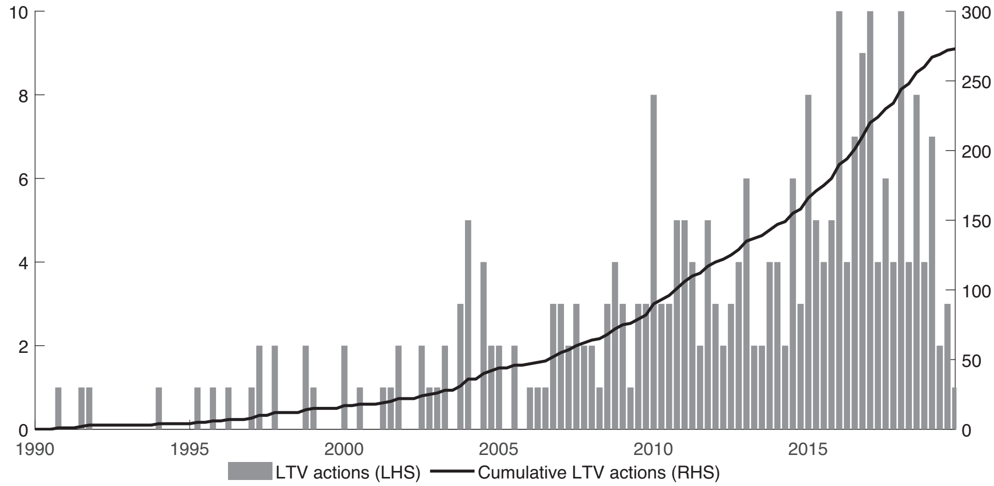

FIGURE 2
LTV policy actions

Note: The bars (left scale) are the number of LTV policy actions in each quarter. The line (right scale) is the cumulative number of LTV policy actions over time at quarterly frequency. The data source is the IMF integrated macro-prudential policy database (iMaPP).

between 2008 and 2012, from 100% to 80%. Krznar and Morsink (2014) estimate that a 1 percentage point reduction in the LTV limit reduced year-on-year credit growth by 0.4 percentage points.

By 2013, LTV limits, together with debt-to-income ratios, had become the most commonly deployed macro-prudential instrument, both in emerging market economies and developed countries (Claessens, 2015).[3] Their adoption has continued to grow ever since. Using data from the IMF integrated macro-prudential policy database (see Alam *et al.*, 2019, for a description), Figure 2 reports the number of LTV policy actions in each quarter (shaded bars) and their cumulative number (solid line) globally between 1990 and 2019. The chart shows a clear acceleration in the use of LTVs since the financial crisis. In Europe alone, Arena *et al.* (2020) count 19 jurisdictions with LTV policies in place by 2018. Their evidence shows a decline in the extension of high LTV mortgage loans following the introduction of these controls in all countries in their sample.

A plausible explanation for these developments is that the financial crisis of 2008 brought renewed attention to the terms and conditions governing borrowers' access to debt finance. The importance of housing markets and the tight links between housing net worth, household consumption and aggregate demand called for instruments that could limit the propagation of financial shocks via the indebtedness of the household sector. Indeed, in many advanced economies, mortgages are at the same time the single largest asset class on the balance sheet of banks and the single largest liability class on the balance sheet of households (Jordá *et al.*, 2016).

As the use of LTV policies has broadened, more systematic empirical analysis has become possible. Kuttner and Shim (2016) use data on 57 countries covering the period 1980 to 2011 for a range of advanced and emerging market economies. Similarly, Araujo *et al.* (2020) conduct a

3. Cerutti *et al.* (2017) document the relative prevalence of borrower-based instruments, including LTV limits, in advanced economies, while emerging markets often rely additionally on foreign exchange related measures. Institutional details on macro-prudential frameworks, both in terms of the tools available and the authorities in charge, vary greatly across countries (Akinci and Olmstead-Rumsey, 2018).

meta analysis encompassing 58 studies of a broad set of macro-prudential policy actions. Both papers find that LTV requirements had a significant effect on household credit but not on house prices. Richter *et al.* (2019) reach a different conclusion regarding the effects of LTV policies on house prices by combining a narrative approach to identification and local projection methods for inference. Their estimates also give a sense of the macroeconomic consequences of LTV policies. In their sample, an exogenous 10 percentage point tightening of LTV limits generates a 1.1% decline in output and an increase in consumer prices of a broadly similar magnitude.[4]

A potential explanation for these heterogeneous estimates of the effects of LTV limits on house prices (and potentially other variables) is the role of the systematic monetary policy response to the aggregate consequences of changes in financing conditions. The VAR evidence in Bachmann and Rüth (2020) speaks directly to this point. Using quarterly US data spanning the period 1978–2008, expansionary LTV shocks increase GDP and business investment but lead to a decline of residential investment and house prices. Crucially, the typical response of monetary policy to these shocks is a rise in the nominal interest rate. Through a counterfactual exercise these authors show that, if the interest rate does not increase, the responses of residential investment and house prices change sign.

These findings illustrate that the interaction of LTVs with monetary policy has an important bearing on their macroeconomic effects. Our analysis studies this interaction both in normal times (*i.e.* when monetary policy is unconstrained) and at the ZLB, while also accounting for the possibility that the LTV limit may not bind at all times.

3. MODEL

This section describes the key building blocks of the model. The household sector contains the key frictions that give rise to a role for macro-prudential policy. We extend the approach of Cúrdia and Woodford (2016) to incorporate an occasionally binding collateral constraint on household borrowing and allow the macro-prudential policymaker to vary the LTV limit over time.

Households are ex-ante identical, but at any point in time their preferences are heterogeneous due to stochastic realizations of the coefficient of relative risk aversion. A random switch in this utility parameter is sufficient to deliver a separation between savers and borrowers, which is the focus of our paper. At the beginning of time households sign state-contingent contracts, but only have access to payoffs from those contracts in the event of a new utility parameter draw. Intermittent access to the contract payments provides a role for financial intermediation to smooth consumption over time while avoiding ever-diverging marginal utilities of income due to different individual histories.

The rest of the model is standard. Banks raise funds from savers through a mix of deposits and equity, and transfer resources to borrowers. Imperfectly competitive wholesale firms set prices on a staggered basis. Retailers are perfectly competitive and combine intermediate inputs to produce the final consumption good. The government conducts monetary and macro-prudential policy to address the inefficiencies arising from nominal rigidities and imperfect risk sharing.

Below, we present the problem of each economic actor. Further details on the microfoundations of the household problem with intermittent access to state-contingent transfers and the full derivations of the equilibrium conditions are in an analytical appendix available upon request.

4. The response in emerging markets drives the estimated effects on output. In addition, the paper presents some evidence of an asymmetric response (greater for a tightening).

3.1. *Households*

A continuum of measure one of ex-ante identical households populate the economy. At time t, a household can be of type b (borrower) or s (saver). Households maximize the present discounted value of utility

$$\mathbb{V}_0^{\tau_t} \equiv \mathbb{E}_0 \left\{ \sum_{t=0}^{\infty} \beta^t \left[\frac{1}{1-\sigma^{\tau_t}} (C_t^{\tau_t})^{1-\sigma^{\tau_t}} + \frac{\chi_H}{1-\sigma_h} (H_t^{\tau_t})^{1-\sigma_h} - \frac{\chi_L}{1+\varphi} (L_t^{\tau_t})^{1+\varphi} \right] \right\},$$

where $\tau_t \in \{b, s\}$ indicates the type at time t. The variable $C_t^{\tau_t}$ denotes consumption of goods, $H_t^{\tau_t}$ consumption of housing services (assumed to be proportional to the stock of housing), and $L_t^{\tau_t}$ hours worked. The parameter $\beta \in (0,1)$ is the individual discount factor, σ^{τ_t} the coefficient of risk aversion (with $0 < \sigma^b < \sigma^s$), $\sigma_h > 0$ the inverse elasticity of housing demand, $\varphi > 0$ the inverse elasticity of labour supply, and χ_H and χ_L are positive parameters that determine steady-state housing demand and hours worked, respectively.

The type τ evolves as an independent two-state Markov chain. With probability $\delta \in [0,1]$, the type remains unchanged. With probability $1-\delta$, a household draws a new type, independently of the previous one. The probability of drawing type τ is $\xi^\tau \in [0,1]$. Since we assume the economy consists of a continuum of households of measure one, the probability of drawing a certain type corresponds to the share of that type in the population. To simplify the notation, we set $\xi^b = \xi$, which in turn implies $\xi^s = 1-\xi$.

Households sign state-contingent contracts with each other at time $t_0 \leq 0$ to insure against idiosyncratic and aggregate risk. A competitive insurance agency provides the payments associated with such contracts. These payments, however, take place if and only if a household draws a new type in period t (and before knowing the new type).

The beginning-of-period financial wealth inclusive of transfers for a household of type τ is

$$A_t^\tau \equiv R_{t-1}^d \max\{D_{t-1}, 0\} + R_{t-1}^e \max\{E_{t-1}, 0\} - R_{t-1}^b \max\{B_{t-1}, 0\} + T_t^\tau,$$

where D_t denotes deposits that pay a gross nominal interest rate R_t^d, E_t equity in banks that pays a gross nominal return R_t^e, B_t debt that carries a gross nominal interest rate R_t^b, and T_t^τ state-contingent transfers.[5]

The budget constraint for a saver is

$$P_t C_t^s + Q_t H_t^s + P_t \Gamma_{ht}^s + D_t + E_t + P_t \Gamma_{et} = A_t^s + W_t L_t^s + Q_t H_{t-1} + \Omega_t^s,$$

where P_t is the consumption price index, Q_t the nominal price of housing, W_t the nominal wage, and Ω_t^τ denotes the share of profits from intermediate goods producers accruing to a household of type τ net of taxes. The function Γ_{et} measures equity holding costs in deviations from the target level $\overline{E}_t$

$$\Gamma_{et} \equiv \frac{\Psi_e}{2} \left(\frac{E_t}{\overline{E}_t} - 1 \right)^2 \overline{E}_t,$$

5. Households who do not draw a new type at time t do not receive a transfer and simply carry their financial wealth on from the previous period. Due to the transfers from the insurance agency, households who have just drawn a new type start the period with zero wealth. Effectively, the insurance agency redistributes resources across households by pooling together debts and assets of all those who draw a new type.

with $\Psi_e > 0$.[6] As in Justiniano *et al.* (2019), the presence of holding costs generates a premium for equity over deposits and a well-defined liability structure in the banks' balance sheet, thus capturing the idea that in practice deposits are generally more liquid and easier to adjust than equity.[7]

