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Aim, focus, shoot. The choice of appropriate and effective macroprudential instruments

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Abstract

We examine the issue of the appropriate selection of macroprudential instruments according to the vulnerabilities identified and the policymakers' objectives using a version of the 3D DSGE model following Mendicino *et al.* (2020) and Hinterschweiger *et al.* (2021) calibrated for the euro area. We consider a broad set of macroprudential instruments, including broad and sectoral countercyclical capital requirements, LTV and LTI limits and assess their transmission channels as well as their effectiveness in mitigating rising broad and sectoral vulnerabilities. We find that sectoral instruments are most effective to increase bank resilience to sectoral risks, limiting spillover effects. LTI limits are superior to LTV limits in containing the growth of mortgage credit and household indebtedness. Finally, we find that macroprudential policy is better suited than monetary policy to address emerging real estate-related imbalances.

Keywords: Financial stability, Banking regulation, Macroprudential policy, Countercyclical capital buffer, DSGE.

JEL Classification: E44, E58, G21, G28

Non-technical summary

The Great Financial Crisis emphasised the importance of systemic risk for the stability of the financial sector, and fostered the rise of macroprudential policy as a new policy area at the global level with concrete objectives and dedicated policy instruments to address systemic risk. Macroprudential policy instruments encompass capital and borrower-based measures. The main objective of capital requirements is to increase banks' ability to absorb losses during downturns, to continue to provide credit to the real economy, thereby mitigating the impact of crises. Borrower-based measures ensure prudent lending standards and the sustainability of borrowers' debt. Depending on their calibration, they can also contribute to taming the real estate cycle.

As the macroprudential toolkit grows and an increasing number of countries implement (combinations of) instruments, understanding the appropriateness of different instruments, their interactions and how such interactions can be internalised in macroprudential actions becomes of paramount importance. Notwithstanding advances in the literature, there are still gaps in these respects, especially in what concerns the appropriate selection of macroprudential instruments according to the vulnerabilities identified and the policymakers' objective. With this paper, we contribute to the existing literature on the effects of macroprudential policy by considering a rich macroprudential toolkit including both broad and sectoral countercyclical capital requirements and two borrower-based instruments, one collateral-based and one income-based. By exploring the (sometimes overlapping) channels through which different instruments transmit to their objective variables, we also aim to offer policymakers a tool to guide the choice of the most appropriate instrument to achieve their objectives.

We adopt the "3D" DSGE model framework following Clerc *et al.* (2015) and Mendicino *et al.* (2020), including staggered interest spread setting as in Hinterschweiger *et al.* (2021), to which we add LTV and LTI limits, and calibrate the model using euro area data ranging between 2001 Q1 and 2020 Q4. First, we aim to shed light on the transmission mechanism of capital and borrower-based macroprudential instruments to achieve their intended objective. Second, we assess the effectiveness of different types of capital and borrower-based instruments in containing rising broad and sectoral vulnerabilities. Finally, we examine the relative effectiveness of monetary and macroprudential policies in stabilising the economy after a sectoral shock affecting the real estate sector.

First, we find that capital regulation leads to significant benefits in terms of bank resilience, with negligible effects on economic activity. Borrower-based measures such as LTV and LTI limits improve borrowers' resilience, however at the expense of a reduction in mortgage credit to the household sector and a reduction in economic activity. In the short-term, tighter broad capital requirements result in a permanent improvement in bank resilience, with only short-lived effects on credit. Sectoral capital requirements allow to increase the resilience of the banking sector to specific exposures, and therefore target specific risks, while limiting spillover effects to other sectors. A permanent tightening of borrower-based limits dampens the mortgage loan market and reduces house prices albeit only with a lag as it takes some time for these measures (which apply to new loans only) to pass-through to the stock of loans.

Secondly, we observe that, in response to a monetary policy shock boosting both household and corporate credit, broad countercyclical capital requirements (i.e. the CCyB) improve bank resilience and limit credit procyclicality without compromising the expansionary effect of monetary policy on GDP and inflation. Among borrower-based instruments, we find that LTI limits are the most effective instrument to mitigate exuberant mortgage credit developments and to ensure that household debt remains sustainable, as LTV limits become less binding due to the expansionary effect of the shock on house prices. Moreover, the results highlight the superiority of sectoral capital requirements over their broad counterparts in addressing vulnerabilities in specific sectors. We show that, in the event of a shock affecting the residential real estate sector only, sectoral countercyclical capital requirements yield the desired increase in banks' resilience while limiting adverse spillovers to other sectors of the economy. Among borrower-based measures, LTV limits are successful in containing the rise of vulnerabilities in the residential real estate sector compared to the baseline case, however, they exhibit a degree of procyclicality which undermines their effectiveness in containing the growth of mortgage credit and household indebtedness compared to other policy options. Interestingly, LTI limits seem to be the most effective instruments in containing the growth of mortgage credit and household indebtedness.

Lastly, we show that macroprudential policy is superior to monetary policy in addressing vulnerabilities building up in the real estate sector. When the monetary authority also reacts to developments in house prices, the policy rate needs to increase substantially to bring composite (goods and house price) inflation down, leading to more severe costs in terms of GDP due to a stronger effect on consumption and an unnecessary penalisation of the corporate sector.

1 Introduction

The Great Financial Crisis emphasised the importance of systemic risk for the stability of the financial sector, and fostered the rise of macroprudential policy as a new policy area at the global level with concrete objectives and dedicated policy instruments to address systemic risk. Macroprudential policy instruments include capital buffers and borrower-based measures.

Macroprudential capital buffers were put forward with the Basel III reform of the international regulatory framework in 2010 and enshrined in European Union law in the Capital Requirements Directive (CRD V) and the Capital Requirements Regulation (CRR II). Capital buffers such as the capital conservation buffer, buffers for individual systemically important institutions such as those for Globally Systemically Important Institutions (G-SII) and Other Systemically Important Institutions (O-SII) are of a structural nature as they hold at all times. Other capital buffers such as the Countercyclical Capital Buffer (CCyB) and, more recently, the Systemic Risk Buffer (SyRB) can be released by macroprudential authorities times of crisis to provide relief to banks and supporting them in providing credit to the economy, thereby mitigating the impact of the downturn. While these are broad instruments, applying to all domestic exposures[1], the EU legislation has recently been amended to foresee the use of the SyRB to target subsets of bank exposures to specific sectors such as, for example, mortgage loans.[2] Currently, 14 euro area countries have implemented a positive CCyB rate, 4 have a broad SyRB in place and 8 have implemented the sectoral Systemic Risk Buffer (sSyRB), mostly targeting residential real estate exposures to address systemic risks related to real estate market developments.

Borrower-based instruments directly affect the availability, terms and conditions of lending which typically relate to the riskiness of loans. Unlike capital instruments, borrower-based measures (BBMs) are not included in the EU harmonised legal framework, and their use is governed by national law, with different institutional set-ups prevailing across Member States. Borrower-based instruments limit the amount that can be borrowed to purchase a dwelling in relation to factors such as the value of the collateral (loan to value ratio, LTV), the income of the borrower (loan to income ratio, LTI) and the loan servicing costs in relation to the income of the borrower (LSTI). In the euro area, 16 countries have BBMs in place, which are considered as structural backstops to ensure that credit standards remain appropriate and households' debt sustainable

[1] The CCyB applies to all domestic credit exposures while the SyRB applies to all exposures.