Similarly, the function Γ_{ht}^{τ} measures housing holding costs, expressed in deviation from a target level that we assume to be the symmetric steady-state level of housing consumption H,

$$\Gamma_{ht}^{\tau} \equiv \frac{\Psi_h}{2}\left(\frac{H_t^{\tau}}{H}-1\right)^2 H,$$

where $\Psi_h > 0$. As in Greenwald (2018) and Menno and Oliviero (2020), housing holding costs limit the degree of reallocation between types over the business cycle. This effect introduces a simple form of housing market segmentation, as discussed for example in Guerrieri *et al.* (2013) and Piazzesi and Schneider (2016).[8]

The budget constraint for a borrower is

$$P_t C_t^b + Q_t H_t^b + P_t \Gamma_{ht}^b - B_t = A_t^b + W_t L_t^b + Q_t H_{t-1} + \Omega_t^b.$$

Borrowers do not invest in equity of banks, and thus do not face the extra cost Γ_{et}, but are subject to a collateral constraint (Kiyotaki and Moore, 1997)

$$B_t \leq \gamma_d B_{t-1} + (1-\gamma_d)\Theta_t Q_t H_t^b, \tag{1}$$

where $\gamma_d \in [0, 1)$ controls the extent of debt inertia (Justiniano *et al.*, 2015) and $\Theta_t \in [0, \Theta]$ represents the maximum LTV ratio available at time t.[9] The standard interpretation of a collateral constraint like (1) is that lenders (banks in this model) require borrowers to have a stake in a leveraged investment to prevent moral hazard behaviour.[10]

Our formulation of the collateral constraint contains two features that are important for the analysis. First, the LTV limit Θ_t varies over time reflecting the assumption that the macro-prudential authority may set the maximum LTV that banks can extend to borrowers. To respect the underlying incentive compatibility constraint encoded in the collateral requirement, the LTV limit Θ_t cannot exceed the value $\Theta \in [0, 1]$, which is the maximum LTV consistent with the

6. Savers take the target level of equity as given. For analytical convenience, we set $\overline{E}_t \equiv \tilde{\kappa}\xi B_t/(1-\xi)$. As we discuss below, this assumption, coupled with the exogenous leverage restriction on banks, ensures that the cost function Γ_{et} does not have direct welfare consequences.

7. Little of substance would change in the first-order accurate solution to the model that we examine if we specified bank equity as a state-contingent claim.

8. Using detailed micro data, Landvoigt *et al.* (2015) document a high degree of segmentation for the San Diego metropolitan area. Justiniano *et al.* (2014) consider the case of full segmentation between borrowers and savers. Poterba (1991) discusses how the segmentation between borrowers and savers that our formulation builds into the model may be related to demographic factors.

9. In principle, all households are subject to the collateral constraint. We abstract from its presence for savers since, in equilibrium, the constraint would never bind for this type. Moreover, since borrowers who have drawn their type at time t have their previous financial wealth reset to zero, the inertia in the collateral constraint only applies to households who were already borrowers at $t-1$ and did not draw a new type.

10. In some contexts (*e.g.* Kiyotaki and Moore, 1997), the collateral constraint depends on expected future, rather than contemporaneous, asset prices. As the focus of our analysis is the real estate market, current prices are particularly suitable because the amount of mortgage loans typically depends on the current value of the house being purchased. The online appendix shows that the two formulations are essentially identical for the purposes of our main quantitative exercise. The reason is that, up to a first order approximation around a steady state in which the collateral constraint is slack, the house price equation is the same in the two cases.

absence of a moral hazard problem.[11] Therefore, the inequality $\Theta_t \leq \Theta$ (the credit supply constraint) imposes an upper bound on the LTV limit.

Second, the collateral constraint (1) incorporates a degree of inertia governed by the parameter γ_d. The inertial formulation of the collateral constraint captures, in reduced form, the idea that only a fraction of borrowers experience a change to their borrowing limit each period, which may be associated with moving or re-mortgaging long-term debt (Guerrieri and Iacoviello, 2017). This modification generates more persistent movements in debt and its marginal value. In particular, debt adjusts only gradually to changes in the value of the housing stock, which is consistent with the data in Figure 1. When $\gamma_d = 0$, the collateral constraint collapses to the familiar contemporaneous specification.

The key difference between this model and one with either complete markets or incomplete markets and fixed types is that the expected future marginal utility of consumption is a weighted average of the marginal utility conditional on no type change and the average marginal utility of the two types.[12]

3.2. *Banks*

A continuum of perfectly competitive banks raise funds from savers in the form of deposits and equity (the banks' liabilities), and make loans (the banks' assets) to borrowers. Thus, the balance sheet of a generic bank is

$$B_t = D_t + E_t. \tag{2}$$

In addition, we assume that equity must account for at least a fraction $\tilde{\kappa}_t$ of the total amount of loans banks extend to borrowers

$$E_t \geq \tilde{\kappa}_t B_t, \tag{3}$$

where the equity requirement $\tilde{\kappa}_t$ is an exogenous shock.

The presence of the cost function Γ_{et} in the household problem breaks down the irrelevance of the capital structure (the Modigliani–Miller theorem). Savers demand a premium for holding equity, which banks pass on to borrowers in the form of a higher interest rate. From the perspective of a bank, equity is expensive, so that deposits are the preferred source of funding. In the absence of any constraint, banks would choose to operate with zero equity and leverage would be unbounded. Equation (3) ensures finite leverage for banks. In equilibrium, the capital requirement constraint is always binding because banks seek to minimize their equity requirement.[13]

Banks' profits are

$$\mathcal{P}_t \equiv R_t^b B_t - R_t^d D_t - R_t^e E_t = [R_t^b - (1 - \tilde{\kappa}_t) R_t^d - \tilde{\kappa}_t R_t^e] B_t,$$

where the second equality follows from substituting the balance sheet constraint (2) and the capital requirement (3) at equality. The zero-profit condition implies that the loan rate is a linear

11. In other words, the policymaker cannot force banks to lend to households at a higher LTV than the level that ensures households will honour the debt contract.

12. As in Cúrdia and Woodford (2016), the marginal utility of consumption is independent of the household type history. The same result also holds for the multiplier on the collateral constraint, which is specific to this model.

13. Since banks are identical, if the capital constraint of all banks were slack, one bank could marginally increase its leverage, charge a lower loan rate, and take the whole market. Therefore, competition drives the banking sector against the constraint.

combination of the return on equity and the return on deposits

$$R_t^b = \tilde{\kappa}_t R_t^e + (1 - \tilde{\kappa}_t) R_t^d,$$

where the weight on the return on equity corresponds to the time-varying capital requirement. An increase in $\tilde{\kappa}_t$ forces banks to delever and raises credit spreads—the difference between the loan rate R_t^b and the deposit rate R_t^d. Vice versa, a relaxation of the equity requirement (a lower $\tilde{\kappa}_t$) reduces spreads. Given the mapping between the equity requirement shock and credit spreads, from now on we refer to $\tilde{\kappa}_t$ as a credit spread shock, which is the key driver for the quantitative experiments that we study later.

We stress that our analysis focuses on the case in which $\tilde{\kappa}_t$ is exogenous, relying on the notion that financial institutions target a certain leverage ratio due to market forces (Adrian and Shin, 2010). An alternative interpretation would be that the macro-prudential authority sets the capital requirement on financial institutions, and thus controls $\tilde{\kappa}_t$ as a policy tool. We do not pursue this approach in this paper for two reasons. First, we believe that properly studying capital requirements, and their interaction with monetary policy, would require a more detailed specification of the financial sector. While our parsimonious description of financial intermediation does capture a connection between capital requirements and credit spreads, the model completely abstracts from a key mechanism—the accumulation of net worth—that determines banks' profitability and may be crucial to understand the effects of capital requirements. Second, as discussed in the introduction, the existing literature has extensively studied capital requirements, either in isolation or in connection with monetary policy. We aim to complement this body of work by focusing on the implications of LTV limits for macroeconomic stability and their interaction with monetary policy decisions, which have been relatively less explored.

3.3. *Firms*

A representative retailer combines intermediate goods according to a technology with constant elasticity of substitution $\varepsilon > 1$

$$Y_t = \left[\int_0^1 Y_t(f)^{\frac{\varepsilon-1}{\varepsilon}} df \right]^{\frac{\varepsilon}{\varepsilon-1}},$$

where $Y_t(f)$ represents the intermediate good produced by firm $f \in [0,1]$. Expenditure minimization implies that the demand for a generic intermediate good is

$$Y_t(f) = \left[\frac{P_t(f)}{P_t} \right]^{-\varepsilon} Y_t, \tag{4}$$

where $P_t(f)$ is the price of the variety produced by firm f and the aggregate price index is

$$P_t = \left[\int_0^1 P_t(f)^{1-\varepsilon} df \right]^{\frac{1}{1-\varepsilon}}.$$

Intermediate goods producers operate in monopolistic competition, are owned by savers and borrowers according to their shares in the population, and employ labour to produce variety f according to

$$Y_t(f) = L_t(f).$$

As in Calvo (1983), intermediate goods producing firms keep their price unchanged with probability $\alpha \in (0,1)$. Those that can adjust choose the price of their product $\widetilde{P}_t(f)$ to maximize expected future profits conditional on no further changes, taking as given the demand for their variety and their marginal cost, which is equal to the real wage ($MC_t = W_t/P_t$) and is independent of firm-specific characteristics. The optimal price setting decision for firms that adjust at time t solves

$$\max_{\tilde{P}_t(f)} \mathbb{E}_t \left\{ \sum_{j=0}^{\infty} (\alpha\beta)^j \frac{\lambda_{t+j}}{\lambda_t} \left[(1+\tau^f) \frac{\tilde{P}_t(f)}{P_{t+j}} - MC_{t+j} \right] Y_{t+j}(f) \right\},$$

subject to (4), where $\tau^f > 0$ is a subsidy to make steady-state production efficient. Since shares are non-tradable and the two types of households own firms in proportion to their size in the population, the discount factor for future profits corresponds to the average marginal utility of consumption

$$\lambda_t = \xi \lambda_t^b + (1-\xi)\lambda_t^s,$$

where $\lambda_t^\tau = (C_t^\tau)^{-\sigma^\tau}$ is the marginal utility of type τ.

3.4. *Market clearing and equilibrium*

The goods market equilibrium requires that total production equals the sum of consumption of the two types plus the resources spent for housing and equity holding costs

$$Y_t = \xi C_t^b + (1-\xi) C_t^s + \Gamma_t,$$

where $\Gamma_t \equiv (1-\xi)\Gamma_{et} + \xi \Gamma_{ht}^b + (1-\xi)\Gamma_{ht}^s$.[14]

We assume housing is in fixed supply, so that the housing market equilibrium requires

$$H = \xi H_t^b + (1-\xi) H_t^s,$$

where H is the total available stock of housing.

In the credit market, total bank lending must equal total household borrowing. Thus, the aggregate balance sheet of the financial sector respects

$$\xi B_t = (1-\xi)(D_t + E_t).$$

Finally, per-capita real private debt, derived by aggregating the budget constraint of new and existing borrowers over their respective measures, evolves according to

$$\frac{B_t}{P_t} = \delta \frac{R_{t-1}^b}{\Pi_t} \frac{B_{t-1}}{P_{t-1}} + \frac{Q_t}{P_t} [(H_t^b - H_{t-1}^b) + (1-\xi)(1-\delta)(H_{t-1}^b - H_{t-1}^s)] + \Gamma_{ht}^b + C_t^b - Y_t - (1-\xi) \frac{W_t}{P_t} (L_t^b - L_t^s).$$

The probability of not changing type drives the persistence of private debt. Differently from Cúrdia and Woodford (2016), housing demand enters the law of motion of debt. In this respect,

14. The resource constraint follows from combining the budget constraints of the two types (aggregated over their respective measures) with the banks' balance sheets.

what matters for debt is not only the change in debt of borrowers but also the difference (or "gap") in the existing level of housing between borrowers and savers, due to the switching between types.

For a given specification of monetary and macro-prudential policy, an imperfectly competitive equilibrium for this economy is a sequence of quantities and prices such that all agents in the economy (households, banks and firms) maximize their objectives subject to the relevant constraints and all markets clear. The analytical appendix reports the full list of variables and the equilibrium conditions for the private sector.

4. OPTIMAL POLICY PROBLEM

This section derives a LQ characterization of the jointly optimal monetary and macro-prudential policy problem. The LQ approach allows us to derive some analytical results and is tractable enough to study numerically cases in which the lower bound on the nominal interest rate and the collateral constraint are occasionally binding.

A second-order approximation to the welfare-based loss function around the steady state contains components reflecting the effects of distortions generated by both nominal rigidities and imperfect risk sharing. In two special cases, we are able to derive targeting rules that fully characterize the optimal policy plan. The targeting rules demonstrate how optimal macro-prudential policy accounts for the potential trade-off between stabilizing the effects of the two key distortions in the model.

We proceed by presenting the welfare-based loss function, the log-linearized equilibrium conditions that constrain the optimal policy problem, and a pair of targeting rules for monetary and macro-prudential policy abstracting from occasionally binding constraints, which we bring back in Section 5.

4.1. *Loss function*

We derive the loss function for the economy by taking the average of the utility functions of borrowers and savers, weighting each type according to their share in the population. A second-order approximation of the resulting objective around an efficient zero-inflation steady state in which the marginal utility of the two types is the same gives

$$\mathcal{L}_0 \propto \frac{1}{2}\mathbb{E}_0\left[\sum_{t=0}^{\infty}\beta^t\left(y_t^2+\lambda_\pi\pi_t^2+\lambda_h\tilde{h}_t^2+\lambda_\omega\omega_t^2\right)\right], \tag{5}$$

where y_t is output, π_t is the inflation rate, $\tilde{h}_t \equiv h_t^b - h_t^s$ is the housing gap between borrowers and savers, and $\omega_t \equiv \sigma^s c_t^s - \sigma^b c_t^b$ is the marginal utility gap.[15]

All relative welfare weights in Equation (5) are positive. In particular, the relative weight on inflation is

$$\lambda_\pi \equiv \frac{\varepsilon}{\gamma(\bar{\sigma}+\varphi)},$$

15. From now on, all variables should be understood as log-deviations from the steady state unless otherwise stated.

where $\gamma \equiv (1-\alpha)(1-\alpha\beta)/\alpha$, $\bar{\sigma}^{-1} \equiv \xi\varpi^b/\sigma^b + (1-\xi)\varpi^s/\sigma^s$, and $\varpi^\tau \equiv C^\tau/Y$ is the steady-state consumption-to-output ratio for type τ. The relative weight on the housing gap is

$$\lambda_h \equiv \frac{\xi(1-\xi)}{\bar{\sigma}+\varphi}\left[\Psi_h + \frac{(1-\beta)\eta_q\sigma_h}{\eta_d}\right],$$

where $\eta_q^{-1} \equiv b/q$ is the steady-state ratio between debt and house prices, and $\eta_d^{-1} \equiv b/Y$ is the steady-state debt-to-GDP ratio. Finally, the relative weight on the marginal utility gap is

$$\lambda_\omega \equiv \frac{\xi(1-\xi)\sigma_\varphi}{\bar{\sigma}+\varphi},$$

where $\sigma_\varphi \equiv \varphi^{-1} + \varpi^b\varpi^s\bar{\sigma}/(\sigma^b\sigma^s)$.

The loss function features two sets of terms. The first includes output and inflation—the standard variables that appear in the welfare-based loss function of a large class of New Keynesian models.[16] Their presence in the loss function reflects the two distortions associated with price rigidities. First, such rigidities open up a “labour wedge”, causing the level of output to deviate from its efficient level. Second, staggered price setting implies an inefficient dispersion in prices, which is proportional to the rate of inflation.

The second set of terms in (5), comprising the housing gap and the marginal utility gap, arises from the incompleteness of financial markets. In particular, even though in steady state the marginal utilities of consumption of both goods and housing services between the two types are equal, limited access to a full set of state-contingent securities generates excessive volatility of marginal utilities over time. In turn, this distortion affects the ability of households to smooth their consumption of both goods and housing services away from the steady state, leading to the presence of $\tilde{h}_t$ and ω_t in the loss function.[17] When the collateral constraint binds (away from steady state), the amount of debt that borrowers can accumulate is less than the desired level, thus increasing their marginal propensity to consume relative to savers.[18] Imperfect risk sharing therefore is a source of welfare losses that a benevolent policymaker takes into account when setting optimal monetary and macro-prudential policy.[19]

4.2. *Log-linearized equilibrium conditions*

In this section, we report the set of log-linearized equilibrium conditions, expressed in terms of welfare-relevant variables, that constrain the LQ approximation to the optimal policy problem.

Taking the average of the Euler equations of borrowers and savers yields an aggregate demand equation

$$y_t = -\bar{\sigma}^{-1}(i_t - \mathbb{E}_t\pi_{t+1} - r_t^*) + \mathbb{E}_t y_{t+1}, \quad (6)$$

16. Since productivity is constant, efficient output is simply equal to its steady-state value, and the efficient output gap corresponds to the deviations of output from steady state.

17. In principle, a rich enough set of state-contingent taxes and transfers would allow a benevolent policymaker to achieve the first-best allocation over time. Some of these instruments would be necessary even in the absence of nominal rigidities because financial market incompleteness would continue to generate marginal utility and housing gaps.

18. Since the steady-state marginal utility of consumption of the two types is the same, the steady-state collateral constraint is always slack.

19. Although the choice of equity involves resource costs through the function Γ_{et}, the assumption that the leverage ratio is an exogenous—albeit time-varying—constraint implies that its fluctuations are independent of policy, and thus irrelevant for ranking alternative policies in terms of welfare.

where i_t is the net nominal interest rate (the log-deviation of the deposit rate from steady state), and r_t^* is the equilibrium real interest rate, that is, the real interest rate consistent with a zero output gap in every period. Differently from the baseline New Keynesian model, the equilibrium real interest rate is endogenous and proportional to the expected quasi-difference of the marginal utility gap

$$r_t^* \equiv (\sigma_\omega + \delta\xi)\mathbb{E}_t\omega_{t+1} - (\sigma_\omega + \xi)\omega_t, \tag{7}$$

where $\sigma_\omega \equiv \xi(1-\xi)\bar{\sigma}(\varpi^b/\sigma^b - \varpi^s/\sigma^s) > 0$.[20] Our numerical experiments document how expansionary credit spread shocks generate a negative marginal utility gap, as borrowers increase their consumption more rapidly than savers, thus linking a build-up of private debt with an increase of the equilibrium real interest rate, as in Eggertsson and Krugman (2012) and Benigno *et al.* (2020). Conversely, a shock that forces borrowers to cut consumption in order to delever generates downward pressure on the equilibrium real interest rate.

The difference between the Euler equations of the two types gives an equation for the marginal utility gap

$$\omega_t = \kappa_t + \mu_t - \beta\gamma_d[\delta + (1-\delta)\xi]\mathbb{E}_t\mu_{t+1} + \delta\mathbb{E}_t\omega_{t+1}, \tag{8}$$

where κ_t is a scaled version of the equity requirement, which we interpret as a credit spread shock (see Section 5.2 for more details), and μ_t is the Lagrange multiplier on the collateral constraint.[21]

Taking the average of the housing demand equations of borrowers and savers yields a pricing equation for housing

$$q_t = (1-\beta)[\bar{\sigma} y_t + \xi\tilde{\sigma}_h\tilde{h}_t + (\xi + \sigma_\omega)\omega_t] + \beta(\mathbb{E}_t q_{t+1} - i_t + \mathbb{E}_t\pi_{t+1}), \tag{9}$$

where q_t denotes real house prices and $\tilde{\sigma}_h \equiv \sigma_h + \Psi_h/[(1-\beta)q]$. House prices are increasing in aggregate income and expected future house prices, and negatively related to the real interest rate, as in a standard user-cost equation. However, since borrowers are credit constrained, house prices are also increasing in both the housing gap and the marginal utility gap.

The difference between the housing demand equations of the two types gives an equation for the housing gap

$$(1-\beta)\tilde{\sigma}_h\tilde{h}_t = (1-\gamma_d)\Theta\mu_t - \omega_t + \beta\delta\mathbb{E}_t\omega_{t+1}. \tag{10}$$

The housing gap is positively related to the tightness of the collateral constraint and negatively to the marginal utility gap.

The approximation of the collateral constraint gives

$$b_t \leq \ln\mathcal{M} + \frac{\delta\gamma_d}{\mathcal{M}}(b_{t-1} - \pi_t) + \frac{(1-\gamma_d)\Theta\eta_q}{\mathcal{M}}[\theta_t + q_t + (1-\xi)\tilde{h}_t], \tag{11}$$

where $\mathcal{M} \equiv \delta\gamma_d + (1-\gamma_d)\Theta\eta_q$ denotes the steady-state ratio of the value of the collateral constraint to the real value of debt and θ_t is the log-deviation of the LTV limit from its steady-state

20. The reason why σ_ω is positive is that borrowers have a lower coefficient of relative risk aversion than savers ($\sigma^b < \sigma^s$), which in turn implies that their steady-state consumption share is relatively higher ($\varpi^b > \varpi^s$).