[2] See Article 133 of the CRD V.

(see Behn and Lang 2023).

The choice of implementing one or a combination of macroprudential instruments crucially depends on the nature of the identified vulnerabilities and on the specific policy objectives (see ESRB 2014 and ESRB 2019). In general, macroprudential policy is used to strengthen the resilience of borrowers and lenders against the consequences of risks materialising as well as to counter the build-up of these risks, thereby lowering the probability of their materialisation (Constâncio *et al.* 2019). However, due to their characteristics, different instruments are particularly suited to target specific objectives (Lo Duca *et al.* 2019). Broad capital requirements such as the CCyB aim to increase the banking sector's resilience to downturns (i.e. limit banks' probability of default and/or deleveraging during a crisis) and curb excessive developments in broad credit growth during the upturn of the cycle. Sectoral capital requirements ensure that adequate buffers are in place to absorb losses that may arise in specific segments of bank loan portfolios in case of adverse developments. Borrower-based instruments are best suited to address flow vulnerabilities stemming, for example, from excessive credit growth, deteriorating credit standards and increasing household indebtedness. Overall, these measures contribute to system resilience in different ways. First, by ensuring that household leverage and debt repayments are sustainable, they increase the resilience of borrowers by reducing their probability of default. Second, over time, they contribute to a safer lending portfolio of banks as the average riskiness of borrowers decreases (see Lo Duca *et al.* 2023). Furthermore, within the category of BBMs, income-based measures such as LTI and LSTI limits primarily improve the resilience of new borrowers, and therefore bank resilience, while collateral-based measures such as LTV limits protect against RRE price corrections (Tereanu *et al.* 2022). Besides increasing resilience, BBMs may also contribute to taming credit growth (as banks are not allowed to supply loans to certain borrowers), limiting the build-up of vulnerabilities in the short run and reducing economic volatility over the medium term.

As the macroprudential toolkit grows and an increasing number of countries implement (combinations of) instruments, understanding the appropriateness of different instruments, their interactions and how such interactions can be internalised in macroprudential actions becomes of paramount importance (Lo Duca *et al.* 2023). Notwithstanding advances in the literature, there are still gaps in these respects, especially in what concerns the appropriate selection of macroprudential instruments according to the vulnerabilities identified and the policymakers' objective. Macroprudential policy is a recent and still evolving area, and practitioners remain uncertain about implementing many of these policies because macroprudential measures inherently pursue multiple objectives simultaneously and involve a wide range of instruments. With this paper, we contribute to the existing literature on the effects of macroprudential policy by considering a rich macroprudential toolkit including both broad and sectoral countercyclical capital requirements and two borrower-based instruments, one collateral-based and one income-based. By exploring the (sometimes overlapping) channels through which different instruments transmit to their objective variables, we also aim to offer policymakers a tool to guide the choice of the most appropriate instrument to achieve their objectives.

We adopt the "3D" DSGE model framework following Clerc *et al.* (2015) and Mendicino *et al.* (2020), including staggered interest spread setting as in Hinterschweiger *et al.* (2021). The set of financial distortions included in the model provides a rationale to the introduction of macroprudential policies based on capital instruments, which can be designed as broad or sectoral, structural or countercyclical.[3] In addition, as households, firms and banks can default, this framework offers a natural measure of resilience (the primary objective of macroprudential policy), namely the agents' probability of default. We include LTV and LTI constraints acting as a penalty cost on banks granting loans to households, whose intensity depends on the extent to which banks grant mortgage loans with more lenient lending standards than the regulatory limits imposed by the macroprudential authority. Albeit alternative, this modelling is consistent with the reality, whereby LTV and LTI constraints are imposed on the banking sector (not on the borrowers directly): while households may wish to obtain a mortgage loan with a LTV/LTI higher than the regulatory limit, banks cannot satisfy their demand. The penalty cost hence represents the consequences banks have to face when breaching regulatory LTV or LTI limits, such as increased supervisory scrutiny, supervisory actions and consequences to their image vis-à-vis shareholders.

We calibrate the model with euro area data over the period from 2001 Q1 to 2020 Q4 and conduct model simulations with a threefold objective. First, we aim to shed light on the transmission mechanism of capital and borrower-based macroprudential instruments to achieve their

[3]The first distortion stems from banks' limited liability and the existence of deposit insurance, which encourages banks to take up risks at the expense of the deposit insurance agency, which may result in cheaper and more abundant bank lending than what a social planner would find optimal when internalizing the full costs of bank default. The second distortion emerges because banks' funding costs depend on aggregate, instead of idiosyncratic, risk, which provides them an incentive to take excessive risk (Clerc *et al.* 2015).

intended objective. Specifically, we examine how the permanent tightening of macroprudential instruments transmits to the key objective variables and the implications of the ensuing monetary policy reaction for achieving policy objectives. Second, we aim to assess the effectiveness of different types of capital and borrower-based instruments in containing rising broad and sectoral vulnerabilities. We consider a broad shock (i.e. an expansionary monetary policy shock) that increases broad-based vulnerabilities and a sector-specific shock (i.e. a housing preference shocks) which leads to an increase of vulnerabilities in the real estate sector in the form of higher mortgage credit demand, house prices and household sector indebtedness. We explore the effectiveness of broad versus sectoral instruments in stabilising the economy after these shocks and in achieving their policy objectives. Finally, we complement the latter results by examining the relative effectiveness of monetary and macroprudential policies in stabilising the economy after a sectoral shock affecting the real estate sector.

From the model simulations we gather relevant insights on the three research questions posed above. First, we find that capital regulation leads to significant benefits in terms of bank resilience, with negligible effects on economic activity. Borrower-based measures such as LTV and LTI limits improve borrowers' resilience, however at the expense of a reduction in mortgage credit to the household sector and a reduction in economic activity. In the short-term, tighter broad capital requirements result in a significant improvement in bank resilience, with only short-lived effects on credit. Sectoral capital requirements allow to increase the resilience of the banking sector to specific exposures, and therefore target specific risks, while limiting spillover effects to other sectors. A permanent tightening of borrower-based limits dampens the mortgage loan market and reduces house prices albeit only with a lag as it takes some time for these measures (which apply to new loans only) to pass-through to the stock of loans. Interestingly, a tightening of the LTV results in lower borrower resilience in the short run, as the drop in house prices leads some existing mortgages to be underwater, prompting households to default. However, in the long-run, borrowers' resilience is improved.

Secondly, we observe that, in response to a monetary policy shock boosting both household and corporate credit, broad countercyclical capital requirements (i.e. the CCyB) improve bank resilience and limit credit procyclicality without compromising the expansionary effect of monetary policy on GDP and inflation. However, we document an important draw-back of a calibration rule for the CCyB based on the credit-to-GDP gap. In fact, after the expansionary monetary policy shock, the credit-to-GDP gap turns negative, as GDP is increasing more than credit, leading to a decline in capital requirements. We show that an alternative rule for the setting of the CCyB whereby the macroprudential authority reacts to the deviation of total credit from the steady state does a much better job in improving bank resilience and reducing the procyclicality of credit in the event of a monetary policy shock. Among borrower-based instruments, we find that LTI limits are the most effective instrument to mitigate exuberant mortgage credit developments and to ensure that household debt remains sustainable, as LTV limits become less binding due to the expansionary effect of the shock on house prices. Moreover, the results highlight the superiority of sectoral capital requirements over their broad counterparts in addressing vulnerabilities in specific sectors. We show that, in the event of a shock affecting the residential real estate sector only, sectoral countercyclical capital requirements yield the desired increase in banks' resilience while limiting adverse spillovers to other sectors of the economy. Among BBMs, LTV limits are successful in containing the rise of vulnerabilities in the residential real estate sector compared to the baseline case, however, they exhibit a degree of procyclicality which undermines their effectiveness in containing the growth of mortgage credit and household indebtedness compared to other policy options. Interestingly, LTI limits seem to be the most effective instruments in containing the growth of mortgage credit and household indebtedness.