21. The multiplier on the collateral constraint is expressed in levels, rather than as a log-deviation, since its steady-state value is zero.

level Θ.[22] Therefore, the complementary slackness conditions are (11), $\mu_t \geq 0$, and

$$\mu_t \left\{ b_t - \ln \mathcal{M} - \frac{\delta \gamma_d}{\mathcal{M}}(b_{t-1} - \pi_t) - \frac{(1-\gamma_d)\Theta \eta_q}{\mathcal{M}}[\theta_t + q_t + (1-\xi)\tilde{h}_t] \right\} = 0. \tag{12}$$

Real debt evolves according to

$$\begin{aligned} b_t = &\frac{\delta}{\beta}(b_{t-1} + i_{t-1} + \kappa_{t-1} - \pi_t) + (1-\xi)\eta_q(\tilde{h}_t - \delta \tilde{h}_{t-1}) \\ &+ \eta_d \left[\left(\frac{\varpi^b \bar{\sigma}}{\sigma^b} - 1 \right) y_t - (1-\xi)\sigma_\varphi \omega_t \right], \end{aligned} \tag{13}$$

where we have used the equation for the nominal interest rate faced by borrowers ($i_t^b = i_t + \kappa_t$) that comes from the banks' problem.

Finally, the Phillips curve is

$$\pi_t = \gamma \left[(\bar{\sigma} + \varphi) y_t + \sigma_\omega \omega_t \right] + \beta \mathbb{E}_t \pi_{t+1}. \tag{14}$$

Because of the different labour supply behaviour of borrowers and savers, financial frictions affect inflation dynamics through the marginal utility gap as in Cúrdia and Woodford (2016), thus playing the role of an endogenous cost-push shock.

Given the sequence of policy instruments $\{i_t, \theta_t\}_{t=0}^{\infty}$, exogenous shocks $\{\kappa_t\}_{t=0}^{\infty}$, and initial conditions on debt, housing gap and the nominal interest rate $\{b_{-1}, \tilde{h}_{-1}, i_{-1}\}$, an equilibrium for the log-linear version of the model is a sequence $\{y_t, \pi_t, \omega_t, \tilde{h}_t, q_t, b_t, \mu_t\}_{t=0}^{\infty}$ that satisfies (6), (8), (9), (10), (11), (13) and (14), $\forall\, t \geq 0$, as well as a set of inequality constraints. These inequality constraints include the contemporary slackness condition (12) and $\mu_t \geq 0$, and the constraints on the policy instruments. In particular, the ZLB requires $i_t \geq \ln \beta$ and the credit supply constraint requires $\theta_t \leq 0$.

4.3. *Optimal targeting rules*

This section builds intuition for the quantitative experiments, which include occasionally binding constraints, by studying two simplified examples. First, we consider the case in which the collateral constraint never binds. Second, we examine optimal policy when the collateral constraint is always binding. In both cases, we assume the nominal interest rate never violates the ZLB ($i_t > \ln \beta \,\forall\, t$). We focus on the discretionary solution for comparability with the numerical experiments in the next section.[23] The main result is that, in both examples, the optimal monetary policy targeting rule is identical to the one obtained in the baseline New Keynesian model. In addition, when the collateral constraint binds, optimal macro-prudential policy balances a trade-off between the stabilization of the distortions caused by financial frictions and those caused by nominal rigidities.

We begin with the case in which the collateral constraint never binds ($\mu_t = 0 \,\forall\, t$). This example is particularly simple because the credit spread shock fully determines the marginal utility gap (from Equation (8)), which in turn pins down the housing gap (from Equation (10)).

22. Since the collateral constraint is slack in steady state, $\mathcal{M} > 1$ and hence $\ln \mathcal{M} > 0$.

23. The analytical appendix reports the Lagrangian formulation of the optimal policy problem for the second example and derives the optimal targeting rules under both discretion and commitment. The discussion in this section informally summarizes the results.

As a consequence, the cost-push shock component associated with the marginal utility gap in the Phillips curve becomes exogenous. Therefore, since the marginal utility gap and the housing gap become independent of policy, the loss function only depends on output and inflation, as in the standard New Keynesian model. Moreover, because house prices and debt enter neither the aggregate demand Equation (6) nor the Phillips curve (14), the solution of the optimal policy problem corresponds to a standard flexible targeting rule that trades off output and inflation

$$\varepsilon\pi_t + y_t = 0. \tag{15}$$

Macro-prudential policy has no bearing on the equilibrium allocation and the optimal LTV ratio is indeterminate. Despite its simplicity, this case clarifies that in our model macro-prudential policy is effective only if the collateral constraint binds, is expected to bind at some point in the future, or if the macro-prudential authority can tighten the LTV limit enough to make the constraint bind. In this simple example, those three conditions are ruled out by assumption.

In the second case that we study analytically, we assume that the collateral constraint always binds ($\mu_t > 0\,\forall\, t$). Since θ_t only enters (11), we can use this equation residually to derive the value of the LTV limit that implements the optimal policy plan.[24] Following the same logic, house prices only affect (9), so that this equation is not a binding constraint for the optimal policy problem. In principle, debt, the nominal interest rate and the housing gap are state variables for this problem through Equation (13). The law of motion of debt, however, does not constrain the optimal policy plan. Thus, the optimal policy problem is purely forward looking, and Equation (13) can be used to determine the equilibrium level of debt. This conclusion also implies that Equation (6) determines residually the nominal interest rate.

The simplified optimal policy problem then consists of minimizing (5) subject to (8), (10) and (14). The optimal targeting rule for monetary policy follows from combining the first order conditions of the optimal policy problem for output and inflation. The central bank continues to trade off output and inflation exactly as in the baseline New Keynesian model and in Equation (15). Distributional variables (the marginal utility gap and the housing gap) do not enter directly the optimal targeting rule for monetary policy.

The optimal targeting rule for macro-prudential policy follows from combining the first order conditions for the marginal utility gap, the housing gap, and the multiplier on the collateral constraint

$$\lambda_\omega \omega_t - \frac{\sigma_\omega}{\bar{\sigma} + \varphi} y_t - \frac{[1-(1-\gamma_d)\Theta]\lambda_h}{(1-\beta)\tilde{\sigma}_h} \tilde{h}_t = 0. \tag{16}$$

If the collateral constraint has no inertia ($\gamma_d = 0$) and the steady-state LTV ratio is 100% ($\Theta = 1$), the optimal targeting rule for macro-prudential policy only trades off the marginal utility gap and the output gap. In particular, optimal policy requires that the two variables move in the same direction since, as we previously discussed, σ_ω is a positive parameter.

Optimal macro-prudential policy is therefore countercyclical. A positive output gap calls for a positive marginal utility gap (higher marginal utility of consumption of borrowers relative to savers). The macro-prudential authority achieves this result by tighter LTV limits, which reduce borrowers' consumption relative to savers' consumption. In this way, the macro-prudential authority strikes an optimal balance between aggregate and distributional variables.

More generally (*i.e.* without restrictions on γ_d and Θ), the housing gap matters too. Since the coefficient multiplying the housing gap is also always positive, optimal macro-prudential policy

24. We also assume that the resulting LTV limit respects the feasibility constraint $\theta_t < 0$.

induces positive co-movement between a combination of the housing gap and the output gap on the one hand, and the marginal utility gap on the other. The targeting rule (16) also suggests that optimal policy does not involve a complete separation of objectives. The presence of output in the optimal targeting rule for macro-prudential policy implies a direct feedback effect from monetary policy.[25]

5. QUANTITATIVE EXPERIMENTS

This section presents our main results, demonstrating the power of optimal LTV limits to stabilize business cycle fluctuations when the lower bound on the nominal interest rate and the collateral constraint can be occasionally binding.

A sequence of credit spread shocks generates a boom-bust scenario for house prices and private debt similar to the dynamics observed in the US (Figure 1), including a recession in which the ZLB constrains the nominal interest rate. In the baseline scenario, monetary policy follows a simple Taylor rule and the LTV limit is constant at its steady-state level. Optimal policy calls for a tightening of LTV limits during the boom phase which prevents the run-up in private debt and mitigates the effects of the bust. Indeed, under the optimal policy plan the nominal interest rate does not encounter the ZLB.

Before illustrating our results, we discuss the calibration of the model, including the process for the credit spread shocks, and the simulation methodology.

5.1. *Parameter values*

Table 1 reports the parameter values used in the simulations. The individual discount factor β equals 0.995 so that the annualized steady-state real interest rate is 2%. The share of borrowers ($\xi = 0.625$) corresponds to the fraction of mortgagors in the US from Cloyne *et al.* (2020), after adjusting for the absence of renters in our model. We set the probability that the type does not change (δ) equal to 0.99 to generate a high persistence in mortgage debt as in the data.[26] Following Cúrdia and Woodford (2016), we choose the ratio between the coefficient of risk aversion of the two types (σ^b/σ^s) equal to 0.2, and back out their levels by imposing that the inverse elasticity of output to the real interest rate $\bar{\sigma}$ in the aggregate demand Equation (6) is equal to one, a common value in the literature (*e.g.* Galí, 2015). Also standard is the value for the elasticity of substitution among varieties ($\varepsilon = 6$), which we choose to deliver a steady-state markup of 20%. While we assume the existence of a subsidy to eliminate the steady-state monopolistic distortion, this parameter remains important in governing the optimal monetary policy trade-off between inflation and the output gap (see Equation (15)).

The curvature of the utility from housing services (σ_h) and the inertia parameter in the collateral constraint (γ_d) correspond to the calibrated value and posterior mode, respectively, in Guerrieri and Iacoviello (2017). The steady-state LTV ratio (Θ) equals 75%, based on the average between 1973 and 2000 in the Federal Housing Finance Agency's Monthly Interest Rate Survey, Table 17. We set the parameter of the housing holding cost function (Ψ_h) to 0.8 in order

25. Optimal targeting rules are not unique. Indeed, inflation could replace the output gap in the optimal targeting rule for macro-prudential policy, as substituting (15) into (16) shows, although the interpretation would not change.

26. The calibrated value of δ is slightly higher than in Cúrdia and Woodford (2016) but is consistent with the idea that being a net borrower/saver is a persistent characteristic over the life cycle.

TABLE 1
Parameter values

Parameter	Description	Value
β	Individual discount factor	0.995
ξ	Fraction of borrowers	0.625
δ	Probability of not changing type	0.990
σ^b	Coefficient of risk aversion (borrowers)	0.707
σ^s	Coefficient of risk aversion (savers)	3.537
χ_H	Housing utility parameter	0.024
σ_h	Inverse elasticity of substitution for housing	1.000
χ_L	Labor utility parameter	0.985
φ	Inverse Frisch elasticity	1.000
Θ	Maximum LTV	0.750
γ_d	Collateral constraint inertia	0.700
α	Probability of keeping price unchanged	0.870
ε	Elasticity of substitution among varieties	6.000
Ψ_h	Housing holding cost	0.800
ψ_π	Taylor rule feedback on inflation	1.500
ψ_y	Taylor rule feedback on output gap	0.125
b/Y	Mortgage debt relative to GDP	2.880
q/b	Value of real estate relative to mortgage debt	1.625
$\rho_{\hat{\kappa}}$	Persistence of temporary spread component	0.925
$\rho_{\bar{\kappa}}$	Persistence of quasi-permanent spread component	0.995

to match the relative decline in housing wealth between savers and borrowers between 2007 and 2010.[27]

We assume that the inverse elasticity of labour supply (φ) is equal to 1, within the range of the macro estimates (Peterman, 2016), though closer to the estimates from micro data (Chetty *et al.*, 2011). The value of the probability that firms do not adjust their price in a quarter ($\alpha = 0.87$) is in line with the recent estimates in Del Negro *et al.* (2015).[28] The baseline specification for monetary policy (discussed in Section 5.3) is an interest rate rule with the coefficients on inflation and the output gap ($\psi_\pi = 1.5$ and $\psi_y = 0.125$) set to standard values (Taylor, 1993).

Finally, we calibrate the steady-state level of mortgage debt to 45% of (annual) GDP, in line with US data in 2000, when the housing boom began. The ratio between the value of housing and mortgage debt, which in US data between 1995 and 2016 is 2.6, gives us a target for q/b.[29]

5.2. *Exogenous shocks and simulation methodology*

In the model, up to a first-order approximation, κ_t corresponds to the credit spread, that is, the difference between the interest rate on loans and on deposits ($\kappa_t = i_t^b - i_t$). We generate a boom-bust scenario in house prices consistent with the US data in Figure 1 through a sequence

27. Using data from the Survey of Consumer Finances, Menno and Oliviero (2020) document large differences in the decline of housing wealth held by borrowers and savers, and separately calibrate the costs (with an identical functional form to ours) for the two types to match those targets. For analytical tractability, we assume the same parameter for borrowers and savers. Setting $\Psi_h = 0.8$ delivers a relative decline of borrowers and savers' housing wealth (measured as the ratio of the log changes in housing wealth) consistent with the data between 2007 and 2010.

28. The implied slope of the Phillips curve is $\gamma(\bar{\sigma} + \varphi) = 0.04$.

29. In the model, we adjust per-capita debt b by the share of borrowers ξ to ensure proper comparability with the data. The analytical appendix describes how we use per-capita debt/GDP and the value of housing relative to mortgage debt to back out the constants χ_L and χ_H, and hence a number of other steady-state variables.

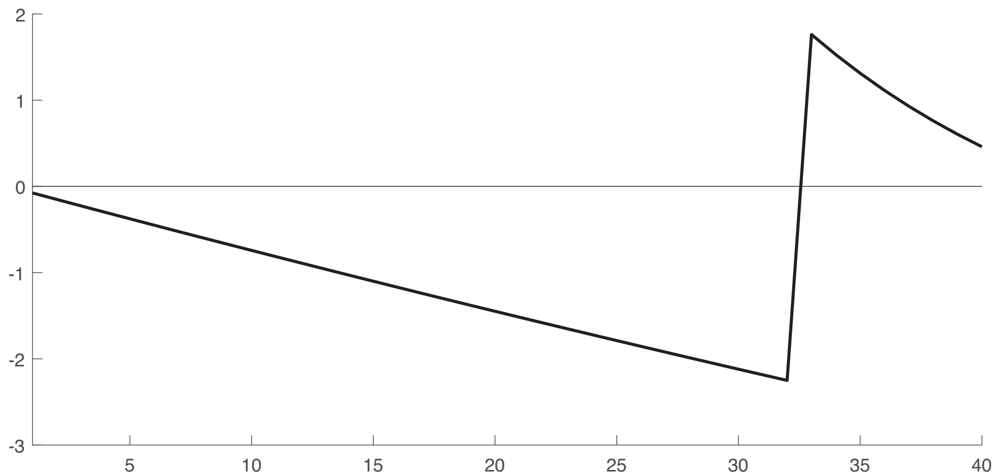

FIGURE 3
The path of the credit spread

Note: The figure plots the path of the credit spread $\kappa_t = \bar{\kappa}_t + \hat{\kappa}_t$ (in annualized units). Both components of the spread follow a stationary first-order autoregressive process, with persistence parameters $0 < \rho_{\hat{\kappa}} < \rho_{\bar{\kappa}} < 1$.

of small unanticipated negative shocks to the credit spread followed by one large positive shock. The credit spread declines persistently during the boom before spiking at the time of the bust.

The shocks determining the persistent fall of the credit spread seek to capture the process of financial liberalization and innovation that took place in the US starting in the second half of the 1990s (Mian and Sufi, 2009; Boz and Mendoza, 2014). The large contractionary shock approximates the tightening of credit standards at the onset of the recession (*e.g.* Chen *et al.*, 2020).

Figure 3 plots the process for the credit spread that drives the simulations.[30] We assume that the credit spread is the sum of two components ($\kappa_t = \bar{\kappa}_t + \hat{\kappa}_t$), each following a stationary first-order autoregressive process ($\bar{\kappa}_t = \rho_{\bar{\kappa}}\bar{\kappa}_{t-1} + \varepsilon_{\bar{\kappa}t}$ and $\hat{\kappa}_t = \rho_{\hat{\kappa}}\hat{\kappa}_{t-1} + \varepsilon_{\hat{\kappa}t}$). We assume that $\bar{\kappa}_t$ is a near-permanent component of spreads and calibrate $\rho_{\bar{\kappa}}$ to 0.995, while we refer to $\hat{\kappa}_t$ as the temporary component and set $\rho_{\hat{\kappa}}$ equal to 0.925.

Negative shocks to the near-permanent component generate the secular decline in the spread. The spike is the combination of a positive shock to the temporary component and a positive shock to the near-permanent component that partially reverses the previous decline. The boom lasts for 32 quarters. The two contractionary shocks arrive in the following period and no further shocks occur thereafter.

The decline of approximately 200 basis points in our simulation is consistent with the evolution of the spread between the average mortgage rate in the Private Label Securities Database (PLSD) and the 10-year Treasury yield between 2000 and 2007 (Justiniano *et al.*, 2022). Over this period, the marginal mortgagor likely belonged to this category. Unfortunately, due to the dry-up of the private label segment of the market at the onset of the financial crisis, the data from

30. In practice, housing demand shocks are likely to have contributed to the gyrations of house prices during the first decade of the 2000s (Adelino *et al.*, 2016). As this type of shock is more difficult to calibrate, we limit our attention to credit spread shocks inferred from spreads. In an earlier version of this paper (Ferrero *et al.*, 2018), we showed that credit spread and housing demand shocks have very similar consequences for macroeconomic variables, especially in the absence of macro-prudential policy.

the PLSD end in 2007. However, even conventional mortgage rates spiked at that time. Menno and Oliviero (2020) document the dramatic rise by about 450 basis points of the spread between the 1-year adjustable rate mortgage and the federal funds rate in 2008–2009. Fixed-rate mortgage rates also jumped at this time. For example, during the same period, the spread between the 30-year fixed mortgage rate and the average of the 5- and 10-year Treasury yields rose by around 150 basis points (Walentin, 2014). The calibrated increase of the spreads in the simulation falls squarely within this range.[31]

We solve the model using a piecewise-linear solution method to account for the possibility that (i) the ZLB on the short-term nominal interest rate becomes binding and/or (ii) the borrowers' collateral constraint (11) becomes slack.[32] This approach accounts for the possibility that the occasionally binding constraints may apply in future periods, although not for the risk that future shocks may cause the constraints to bind. Thus, our approach, which is based on the methods developed by Guerrieri and Iacoviello (2015) and Harrison and Waldron (2021), abstracts from the skewness in the expected distribution of future endogenous variables arising from the possibility of being constrained in future. The online appendix contains a full description of the approach.

5.3. *Baseline scenario: the pre-crisis consensus*

This section presents our baseline scenario, which we label "the pre-crisis consensus". In the pre-crisis consensus, the central bank controls the short-term nominal interest rate to stabilize fluctuations in inflation and output while macro-prudential policy is inactive. This policy configuration captures well the reliance on monetary policy for macroeconomic stabilization and the general absence of macro-prudential policy frameworks that prevailed in many economies before the financial crisis of 2008.

In the context of our model, inactive macro-prudential policy implies that the LTV limit remains constant at its steady-state level ($\theta_t = 0, \; \forall\, t$). We assume that the central bank conducts monetary policy according to a standard nominal interest rate rule (Taylor, 1993)

$$i_t = \psi_\pi \pi_t + \psi_y y_t, \tag{17}$$

where $\psi_\pi > 1$ and $\psi_y \geq 0$ (see Section 5.1 for the calibration of these two parameters).

Figure 4 shows the response of the economy to the evolution of credit spreads under the baseline policy assumptions. The solid lines correspond to the case in which both the collateral constraint and the zero bound on the policy rate can be occasionally binding. To illustrate the importance of the ZLB, the dashed lines display the results when the nominal interest rate can become negative.

The initial decline in mortgage spreads encourages borrowers to increase their leverage and purchase more housing. During the boom period, house prices (panel a) go up by slightly more than 20 percentage points while debt (panel b) rises by more than 30% relative to its steady-state value. Borrowers remain unconstrained during the boom period (panel c), while the housing gap

31. At the time of the crisis, spreads soared pretty much in all segments of private credit markets (Gilchrist and Zakrajšek, 2012).

32. In our model, a binding ZLB on the short-term nominal interest rate also implies a zero nominal rate of return to savings. Theoretically, a ZLB on savings rates arises from the existence of an unmodeled zero-interest-bearing alternative saving instrument (*e.g.* cash). In practice, the evidence on negative interest rates (*e.g.* Eisenschmidt and Smets, 2019) suggests that deposit rates feature a hard floor at zero, although anecdotally some banks may have introduced new fees on deposit accounts when official interest rates became negative.