Lastly, we show that macroprudential policy superior to monetary policy in addressing vulnerabilities building up in the real estate sector. When the monetary authority also reacts to developments in house prices, the policy rate needs to increase substantially to bring composite (goods and house price) inflation down, leading to more severe costs in terms of GDP due to a stronger effect on consumption and an unnecessary penalisation of the corporate sector. Hence, we confirm macroprudential policy's role as first line of defence for financial stability.

2 Literature review

The analysis of the effectiveness and interaction between macroprudential policy instruments is a still expanding research field. In recent years, a growing strand of literature has examined the transmission channels of capital and borrower-based instruments in a DSGE modelling framework and assessed their effectiveness in stabilising the economy in the event of shocks. While, in the following, we review the papers most closely related to ours, Grodecka and Finocchiaro (2018) present an extensive review of the literature on the impact of macroprudential policy.

Regarding capital requirements, overall, the literature finds that a higher level of capital increases banks' resilience and reduces the economic costs of financial crises (see for example Gerali *et al.* 2010, Angeloni and Faia 2013, Clerc *et al.* 2015). Focusing specifically on countercyclical capital requirement rules, the literature has focused on examining the optimal designs of policy rules for the CCyB. While the optimal design of the rule may depend on specific shocks, countercyclical capital regulation is found to have significant advantages in terms of economic stabilisation and aggregate welfare (Lozej *et al.* 2022, Aguilar *et al.* 2019, Faria-e Castro 2021). In a recent study, Lima *et al.* 2023 establish a strategic complementarity between cyclical and structural capital requirements, which is due to the fact that they reinforce each others' policy goals. Studies focusing on broad versus sectoral capital requirements are more scarce. Chen and Columba (2016) focus on sectoral risk weights and show that higher risk weights on household mortgages lower household debt. Castro (2019) examines the impact of introducing broad versus sectoral countercyclical capital buffers in an estimated DSGE model for Brazil, and finds that a sectoral CCyB is a flexible instrument that allows achieving better macroeconomic stabilization in terms of variances of credit, total capital requirement and capital adequacy ratio.

Regarding BBMs, Mendicino and Punzi (2014) find that a countercyclical LTV rule that responds to changes in house prices limits leverage and domestic borrowing capacity during periods of expansion and facilitates the use of credit during recessionary periods, helping borrowers to smooth consumption over time. Alpanda and Zubairy (2017) examine the effectiveness of different policies on household indebtedness, and find that mortgage interest rate deductions and LTV limits are the most effective, the latter at the expense of lower output and aggregate consumption.[4] Greenwald (2018) and Grodecka (2020) consider both collateral and income-based limits and conclude that the latter are more effective than LTV limits in limiting boom-bust cycles and in containing the rise in household indebtedness. Grodecka (2020) also finds that LTV limits may actually result in higher real estate prices in equilibrium.

A limited number of studies examine capital and borrower-based measures jointly. Chen and Columba (2016) consider LTV limits and sectoral risk weights, however, the focus of their analysis is on their effectiveness vis-à-vis monetary policy. Millard *et al.* (2024) examine the impact of broad bank capital requirements and DSTI limits on macroeconomic outcomes and find that capital requirements are the optimal tool to mitigate the impact of financial shocks,

[4]Finocchiaro *et al.* (2016) also study the same policies, however focusing on how they affect different households

while DSTI limits are optimal following a housing demand shock, as they disconnect the housing market from the real economy and reducing the volatility of inflation. Finally, using an estimated version of the 3D DSGE model for the UK, Hinterschweiger *et al.* (2021) assess the welfare implications of combinations of macroprudential instruments, including LTV limits on mortgage lending and sectoral capital requirements. They find that the appropriate combination of these instruments achieves a higher welfare improvement compared to a situation when the tools are used individually. Specifically, when optimised jointly, a looser LTV ratio is compensated by higher sectoral capital requirements.

Our paper contributes to this body of literature by focusing on the effectiveness of a broad set of macroprudential instruments, including broad and sectoral countercyclical capital requirements, collateral and income-based limits. Our modelling framework is closest to the 3D DSGE model version with staggered interest rates used by Hinterschweiger *et al.* (2021), to which we introduce monetary policy in light of its important interactions with macroprudential policy. Staggered interest rate setting is an important feature as it leads to a smoother interest rate pass-through from monetary policy rates to bank lending rates and a slower adjustment of lending rates to changes in banks' cost of equity stemming, for example, from higher capital requirements. Furthermore, differently from Hinterschweiger *et al.* (2021), we assume that bank capital requirements are always binding (i.e. banks do not hold voluntary buffers, as in Mendicino *et al.* (2020)) and we model LTV and LTI constraints acting as a penalty cost on banks granting loans to households, whose intensity depends on the extent to which banks grant mortgage loans with more lenient lending standards than the regulatory limits imposed by the macroprudential authority. While this modelling choice deviates from the above-mentioned papers, which model LTV/LTI limits as constraints on borrowers' demand for mortgage loans following Iacoviello 2005, we show that this approach would result, in the 3D DSGE model context, in either capital or borrower-based measures not being binding, with implications for the transmission of macroprudential policy. In fact, Hinterschweiger *et al.* (2021) use a similar "3D" model setup, modelling borrower-based measures as collateral constraints and bank capital requirements as a penalty cost (this approach is also followed by Gerali *et al.* 2010, Gelain and Ilbas 2017, Lozej *et al.* 2022 and Millard *et al.* 2024). Albeit alternative, this modelling is consistent with the reality, whereby LTV and LTI constraints are imposed on the banking sector (not on the borrowers directly): while households may wish to obtain a mortgage loan with a LTV/LTI higher than the regulatory limit, banks cannot satisfy their demand. The penalty cost hence represents the consequences banks have to face when breaching regulatory LTV or LTI limits, such as increased supervisory scrutiny, supervisory actions and consequences to their image vis-à-vis shareholders. Furthermore, we assume that banks maximise profits by choosing the optimal lending spread rather the optimal lending rate. We focus on lending spreads rather than loan rates because spreads are a better indicator of a banks' net interest margin (i.e. their capacity to generate income), which are relevant for banks' loan pricing strategy (see also Kanngiesser *et al.* (2017) and Gambacorta and Signoretti (2014)).

3 The model

The core of the modelling framework closely follows Clerc *et al.* (2015) and Mendicino *et al.* (2020).