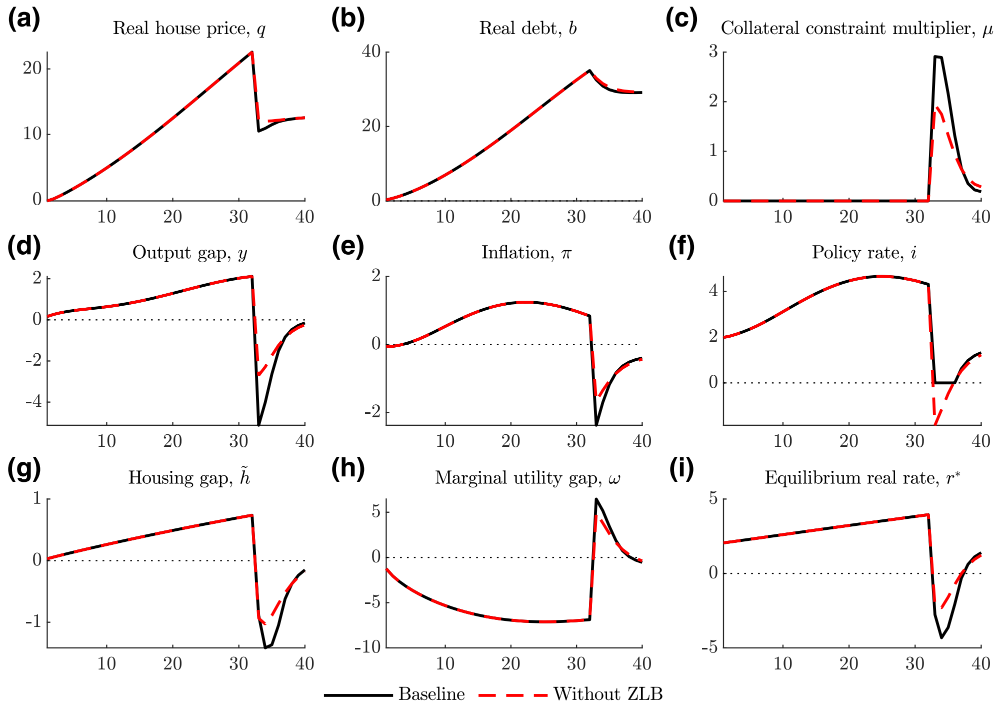

FIGURE 4

Baseline scenario (constant LTV limit)

Note: All variables are scaled by 100 and plotted as log-deviations from steady state, except for the multiplier on the collateral constraint, the policy rate and the equilibrium real interest rate, which are in levels. Inflation, the policy rate and the equilibrium real interest rate are in annualized units.

becomes positive (panel g), which reflects the increase of housing demand by borrowers relative to savers.

The large boom in house prices and the increase in debt coincides with a moderate expansion of real economic activity. The output gap approaches 2% at the onset of the bust (panel d). Inflation also rises above target during the boom period (panel e), though the fall of the marginal utility gap (panel h) due to the increase in credit availability mitigates the effect of the boom acting like an endogenous negative cost-push disturbance. During this phase, the nominal interest rate increases by about 200 basis points (panel f). The policy rate rises alongside (albeit not exactly one for one) the equilibrium real interest rate (panel i), which is itself inversely related to the marginal utility gap, as Equation (7) shows.

The baseline scenario also captures the broad contours of the Great Recession. As house prices collapse, borrowers start to delever. The persistence in the collateral constraint slows down the adjustment, which lasts for several quarters, in line with the decoupling between house prices and mortgage debt observed in the data. As in Eggertsson and Krugman (2012) and Guerrieri and Lorenzoni (2017), the deleveraging process pushes the equilibrium real interest rate into negative territory. The nominal interest rate falls all the way to zero and remains at the lower bound for four quarters.[33]

33. At the time of the financial crisis, market participants expected the Fed funds rate to remain at the ZLB for 1 year (Moore, 2008).

During this time, the economy experiences a severe recession, exacerbated by the inability of monetary policy to provide full accommodation. Output falls five percentage points below trend and inflation misses the central bank's target by slightly more than two percentage points on an annualized basis.[34]

When the housing bust occurs, the collateral constraint becomes binding and the shadow value of an additional unit of debt increases significantly. The tightening of the collateral constraint contributes to amplifying the impact of the shock (Guerrieri and Iacoviello, 2017). The bust entails substantial redistribution from borrowers to savers as the patterns of both the marginal utility gap and the housing gap observed during the boom reverse sharply. The welfare-based loss (5) suggests that a monetary policy response focused solely on inflation and the output gap, as the baseline rule prescribes, fails to address all the costs of the recession. Once the downturn is over, the process of monetary policy normalization is gradual, consistent with the sluggish recovery in the data.

The results from the simulation that ignores the lower bound on the interest rate shed further light on the interplay between financial frictions and monetary policy during the housing bust. As the dashed lines in Figure 4 show, allowing the policy rate to fall below zero substantially mitigates the effects of the crisis. As the negative shock hits, the policy rule prescribes a peak-to-trough decline in the nominal interest rate of around 600 basis points, deep into negative territory. This response cushions the drop of output and inflation. While the housing gap still falls sharply on impact, the recovery is much swifter and the increase in the marginal utility gap is slightly less extreme. Similarly, the collateral constraint binds less tightly so that house prices fall by a few percentage points less than in the baseline case.

The presence of the ZLB therefore exacerbates the effects of the debt deleveraging process on spending and inflation (Korinek and Simsek, 2016), which reflect the relation between the equilibrium real interest rate and the marginal utility gap.[35] The ZLB limits the feasible reduction of the nominal and hence real interest rate, thus depressing in particular borrowers' spending, increasing the marginal utility gap, and tightening the collateral constraint. As a result, the equilibrium real rate falls further, which creates a negative aggregate demand loop.

5.4. *Optimal LTV policy*

The last section highlighted how a tightening of the collateral constraint can generate large declines in the equilibrium real interest rate and amplify the effects on aggregate demand, especially if monetary policy is unable to adequately respond because of the ZLB. These results suggest that macro-prudential policies directly affecting the collateral constraint, and hence its tightness, may be able to mitigate the effects of a sharp increase in the cost of credit. In this section, we verify this conjecture by allowing the policymaker to set the macro-prudential LTV limit θ_t during the boom-bust scenario.

A natural benchmark is the joint determination of monetary and macro-prudential policy to minimize the welfare-based loss function (5). As we focus on time-consistent policies, the policymaker is unable to make promises about future actions in order to improve stabilization outcomes today.[36] One motivation for studying time-consistent policies is to limit the power of

34. Our results are consistent with a moderate decline of inflation (and little actual deflation relative to a 2% target) because the inflationary effect of the marginal utility gap in the Phillips curve partly compensates the deflationary pressures associated with the decline in aggregate demand (Gilchrist *et al.*, 2017).

35. A similar channel arises in Eggertsson and Krugman (2012) and Benigno *et al.* (2020).

36. In this case, we can treat the multiplier on the collateral constraint μ_t as the macro-prudential instrument. When the collateral constraint binds, a one-to-one mapping links the LTV limit and the multiplier on the collateral

monetary policy at the ZLB. While optimal commitment policies can be very effective at mitigating the negative consequences of the ZLB in standard New Keynesian models (see, for example, Eggertsson and Woodford, 2003), several recent contributions have questioned their empirical relevance (*e.g.* Del Negro *et al.*, 2012). Our setting rules out these commitments and maximizes the potential scope for macro-prudential policies to improve outcomes when used alongside monetary policy.[37] Qualitatively, however, a jointly optimal commitment policy delivers similar results to the time-consistent policy considered here (see the online appendix for details).

Figure 5 compares the outcomes in the housing boom-bust scenario under the baseline assumptions of a Taylor rule and a constant LTV limit (solid lines) with the case in which a single policymaker jointly sets the interest rate and the LTV limit to minimize the welfare-based loss function (5) (dashed lines).

The key result is that the active LTV policy markedly improves stabilization of the welfare-relevant variables during both the boom and the bust. The jointly optimal policy plan almost fully stabilizes inflation, the output gap, and the marginal utility gap, while the volatility of the housing gap visibly declines.

Focusing first on the boom, we observe that under optimal policy debt actually declines in response to the reduction of credit spreads (panel b). As we discuss more extensively below, the jointly optimal policy plan forces agents to reduce their debt through a lower LTV limit. As a consequence, the collateral constraint tightens, as implied by the significant rise of its shadow value (panel c). This effect, together with an approximately constant real interest rate (panel i), pushes house prices higher than under the baseline policy (panel a).

The finding that house prices increase under a tighter macro-prudential stance is consistent with the empirical evidence presented in Section 2, which showed that the joint behaviour of monetary and macro-prudential policy is crucial in determining the effects of LTV limits on house prices. Quantitatively, two key opposing effects determine the overall impact on house prices in the model. First, compared to the baseline, the tighter LTV limit reduces housing demand, as measured by the housing gap, exerting downward pressure on house prices. Second, because of active macro-prudential policy, the stabilization of inflation and the output gap requires an easier monetary policy, and so a lower real interest rate, leading to higher house prices. In our simulation, the second effect is approximately twice the size of the first, with the net result being an increase in house prices under jointly optimal policy compared to the baseline.[38]

Interestingly, output and inflation remain close to their target values (panels d and e) despite a stable path of the nominal interest rate. The reason is that the active LTV policy stabilizes the marginal utility gap (panel h). As a consequence, no material trade-off between output and inflation stabilization emerges. The only welfare-relevant variable that significantly moves away

constraint so that selecting μ_t as the policy instrument merely represents a change of variables in the policy problem. When the collateral constraint is slack, a range of values for θ_t above a certain threshold is consistent with the equilibrium. As the multiplier cannot be negative, the lower bound on μ_t corresponds to a constraint on policy. This credit demand constraint rules out cases in which the policymaker forces borrowers to hold more debt than demanded at market prices. Moreover, under this interpretation of the policy problem, the credit supply constraint $\theta_t \leq 0$ can be recast as a time-varying lower bound on μ_t. The online appendix discusses the technical details of the solution.

37. Our analysis therefore contributes to an emerging literature studying monetary and macro-prudential policies under discretion. Bianchi and Mendoza (2018) argue that the nature of financial frictions generates an inherent time-inconsistency problem for macro-prudential policymakers. Laureys and Meeks (2018) demonstrate that discretionary policies can generate better outcomes than a class of simple macro-prudential policy rules studied in the existing literature.

38. The online appendix further illustrates this result by decomposing the house price equation in the model.

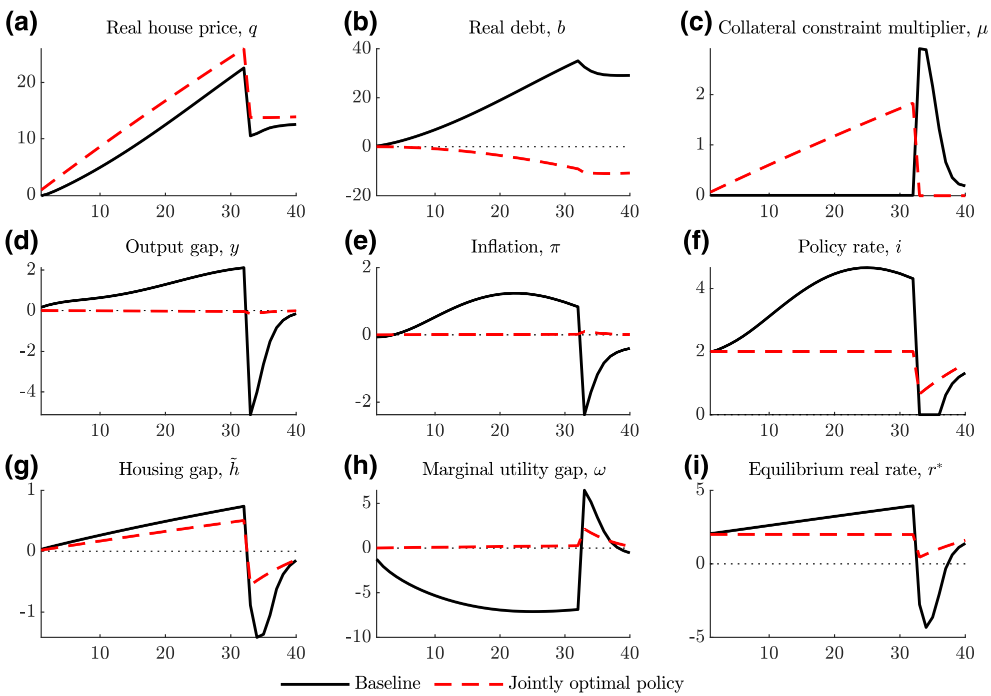

FIGURE 5

Jointly optimal policy

Note: All variables are scaled by 100 and plotted as log-deviations from steady state, except for the multiplier on the collateral constraint, the policy rate and the equilibrium real interest rate, which are in levels. Inflation, the policy rate and the equilibrium real interest rate are in annualized units.

from target is the housing gap (panel g), although its increase is somewhat smaller than in the baseline scenario.

When credit spreads reverse, so does the policy stance.[39] From the macro-prudential perspective, the policymaker would ideally support borrowing, effectively subsidising debt by setting $\mu_t < 0$. However, the contemporary slackness conditions imply a lower bound on the multiplier ($\mu_t \geq 0$) and the credit demand constraint binds. The policymaker cuts the nominal interest rate, though without reaching the ZLB. The introduction of an active LTV policy mitigates the impact of the shock on the marginal utility gap, which in turn translates into a smaller decline of the equilibrium real interest rate. The combined monetary and macro-prudential response continues to ensure almost full stabilization of output and inflation, as during the boom. The housing gap falls, but its movement is less than half of that in the baseline scenario.

Figure 6 plots the level of the LTV limit (Θ_t) under the jointly optimal policy plan, confirming the prediction in Section 4.3 that optimal macro-prudential policy is strongly countercyclical. Indeed, optimal policy requires an aggressive reduction of the LTV limit during the boom, which implies a tightening of the collateral constraint. As discussed above, this tightening increases the shadow value of debt and reduces its equilibrium level. During the bust, the credit demand constraint ($\mu_t \geq 0$) prevents the policymaker from inducing borrowers to hold more debt and further

39. In practice, without the boom period, the financial crisis may have never happened and spreads may have not spiked. We nevertheless find it instructive to discuss the optimal policy configuration in response to an increase in credit spreads.

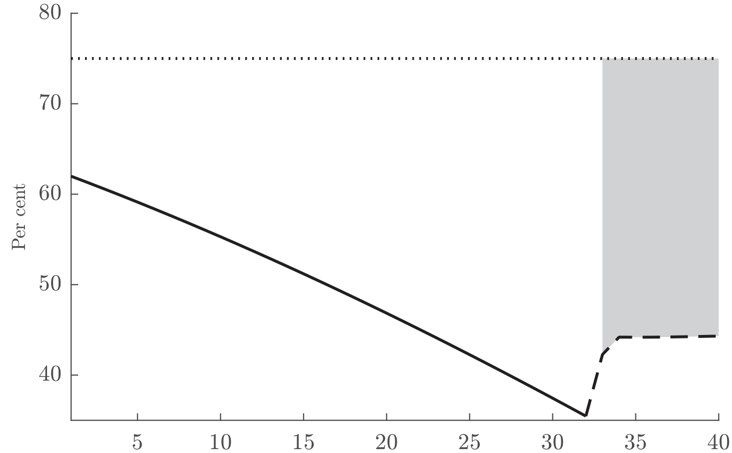

FIGURE 6
LTV limit under the jointly optimal policy plan

Note: The figure plots the level of the LTV limit under the jointly optimal policy plan. The solid line corresponds to periods in which the collateral constraint binds. The dashed line corresponds to periods in which the collateral constraint is slack. In these periods, any value in the shaded area is consistent with the equilibrium. The dotted line corresponds to the steady-state value of the collateral constraint (75%), which the simulation treats as an upper bound.

closing the marginal utility gap. The shaded area shows the range of LTV limits that are consistent with the equilibrium, in which the collateral constraint is slack.[40] The adjustments of the LTV limit required to deliver the jointly optimal policy are substantial, although not unprecedented. For example, as noted in Section 2, South Korea implemented similarly restrictive LTV limits shortly after their introduction as macro-prudential tools.

Our results illustrate the extent to which LTV limits may act as a substitute for monetary policy action. During the boom, active macro-prudential policy eliminates upward pressure on the equilibrium real interest rate and the need for a monetary policy tightening. When credit conditions worsen, the collateral constraint becomes slack, so that macro-prudential policy is unable to support borrowing as to fully stabilize the equilibrium real interest rate. Nevertheless, the macro-prudential policy loosening cushions the decline in the equilibrium real interest enough to avoid the ZLB and the associated feedback effects on the equilibrium real rate observed in the baseline scenario.

Finally, we note that the countercyclical adjustment of the LTV limit is the main source of improvement in macroeconomic outcomes relative to the baseline scenario. The online appendix considers the case in which monetary policy continues to follow the baseline Taylor rule (17), whereas the macro-prudential policymaker sets the LTV limit to minimize the welfare-based loss function. The results for that policy configuration are almost identical to those under jointly optimal policy shown in Figure 6, with the exception of small differences in the paths of the output gap and inflation, which reflect the slightly different trade-off between output gap and inflation stabilization under the baseline monetary policy rule compared to optimal monetary policy.

40. Figure 6 also clarifies that the LTV limit never exceeds its steady-state limit of 75% (dotted line).

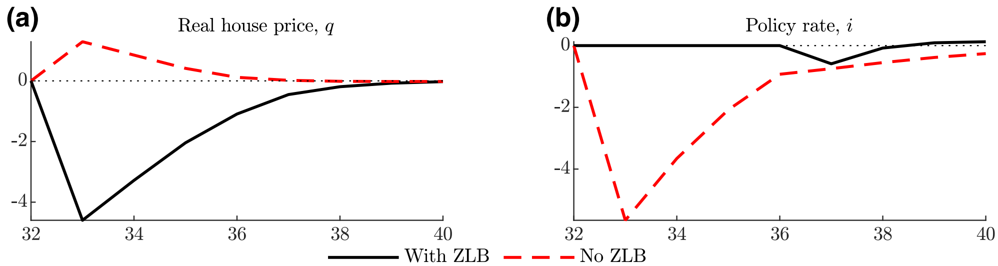

FIGURE 7

Macro-prudential tightening in the bust

Note: Both variables are plotted as log-deviations from the baseline simulation. Real house prices are scaled by 100 while the policy rate is in annualized percentage points.

5.5. *State-contingent effects of LTV limits*

Two striking results emerge from the simulations in Section 5.4. First, house prices rise by more during the boom under the jointly optimal policy plan than in the baseline simulation, even though optimal policy involves a substantial tightening of the LTV limit. Second, the active use of LTV limits is very effective in cushioning the consequences of the bust on welfare-relevant variables, even though the credit demand constraint somewhat limits the scope of macro-prudential policy.

In this section, we use two experiments, inspired by observed macro-prudential policy actions, to explore the state-contingent nature of LTV limits, that is, their efficacy in relation to the broader macroeconomic environment.

5.5.1. The monetary policy response. We begin by investigating how the effects of changes in the LTV limit on house prices depend on the response of monetary policy in an empirically relevant scenario. In this experiment, the macro-prudential authority implements a persistent reduction of the LTV limit by 5 percentage points at the same time as credit spreads spike. While the main objective of this experiment is simply to illustrate the importance of the monetary policy response, the Canadian experience in 2008 provides a realistic target for the scale of the shock (Allen *et al.*, 2017).[41]

To show the importance of the monetary policy reaction to the LTV tightening, we simulate the model with and without the ZLB constraint on the policy rate. In both cases, the monetary authority follows the baseline interest rate rule (17). We present the results for each case in deviations from the baseline scenario constructed in Section 5.3, in which the ZLB is binding. This approach permits a straightforward comparison of the macroeconomic effects of the LTV tightening under different assumptions about the monetary policy response.[42]

The solid line in the left panel of Figure 7 shows the response of house prices in deviations from the baseline scenario. The dashed line corresponds to the case in which we ignore the ZLB constraint following the tightening of the LTV limit. The right panel plots the response of the nominal interest rate, also in deviations from the baseline scenario.

41. The experiment assumes that the LTV limit θ_t is exogenous and follows a first-order autoregressive with high persistence ($\rho_\theta = 0.995$). A single innovation to the process at the time the bust occurs determines the size of the calibrated initial LTV limit reduction.

42. A simple LTV tightening shock starting from the steady state would require a counterfactually large shock to make the ZLB binding. The online appendix reports the full set of responses for this exercise. Unsurprisingly, the impact of the LTV tightening on both aggregate and distributional variables in less pronounced when the ZLB is not binding.

The figure demonstrates that our model, when confronted with an empirically relevant experiment, is consistent with the evidence in Bachmann and Rüth (2020) discussed in Section 2. The sign of the response of house prices to a tightening of the LTV limit crucially depends on the monetary policy response. In the absence of the ZLB, house prices actually increase relative to the baseline in response to the LTV tightening because of the large contemporaneous decline of the nominal interest rate. Conversely, when the ZLB binds, house prices fall because monetary policy is relatively tight. This exercise therefore documents an important dimension of the interaction between monetary and macro-prudential policy that should be of relevance to policymakers when setting their respective instruments.

5.5.2. Debt accumulation and the credit supply constraint. Our second experiment illustrates the extent to which the ability of optimal policy to cushion the economy from the effects of the housing bust hinges upon contemporaneously preventing a substantial run up in debt during the boom. For this purpose, we study the introduction of the jointly optimal policy plan only at the time of the housing bust. This simulation mimics, in a stylized way, the adoption of macro-prudential policy frameworks in the wake of the global financial crisis.