Households consume, supply labour to the production sector and purchase housing. The economy is populated by two dynasties of ex-ante identical households, savers and borrowers, denoted respectively with the superscripts s and m. Savers are patient, and have a higher discount factor than borrowers. In equilibrium, savers purchase houses using their own equity, and save in bank deposits and a risk-free bond. Bank deposits are partially insured by a deposit insurance agency and remunerated at the prevailing deposit rate. The remaining fraction is unsecured, and depositors price it on the basis of their expectations about the risk of bank default. The deposit insurance is financed through taxes levied on all households, implying that the cost of bank default partly falls on taxpayers and affects consumption. Borrowers stipulate bank loans to finance their housing investments. Borrowers default on their mortgage loans when the value of the real estate collateral falls below the outstanding debt, i.e., when their leverage becomes excessive.

Entrepreneurs own the stock of physical capital, which they rent to firms involved in the production of the consumption good, and pay dividends to saving households. The fraction of entrepreneurs who survives to the next period passes on the remaining wealth to the next generation of entrepreneurs. Entrepreneurs finance capital purchases with the inherited net worth and bank loans. Similar to households, they default on their loans when the value of the capital stock falls below the outstanding debt obligations.

Bankers provide equity to the banks. Similar to entrepreneurs, they pay dividends (gross return on equity) to the saving households and leave bequests to the next generation of bankers. We assume that there are two types of identical bankers, one providing equity to banks lending to households and one providing equity to banks lending to entrepreneurs.

Banks There exist two types of banks: banks providing mortgage loans to households (mortgage banks, denoted with superscript m) and banks lending to entrepreneurs (corporate banks, denoted with superscript f). Banks operate under limited liability and may default due to both idiosyncratic and aggregate shocks to the performance of their loan portfolios. Banks fund their loan portfolio with deposits raised among saving households. For the savings household standpoint, recovering the fully insured principal and interest of their deposits in the case of bank failure is costly in terms of time and effort, so that deposits may still pay a risk premium that depends on the average bank's default risk. Differently from Clerc *et al.* (2015) and Mendicino *et al.* (2020), we introduce imperfect competition in the banking sector and staggered interest rate setting as in Hülsewig *et al.* (2009) and Hinterschweiger *et al.* (2021). The differentiation of loans may emerge from specialization in certain types of lending (e.g. small/large firms or to different sectors) or in certain geographical areas (see e.g., Carletti *et al.* 2007). However, differently from the aforementioned papers, we assume that banks maximise profits by choosing the optimal lending spread rather than the loan rate. This reflects the importance of interest margins for banks' loan pricing strategy. In a perfectly competitive environment, each bank would set the lending spread as a mark-up over marginal costs, and all banks would set the same, optimal, lending spread. However, banks face frictions when setting the loan spread: in each period, only a fraction of banks is able to set the lending spread optimally, while the remaining fraction of banks set the lending spread at the level prevailing in the previous period. Therefore, while in Clerc *et al.* (2015) and Mendicino *et al.* (2020), changes in the cost of equity and in the monetary policy rate are immediately passed through to the loan price, our modelling strategy implies a smoother interest rate pass-through from monetary policy rates to bank lending rates. Also, it implies that banks cannot immediately adjust lending rates to compensate for the increased cost of equity stemming from higher capital requirements. The equity provided by bankers is necessary for banks to comply with the capital requirements imposed by the macroprudential authority. Furthermore, we introduce a novel modelling of LTV and LTI constraints acting on the supply side of the loan market, by assuming that mortgage banks incur in a penalty cost when granting loans with LTV/LTI higher than the regulatory limit. This has a twofold motivation. First, regulators impose lending standards on the banking sector, which then has to grant loans respecting the regulatory limits. Therefore, while both borrowers and banks would, in the absence of regulation, settle on a lending contract whose conditions satisfy borrowers' demand fully, borrower-based instruments restrict the conditions at which banks are allowed to lend. Therefore, while they may be willing to fully satisfy borrowers' demand, they are not able to do so. Secondly, in our setup featuring both capital requirements and borrower-based limits, modelling the latter as collateral constraints on the impatient households, following Iacoviello (2005), Greenwald (2018), Grodecka (2020), Millard *et al.* (2024) results in either the collateral constraint on borrowers or the bank participation constraint not being binding (see Appendix B for a proof).

Producers combine capital (rented from entrepreneurs) and labor to produce a consumption good. They operate in a regime of imperfect competition and face staggered price setting. Production firms are owned by saving households.

Capital and housing producers are perfectly competitive firms, owned by saving households, producing, respectively, new capital and housing good through an investment technology with investment adjustment costs.

In what follows, we outline the optimisation problem of the key agents in more detail. The full set of first order conditions is reported in the appendix.

3.1 Households

3.1.1 Savers

Saving households maximise:

$$\mathbb{E}_t\left[\sum_{i=0}^{\infty}(\beta_s)^{t+i}\left\{\log(c^s_{t+i}-\theta c^s_{t+i-1})+v_s\log(h^s_{t+i})-\frac{\varphi_s(l^s_t)^{1+\eta}}{1+\eta}\right\}\right] \quad , \tag{3.1}$$

where c^s_t is consumption, u_s is the housing preference parameter, h^s_t is the stock of housing, φ_s is the labour preference parameter, l^s_t denotes the hours worked in the consumption-good producing sector, with η being the Frisch elasticity of labor supply.

The dynamic budget constraint of saving households is:

$$\begin{aligned}&c^s_t\,P_t+k^s_t\,(q^k_t+s^k_t)-(C^e_t+C^b_t)/n_s+q^h_t(h^s_t-(1-\delta^h_t)h^s_{t-1})+D_t+B_t\\ =&w_t\,l^s_t+(r^k_t+(1-\delta^k_t)q^k_t)k^s_{t-1}+R^{DD}_t\,D_{t-1}+R_{t-1}\,B_{t-1}-T_t\frac{a_s}{n_s}+G^I_t+G^h_t+G^k_t \quad ,\end{aligned} \tag{3.2}$$

Households directly hold physical capital k^s_t with nominal price q^k_t, depreciation rate δ^k and rental rate r_t^k and are subject to a per unit management cost[5] s_t^k. Savers further own a stock of housing h_t^s with nominal price q_t^h and depreciation rate δ_h, as well as holdings of the risk-free bond B_t and bank deposits D_t paying, respectively, the gross short-term nominal risk-free rate R_{t-1} and the gross returns R_{t-1}^{DD} and at time t.[6] The gross return on the stock of deposits is given by:

$$R_t^{DD} = R_{t-1}^D(1 - pp\ PD_t^b/4) \ , \tag{3.3}$$

where R_{t-1}^D is the promised return rate on the share of insured deposits (pp), while PD_t^b is the yearly average loss per unit of deposits applying to the fraction of uninsured deposits. Saving households receive dividends from entrepreneurs (C_t^e) and bankers (C_t^b), wages w_t and profits from investment (G_t^I), housing investment (G_t^h) and capital management firms (G_t^k). Finally, n_s denotes the proportion of savers in the economy, P_t denotes the consumption good price and T_t is the deposit insurance premium.

3.1.2 Borrowers

Borrowing households maximise a similar objective function as (3.1), however with a discount factor $\beta_m < \beta_s$ inducing them to borrow rather than to save in equilibrium. The dynamic budget constraint of borrowing households reads:

$$c_t^m\, P_t + q_t^h\, h_t^m - (1 - \Gamma_t^m) R_t^h\, q_{t-1}^h h_{t-1}^m = w\, l_t^m + b_t^m - T_t \frac{a_m}{n_m} \ , \tag{3.4}$$

where a_m is the share of deposit insurance paid by borrowers and n_m denotes the share of borrowers. R_t^h is the rate of return on housing defined in (A.30), which is depends on the housing price and the housing depreciation rate. Borrowers finance house purchases with one period bank loans b_t^m obtained from mortgage banks, carrying a contractual gross interest rate R_t^m. At the beginning of each period, each borrowing household experiences an idiosyncratic shock ω_t^m which alters the value of the housing stock accumulated in the previous period. The shock ω_t^m is independently and identically distributed across households and time and it is assumed to follow a lognormal distribution with density and cumulative distribution functions denoted by

[5] Management firms are described as in Clerc *et al.* (2015).

[6] Governments bond are assumed to be in net zero supply as is standard in the literature (see e.g., Galí 2015).

$f(\omega_t^m)$ and $F(\omega_t^m)$ respectively, and $\mathbb{E}_t(\omega_t^m) = 1$. The realisation of the shock is freely observed by borrowers, but lenders can only observe it by incurring a monitoring cost μ_m proportional to the gross return on housing $\mu_m(\omega_{t-1}^m(i) R_{t-1}^h q_{t-1}^h h_{t-1}^m)$. This asymmetric information is at the core of the financial frictions introduced by Bernanke *et al.* (1999). Therefore, as debt is non-recourse and costless for borrowers, they have an incentive to default whenever the realised value of their housing stock is lower than the outstanding debt repayment obligations: $\omega_t^m q_t^h (1-\delta_t^h) h_{t-1}^m < R_{t-1}^m b_{t-1}^m$. Put it differently, household default when:

$$\omega_t^m q \leq \bar{\omega}_t^m = \frac{R_{t-1}^m b_{t-1}^m}{q_{t-1}^h h_{t-1}^m} \tag{3.5}$$

where the term on the right-hand side of equation (3.5) is a measure of household leverage. from which it follows that borrower's probability of default is an increasing function of leverage. Upon default, mortgage banks seize the housing asset after paying the monitoring cost. Denoting as $\Gamma_t^m \, R_t^h \, q_{t-1}^h \, h_{t-1}^m$ (see A.103) the net housing equity remaining to borrowers after accounting for the fraction of housing repossessed by the bank from defaulting borrowers, and as $(1 - \mu_m G_t^m \, R_t^h \, q_{t-1}^h \, h_{t-1}^m)$ (where G_t^m is defined in A.111) the corresponding payoff accruing to lenders after paying the monitoring cost, the participation constraint for mortgage banks reads:

$$(1-\Gamma_t^h)(\Gamma_t^m - \mu_m G_t^m) R_t^h q_t^h h_{t-1}^m - f_{LTV} \zeta_{LTV} \log \frac{LTV_t}{E_{LTV}} - f_{LTI} \zeta_{LTI} \log \frac{LTI_t}{E_{LTI}} = \rho_t^h \phi_t^h b_t^m \quad . \tag{3.6}$$

Banks enter the mortgage contract if the payoffs that the bank generates by granting mortgage loans to the borrowing households are large enough to compensate bankers for the opportunity cost of the equity financing contributed to such loans, $\rho_t^h \phi_t^h b_t^m$ where ρ_t^h represents the cost of capital for mortgage banks and $\phi_t^h b_t^m$ is the (binding) capital requirement for this class of loans. The bank's participation constraint also takes into account the prevailing LTV and LTI limits. As explained later (in section 3.2), we introduce LTV limits on the supply side of the loan market, assuming that banks granting mortgage loans in breach of the requirements face a pecuniary cost. We model LTV limits as applying only to the flow of new loans granted in each period, namely $b_t^m - (1-\delta_h) b_{t-1}^m$. The LTV ratio in the model is defined as:

$$LTV_t = \frac{b_t^m - (1-\delta_h) b_{t-1}^m}{(h_t^m - (1-\delta_h) h_{t-1}^m) q_t^h} \tag{3.7}$$

The term $f_{LTV}\zeta_{LTV}\log\frac{LTV_t}{E_{LTV}}$ in equation (3.6) represents the pecuniary cost ξ_{LTV} incurred by the bank when granting new loans with LTV_t greater than the regulatory limit E_{LTV}, if LTV limits are active (i.e. if $f_{LTV}=1$).

In the same fashion, LTI limits also apply to the flow of new loans granted in each period. The LTI ratio in the model is defined as:

$$LTI_t^m = \frac{b_t^m - (1-\delta_B)b_{t-1}^m}{\delta_B w_t l_t^m} \quad , \tag{3.8}$$

where $w_t l_t^m$ is the average borrower income (see Finocchiaro *et al.* 2016). As in the case of the LTV the term $f_{LTI}\zeta_{LTI}\log\frac{LTI_t}{E_{LTI}}$ represents the pecuniary cost ξ_{LTI} incurred by the bank when granting new loans with LTI_t greater than the regulatory limit E_{LTI}, if LTI limits are active (i.e. if $f_{LTI}=1$). We assume that both penalty costs are used to finance the premium of the deposit insurance.

3.1.3 Entrepreneurs

Entrepreneurs are patient households who live over two periods. An entrepreneur starting to exist at time t inherits wealth in the form of retained earnings from the previous generation of entrepreneurs. They aim at maximising the dividends they will transfer to the patient dynasty in the next period (C_{t+1}^e) and the retained earnings they will transfer to the next cohort of entrepreneurs (n_{t+1}^e). The optimisation problem of the representative entrepreneur is:

$$\max_{C_{t+1}^e, n_{t+1}^e} (C_{t+1}^e)^{\chi_e}(n_{t+1}^e)^{1-\chi_e} \tag{3.9}$$

subject to:

$$C_{t+1}^e + n_{t+1}^e \le W_{t+1}^e \tag{3.10}$$

where W_{t+1}^e represents entrepreneurial wealth resulting from activity in the previous period. Similar to borrowing households, entrepreneurs use their own equity (n_t^e) and loans from corporate banks (b_t^e) carrying a nominal interest rate R_t^f to purchase capital k_t at a nominal price q_t^k, which they will then rent to production firms at a rental rate r_t^k. When stipulating the contract with the bank, the entrepreneur chooses the loan amount and the capital investment to maximise his own wealth subject to the bank's participation constraint, namely he solves:

$$\max_{b_t^e, k_t} E_t[(1 - \Gamma^e(\bar{\omega}_{t+1}^e))] \left[r_{t+1}^k + (1 - \delta_t^k) q_t^k \right] k_t^e \tag{3.11}$$

subject to its budget constraint $b_t^e = q_t^k k_t^e - n_t^e$ and the bank's participation constraint:

$$(1 - \Gamma_t^f)(\Gamma_t^e - \mu_e G_t^e) R_t^f q_t^k k_{t-1}^t = \rho_t^f \phi_t^f b_t^e \ , \tag{3.12}$$

which mirrors equation 3.6 for borrowing households. As in the case of borrowing households, Γ_t^f is a quantity linked to the default of corporate banks defined in equation (A.105), μ_e is the proportional verification cost incurred in the repossession of the fraction G_t^e of capital units in the event of default, ρ_t^f is the cost of capital of corporate banks and ϕ_t^f their capital requirement.