We assume that, for the duration of the boom, policy follows the baseline assumptions: the interest rate is set according to the Taylor rule (17) and the LTV limit is fixed ($\theta_t = 0$). When credit spreads spike, policy switches to the jointly optimal policy configuration: the interest rate and the LTV limit are set to minimize the welfare-based loss function (5).[43]

Figure 8 displays the results of the experiment, focusing on the responses of variables during the bust phase of the simulation. The dashed lines depict the case of jointly optimal policy activated in the bust. For comparison, the dashed-dotted lines correspond to the case in which the policymaker optimally sets only the LTV limit when credit spreads spike, while continuing to follow the baseline interest rate rule for monetary policy. The solid lines show the responses under the baseline policy configuration during both the boom and bust.

Optimal policy seeks to loosen the collateral constraint in order to cushion the effect of the spike in credit spreads on borrowers. Ideally, the policymaker would like to increase the LTV limit sufficiently to ensure that the collateral constraint is slack, as is the case when optimal policy is in place also during the boom. However, the baseline policy configuration followed during the boom has allowed debt to increase by around 30 percentage points above steady state when credit spreads spike. The inertia in the collateral constraint implies that such a large stock of debt accumulated during the boom hinders the ability of optimal policy to mitigate the recessionary effects of the bust. In this experiment, the collateral constraint can become slack only if the credit supply constraint is violated.

Our simulation imposes the credit supply constraint ($\theta_t \leq 0$), which forces the multiplier on the collateral constraint μ_t to remain temporarily positive. Figure 9 shows that the credit supply constraint binds when policy (either jointly or macro-prudential only) becomes optimal in the bust. In this figure, the solid lines depict the path of the LTV limit that respects the credit supply constraint. As before, the dashed lines and the shaded areas indicate the range of LTV limits consistent with an optimally slack collateral constraint. Finally, the dotted-dashed lines show the results of a counterfactual simulation in which we ignore the credit supply constraint. In this case, the LTV limit persistently exceeds the level consistent with avoiding the moral hazard problem underpinning the collateral constraint.

43. The policy "regime change" is completely unanticipated. The online appendix provides details of the solution method in this case.

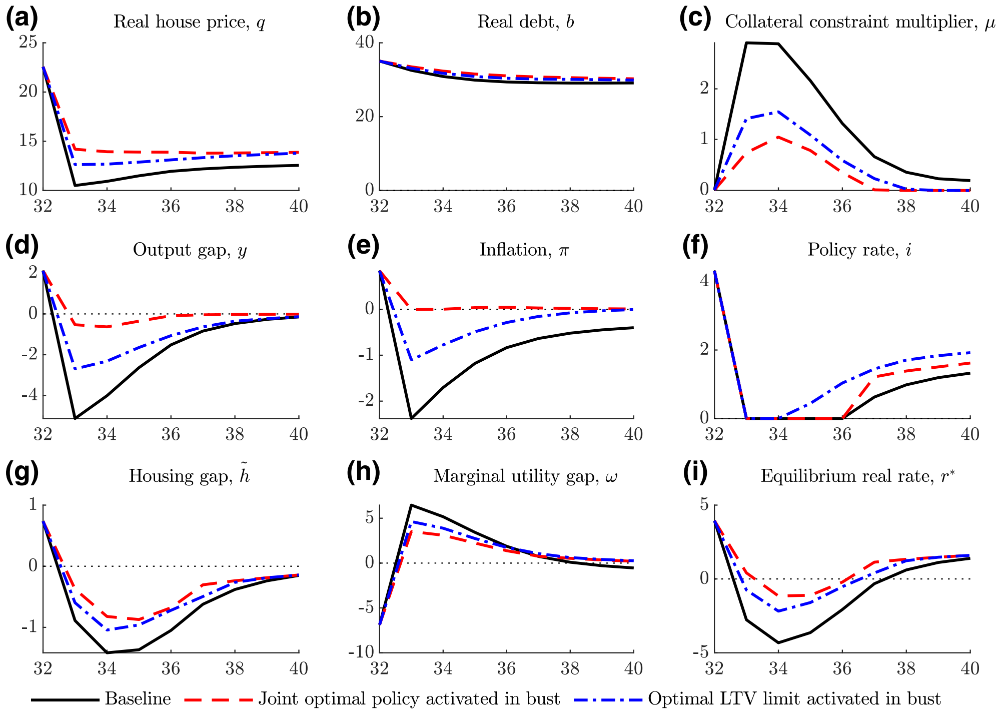

FIGURE 8

Optimal policy activated in the bust

Note: All variables are scaled by 100 and plotted as log-deviations from steady state, except for the multiplier on the collateral constraint, the policy rate and the equilibrium real interest rate, which are in levels. Inflation, the policy rate and the equilibrium real interest rate are in annualized units.

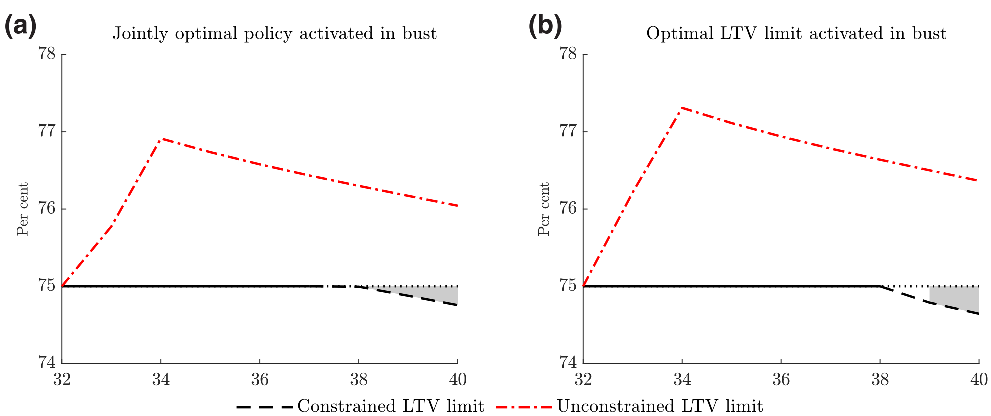

FIGURE 9

LTV limit under optimal policy in the bust

Note: The two panels plot the level of the LTV limit under the jointly optimal policy plan activated during the bust, and under the optimal LTV policy activated during the bust, respectively. The solid lines correspond to periods in which the collateral constraint binds. The dashed lines corresponds to periods in which the collateral constraint is slack. In these periods, any value in the shaded area is consistent with the equilibrium. The dotted lines correspond to the steady-state value of the collateral constraint (75%), which the simulation treats as an upper bound. The dashed-dotted lines show the results abstracting from the upper bound on the LTV limit (the credit supply constraint).

When the jointly optimal policy plan becomes active in the bust, the LTV limit is at its upper bound for five quarters. If only the optimal LTV limit policy becomes active, the LTV limit remains at the upper bound for one additional quarter. While the LTV limit is constrained, the economy experiences a slightly milder variant of the debt-deflation dynamics that also characterize the baseline simulation. In particular, the binding collateral constraint reduces the equilibrium real interest rate, which becomes somewhat negative. As a result, the policy rate hits the ZLB, and the inability to track the decline of the equilibrium real interest rate generates a recession, which is significantly deeper when only the LTV policy is optimal.

The key difference between activating only the optimal LTV policy relative to activating the jointly optimal plan is the degree of monetary accommodation. Under the jointly optimal policy, the nominal interest rate exits the ZLB at the same time as in the baseline scenario. In contrast, when just the optimal LTV policy becomes active, the baseline interest rate rule prescribes an anticipated liftoff while the credit supply constraint (and hence the collateral constraint) is still binding. The early monetary tightening generates a deeper recession. This experiment therefore demonstrates that a binding credit supply constraint impairs the ability of the optimal LTV limits to deliver a similar performance to that achieved by the jointly optimal policy.

After the credit supply constraint ceases to bind, the LTV limit lies just below the steady-state level of 75%. From this point onward, the credit supply constraint never binds again. As a result, the policymaker is able to adjust the LTV limit to set the desired level of μ_t, and the equilibrium allocations for the welfare-relevant variables coincide exactly with those observed when the jointly optimal policy plan is in place also during the boom.[44] This experiment thus also demonstrates that the LTV limit by itself is not necessarily a sufficient statistic to gauge the stance of macro-prudential policy.

6. CONCLUSION

This paper has studied the jointly optimal monetary and LTV policy in a New Keynesian model with borrowers and savers. Our results demonstrate the power of active borrower-based macro-prudential policies in containing a build-up of private leverage arising from the housing market.

We show that if the collateral constraint on borrowers either never or always binds, the monetary policy tradeoff between output and inflation is unchanged compared to the baseline New Keynesian model. However, the interaction between monetary and macro-prudential policy becomes particularly important when both the lower bound on the nominal interest rate and the collateral constraint can be occasionally binding. In these circumstances, strongly countercyclical LTV limits can avoid a liquidity trap caused by the endogenous debt-deleveraging response to a credit spread shock. Optimal policy prevents an excessive accumulation of debt during a house price boom and the associated widening of the gap in the marginal utility of consumption between borrowers and savers. As a consequence, the equilibrium real interest rate remains roughly constant and the policymaker can stabilize output and inflation without significant changes of the nominal interest rate.

If macro-prudential policy becomes active only after a housing bust has occurred, the LTV limit remains at its maximum level for the duration of the liquidity trap. In this case, the nominal interest rate reaches its lower bound even under optimal policy. However, the use of LTV limits

44. The level of debt and the LTV limit however differ between the two equlibria. The policymaker adjusts the LTV limit to deliver the optimal path for the multiplier on the collateral constraint. In turn, the exact level of the LTV limit required to achieve a certain path for the multiplier crucially depends on the accumulated level of debt.

still greatly mitigates the effects of the recession. Conversely, an exogenous LTV tightening during a recovery, possibly for reasons other than macroeconomic stabilization, generates a deeper recession and delays the liftoff of the nominal interest rate from the ZLB.

Of course, LTV limits are only one of the many tools available to macro-prudential authorities. In this paper, we have focused on their implications for monetary policy. Going forward, the extent to which the presence of multiple instruments reduces the burden of adjustment on LTVs certainly deserves further consideration. Research along these lines may uncover broad-ranging policy lessons as both borrower-based and lender-based tools are likely to play major roles in the future development of macro-prudential policy frameworks. The implications of the wide array of macro-prudential policy actions observed in practice for the monetary policy stance, in particular via their effects on the equilibrium real interest rate, are likely to become another area of active policy debate. We leave the study of these questions for future research.

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Supplementary Data

Supplementary data are available at *Review of Economic Studies* online.

Data Availability Statement

The replication package for this paper is available on Zenodo (https://dx.doi.org/10.5281/zenodo.7551954).

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