3.2 Banks

The financial system is populated by two types of banks, one specialised in lending to households (with subscript h) and one specialised in lending to entrepreneurs (corporate banks, with subscript f). Loans to households and firms may default depending on aggregate and idiosyncratic shocks, in which case the banks seize the assets subject to verification costs. On the liabilities side of banks' balance sheet there are the equity provided by shareholders (bankers) and the deposits (partially insured by the Deposit Insurance Agency) from saving households. Banks face capital requirements set by the macroprudential authority which requires banks to fund with equity at least a fraction ϕ_t^h of the loans granted in a given period:

$$e_t^h = \phi_t^h b_t^m \tag{3.13}$$

This implies that, in equilibrium: $b_t^m = e_t^h / \phi_t^h$ and that deposits $D_t^h = (1 - \phi_t^h) e_t^h / \phi_t^h$. In addition, as explained in section 3.1.2, mortgage banks face regulatory limits on the LTV on mortgage loans, while banks lending to entrepreneurs do not face restrictions on lending standards.

Banks are also subject to two borrower-based instruments, namely loan-to-value (LTV) and loan-to-income (LTI) limits imposed, differently from the existing literature, on the supply side of the loan market. This has a twofold motivation. First, regulators impose lending standards on the banking sector, which then has to grant loans respecting the regulatory limits. Therefore, while both borrowers and banks would, in the absence of regulation, settle on a lending contract whose conditions satisfy borrowers' demand fully, borrower-based instruments restrict the conditions at which banks are allowed to lend. Therefore, while they may be willing to fully satisfy borrowers' demand, they are not able to do so. Secondly, in our setup featuring both capital requirements and borrower-based limits, modelling the latter as collateral constraints on the impatient households, following Iacoviello (2005), Greenwald (2018), Grodecka (2020), Millard *et al.* (2024) results in either the collateral constraint on borrowers or the bank participation constraint not being binding (see Appendix B).

We introduce LTV and LTI limits by assuming that banks face a penalty cost when granting loans with LTV or LTI higher than the regulatory limit. The penalty function acts on the participation constraint of the representative bank lending to households, and kicks-in whenever the LTV (LTI) ratio on new mortgage loans is higher than the specified regulatory limit. We calibrate the parameters of the penalty function such that banks have such a strong disincentive to deviate from the regulatory limit that, in practice, they never do, and the constraint acts as a de-facto quantity constraint on lending. The LTV and LTI penalties that enter in the bank participation constraint (3.6) are given by:

$$f_{LTV}\xi_{LTV}\log\frac{LTV_t}{E_{LTV}} \tag{3.14}$$

$$f_{LTV}\xi_{LTI}\log\frac{LTI_t}{E_{LTI}} \quad . \tag{3.15}$$

The pecuniary cost is imposed on banks that violate the LTV or LTI limits and is transferred back to savers and borrowers to compensate them of the losses due to the payment of the deposit insurance premium.

Banks may themselves default. Similar to borrowing households and entrepreneurs, banks face an idiosyncratic portfolio return shock ω^h_{t+1} which is i.i.d. across the banks of each type and follows a log-normal distribution with a mean of one and a distribution function F^h_{t+1}. Banks default for realisation of the idiosyncratic productivity shocks for which the realized return on the loan portfolio is lower than the deposit repayment obligations. In case of default, the banks' remaining assets are seized by the DIA, subject to costly state verification.

As in Hinterschweiger *et al.* (2021), Hülsewig *et al.* (2009), Gerali *et al.* (2010), banks operate in a regime of imperfect competition, offering differentiated loans. As both types of banks face the same problem, we focus on mortgage banks, while the relevant equations for corporate banks are reported in Appendix A.[7]

We assume that banks maximize profits by choosing the optimal lending spread over the funding rate instead of the loan interest rates. We focus on lending spreads rather than loan rates because spreads are the banks' net interest margin (i.e. their capacity to generate income), which are the key metrics used for banks' loan pricing strategy. In particular, the spread should be above the bank's marginal costs (other than the funding cost) which in this framework are only the cost of the equity: for every unit of loan the cost of capital of the bank (ρ_t^h) multiplied by the capital requirements (ϕ_t^h). Hence, there is a connection between the bank's marginal cost and LTV (LTI) penalty through the mortgage bank participation constraint (3.6). The representative mortgage bank (identified with k) maximises

$$\Pi_t^h(k) = (S_t^h(k) - MC_t^h) b_t^m(k) \quad , \tag{3.16}$$

where $S_t^h(k)$ is the spread charged by bank k and

$$MC_t^h = 1 + \phi_t^h(\rho_t^h - 1) \tag{3.17}$$

is its marginal cost.

We assume that the demand for mortgage loans for the kth bank is given by

$$b_t^m(k) = \left(\frac{S_t^h(k)}{S_t^h} \right)^{-\epsilon_{Sh}} b_t^m \quad , \tag{3.18}$$

where S_t^h denotes the average spread of mortgage banks and ϵ_{Sh} is the elasticity of substitution between the different types of loans. Analogously to a Calvo (1983) framework, in a perfectly competitive environment, each bank would set the lending spread as a mark-up over marginal costs, and all banks would set the same optimal spread. As in Gerali *et al.* (2010), only a fraction ϕ_{S_h} of banks adjust the spread optimally in each period, while the remaining fraction keeps the spread unchanged.[8] A bank re-optimizing in period t will choose the optimal spread $(S_t^h(k))^*$

[7] With the only difference that corporate banks are not affected by LTV and LTI limits.

[8] In the long-run the loan rate converges to a deterministic steady state, which is equal to the flexible loan market equilibrium.

that maximises

$$\mathbb{E}_t \left[\sum_{i=0}^{\infty} \Lambda_{t,t+l} \phi_{Sh}^l \left\{ S_t^h(k)^{1-\epsilon_{Sh}} - MC_t^h S_t^h(k)^{-\epsilon_{Sh}} \right\} b_{t+l}^m (S_{t+l}^h)^{\epsilon_{Sh}} \right] \quad . \tag{3.19}$$

Since $(S_t^h(k))^*$ is identical for all banks we rename it $(S_t^h)^*$ and obtain it from the first order condition of the bank maximization problem:

$$(S_t^h)^* = \frac{\epsilon_{Sh}}{\epsilon_{Sh} - 1} \frac{\sum_{l=0}^{\infty} \Lambda_{t,t+l} \phi_{S_h}^l (b_{t+l}^m)(S_{t+l}^h)^{\epsilon_{Sh}} MC_{t+l}^h}{\sum_{l=0}^{\infty} \Lambda_{t,t+l} \phi_{S_h}^l b_{t+l}^m (S_{t+l}^m)^{\epsilon_{Sh}}} \quad , \tag{3.20}$$

which we rewrite

$$(S_t^h)^* = \frac{Z_t^1}{Z_t^2} \frac{\epsilon_{Sh}}{\epsilon_{Sh} - 1} \quad ,$$

where

$$Z_t^1 = MC_t^h (S_t^h)^{\epsilon_{Sh}} b_t^m + \Lambda_{t,t+1} \phi_{S_h} Z_{t+1}^1 \quad ,$$

and

$$Z_t^2 = (S_t^h)^{\epsilon_{Sh}} b_t^m + \Lambda_{t,t+1} \phi_{S_h} Z_{t+1}^2 \quad .$$

Finally, the aggregate loan spread evolves according to:

$$S_t^h = \left((1 - \phi_{Sh})(S_{t-1}^h)^{1-\epsilon_{Sh}} + \phi_{S_h} ((S_t^h)^*)^{1-\epsilon_{Sh}} \right)^{1/(1-\epsilon_{Sh})} \quad , \tag{3.21}$$

and the interest rate payed by borrowers is

$$R_t^m = S_t^h - 1 + R_t^D (1 - \phi_t^h) + \phi_t^h \quad . \tag{3.22}$$

3.2.1 Macroprudential policy

The model features four types of capital-based macroprudential instruments: a minimum fixed capital requirement, a risk weight for household mortgages[9], a broad countercyclical capital buffer (CCyB) and a sectoral systemic risk buffer (sSyRB). Capital requirements force banks to hold a larger fraction of (more expensive) equity to fund their loan portfolio. The CCyB

[9]Following Clerc *et al.* (2015), in the baseline calibration, risk weights on mortgage loans are set to 50%, while risk weights on loans to firms are set to 100%.

is a buffer imposed on the entire stock of bank loans, and it is tightened or loosened counter-cyclically depending on the evolution of broad credit. To reflect as closely as possible the reality, we assume that the CCyB is increased when the credit to GDP ratio is above its steady state value, a proxy for the credit-to-GDP gap.[10] The sSyRB is a targeted capital requirement which is imposed only on a subset of credit exposures, in our case mortgage loans.[11] We model the policy rule for the sSyRB so that it is tightened or loosened based on the deviation of mortgage credit growth from its steady state value.

Formally, the capital requirement of corporate banks is given by:

$$\phi_t^f = \left(\phi_{Fs} + \varphi_F \log \frac{b_t GDP_0}{b_0 GDP_t} \right) \quad . \tag{3.23}$$

Where ϕ_{Fs} denotes the minimum capital requirement, $\varphi_F \log \frac{b_t GDP_0}{b_0 GDP_t}$ represents the CCyB, which is set based on the logarithm of the deviation of the ratio between total credit (b_t) and GDP from its steady state level. ϕ_{Fs} is set to 0.5 consistently with Clerc *et al.* (2015). φ_F represents the reaction coefficient of the macroprudential authority to such deviations: the higher the coefficient, the stronger the macroprudential response to deviations of the credit to GDP gap from its steady state.

The capital requirement faced by banks lending to households is given by:

$$\phi_t^h = RW_t \left(\phi_{Fs} + \varphi_F \log \frac{b_t GDP_0}{b_0 GDP_t} + \varphi_S \log \frac{b_t^m}{b_0^m} \right) \quad ,$$

where RW_t is the risk weight applied to mortgage loans, calibrated at 0.5 to reflect the lower riskiness of mortgage loans compared to corporate loans, which have a risk weight of 1. $\varphi_S \log \frac{b_t^m}{b_0^m}$ represents the sSyRB, which is set based on the logarithm of the deviation of mortgage credit b_t^m from the steady state, and only affects mortgage loan exposures. We calibrate $\varphi_S = 0.2$ so that the impact on retail bank capital requirements after a housing preference shock is the same, on average, for the CCyB and the sSyRB.

In addition, the macroprudential authority sets the maximum limit for the LTV and the LTI ratios on mortgage lending.

[10]The deviation of the credit to GDP gap from its long-term trend is one of the key indicators guiding the calibration of the CCyB, see Basel Committee on Banking Supervision (2010).

[11]The possibility to target the systemic risk buffer to specific exposures was introduced in European legislation with the CRD V. The Directive further foresees the cyclical use of this instrument, which can be released in the event of stress. In the euro area, Belgium and Germany have recently implemented the sSyRB on mortgage loans.

3.3 Bankers

Bankers that provide equity to banks, similarly to entrepreneurs, are saving households which live across two periods and derive utility from paying dividends to saving households in the next period (C^{b}_{t+1}) and leaving bequests (retained earnings) to the next generation of bankers (n^{b}_{t+1}). We assume that there exist two types of bankers, one providing equity to corporate banks (with superscript bf) and one providing equity to mortgage banks (with superscript bh). Taking the latter as example, the maximisation problem reads:

$$\max_{C^{bh}_{t+1}, n^{bh}_{t+1}} (C^{bh}_{t+1})^{\chi_b} (n^{bh}_{t+1})^{1-\chi_b} \quad , \tag{3.24}$$

subject to:

$$C^{bh}_{t+1} + n^{bh}_{t+1} \leq W^{bh}_{t+1} \quad . \tag{3.25}$$

A banker born at time t and investing equity n^{bh}_{t} in mortgage banks will, in the next period, have net worth equal to:

$$W^{bh}_{t+1} = \rho^{h}_{t+1} n^{bh}_{t} \quad , \tag{3.26}$$

where ρ^{h}_{t} is the return on equity of mortgage banks.
The maximization yields the optimal dividend rule

$$C^{bh}_{t+1} = \chi_b W^{bh}_{t+1} \quad , \tag{3.27}$$

and the earnings retention rule

$$n^{bh}_{t+1} = (1 - \chi_b) W^{bh}_{t+1} \quad . \tag{3.28}$$

Finally, the law of motion of the initial wealth of each cohort of bankers is:

$$n^{bh}_{t+1} = (1 - \chi_b) \rho^{h}_{t+1} n^{bh}_{t} \quad . \tag{3.29}$$

3.4 Production sector

3.4.1 Consumption goods producers

A continuum of monopolistically competitive firms produces a differentiated intermediate good $y_t(i)$ combining labor $l_t(i)$ provided by households and capital $k_t(i)$ according to the production function:

$$y_t(i) = k_{t-1}(i)^{\alpha}\, l_t(i)^{1-\alpha} \tag{3.30}$$

where α is the share of capital in production. Intermediate good firms are owned by patient households, to which they distribute profits (or losses). The intermediate output is then purchased by the perfectly competitive firms that produce the final consumption good Y_t according to a CES technology. Intermediate producers face price stickiness à la Calvo, implying that in each period, only a fraction of producers can set the goods' price optimally, while the rest of producers sets the price equal to that prevailing in the previous period. Producers set the price by optimising the present discounted value of future profits.

3.4.2 Capital and housing producers

Producers of capital goods and of housing goods combine investment with the old stock of capital or housing to produce new capital and housing goods which are then sold to firms and households. In each period, they produce $I_t^k = k_t - (1-\delta^k)k_{t-1}$ of new capital and $I_t^h = H_t - (1-\delta^h)H_{t-1}$ of new houses, using a technology facing adjustment costs. These firms are owned by patient households.

3.5 Monetary policy

The monetary policy authority follows a standard Taylor-type rule reacting to deviations of inflation and output from their steady state:

$$\frac{R_t}{R_0} = \left(\frac{R_{t-1}}{R_0}\right)^{\phi_R} \left(\frac{\Pi t}{\Pi_0}\right)^{\phi_\Pi} \left(\frac{GDP_t}{GDP_0}\right)^{\phi_{GDP}} \quad , \tag{3.31}$$

where R_t is the policy rate, GDP_{acc}^t is the GDP, Πt is the inflation (on consumer prices), and ϕ_R, ϕ_Π, ϕ_{GDP} are the three Taylor rule parameters.

We also consider an alternative Taylor rule where the inflation index considered by the monetary authority also includes house prices.

$$\frac{R_t}{R_0} = \left(\frac{R_{t-1}}{R_0}\right)^{\phi_R} \frac{\Pi t}{\Pi_0} \left(\frac{C_t}{C_t + H_t} + \frac{\Pi_t^h}{\Pi_h^0} \frac{H_t}{C_t + H_t}\right)^{\phi_\Pi} \left(\frac{GDP_t}{GDP_0}\right)^{\phi_{GDP}} , \tag{3.32}$$

where Π_t^h represents housing inflation, C_t the total consumption, H_t the total quantity of houses.

3.6 Calibration

The model is calibrated using aggregate data for the euro area at a quarterly frequency from 2001 Q1 to 2020 Q4. We calibrate a number of parameters consistently with the literature and calibrate the rest and relevant steady state ratios on the basis of the macroeconomic time-series (see Appendix C for a full overview of the calibrated parameters).[12] All series are in real terms and we have detrended their log value. The data on GDP, the GDP deflator, Business Loans, Households Loans, Write-offs, Housing Investment, Housing wealth, Bank equity return, Cross sectionals mean and standard deviation of Total capital ratio are sourced from the ECB' a Statistical Data Wharehouse.[13] Loan spreads are computed using data from SDW and Bankscope data. The fraction of borrowers and the housing wealth of borrowers are calibrated using data from the Household Finance and Consumption Survey.[14]
The calibrated first order moments for the main model variables are reported in table1.

4 Policy exercises

This section outlines the results of four sets of policy exercises performed with the model. First, we study the long-run effect of broad and sectoral capital requirements, risk weight, LTV and LTI limits in the steady-state. Second, we explore the transmission channels of a permanent tightening of capital and borrower-based macroprudential measures, and the measure in which they contribute to reach their objectives. Third, we assess the effectiveness of different macroprudential instruments in achieving their policy objectives when broad and sectoral vulnerabilities emerge. Specifically, we consider a monetary policy shock leading to a broad increase in credit and a shock affecting the residential real estate sector (i.e. a shock leading to an increase in the

[12]Details are available upon request.
[13]See https://www.ecb.europa.eu/stats/ecb_surveys/hfcs/html/index.en.html.
[14]See https://www.ecb.europa.eu/stats/ecb_surveys/hfcs/html/index.en.html.

Description	Data	Model
Fraction of borrowers [%]	43.7	43.7
Return on average Equity[%]	6.4	6.4
Capital Requirement Ratio[%]	14.1	14.1
Risk-free interest rate [%]	2	2
Write-off for households (annualized) [%]	0.41	0.31
Write-off for entrepreneurs (annualized)[%]	0.71	0.72
NFC loans to GDP ratio	1.71	1.71
Mortgages to GDP ratio	2.1	2.1
Investment in Housing to GDP ratio	0.1	0.1
Housing wealth held by borrowers	0.5	0.5
Spread corporate loans (annualized) [%]	1.3	1.3
Spread retail loans (annualized) [%]	0.7	1.1
Corporate Bank default(annualized)[%]	0.8	0.8
Retail Bank default(annualized)[%]	0.8	0.8
LTV	0.55	0.55

Table 1: Data and calibrated first order moments.

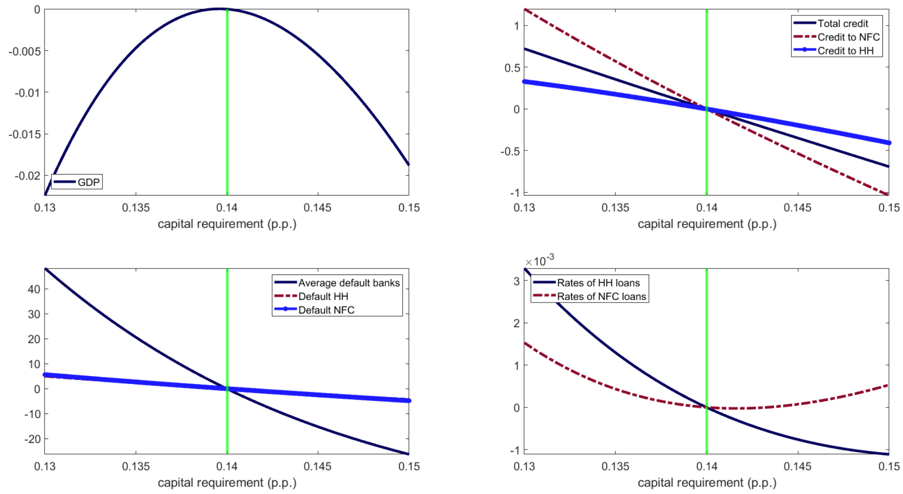
demand for credit and house prices).

4.1 Long-run effects of macroprudential policy

This section presents the simulated long-run effects of tighter macroprudential measures, which refer to changes in the long-run steady state induced by changing the policy parameters of the model. Note that, in the steady state, all prices are constant, therefore monetary policy plays no role.

In the long-run, increasing broad capital requirements leads to significant benefits in terms of bank resilience, with negligible effects on economic activity. When increasing capital requirements by 0.5 p.p., the average default of banks decreases 29% (Figure 1 and Table 2). Higher capital requirements push the cost of equity up while lower bank defaults reduce the cost of deposits. As a result, lending rates' changes are nonlinear and below the basis point. Total credit goes down 0.11%, credit to NFC being the most affected in light of the higher risk weights on corporate (100%) than mortgage (50%) exposures.

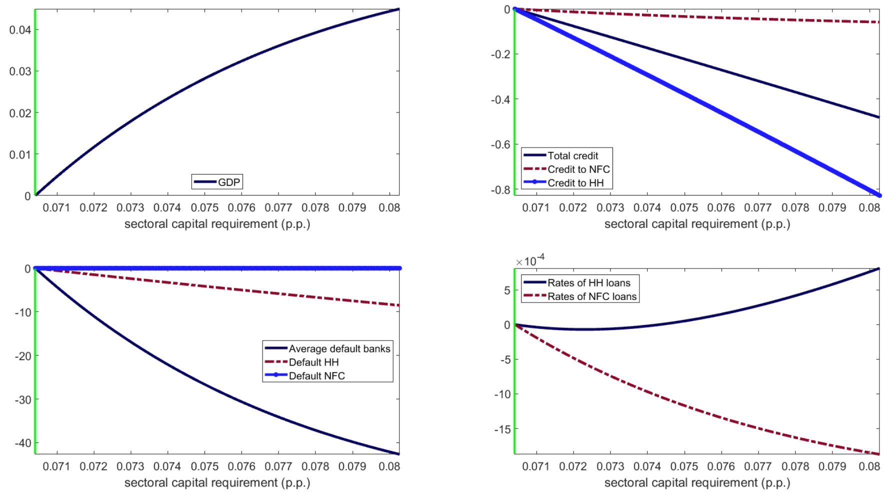
Figure 1: Long-run effects (Steady State). Changes in key variables wrt. ceteris paribus changes in the capital requirement level.



Note: the green line identifies the calibrated steady state level of capital requirements for corporate banks. On the x-axis we plot the level of capital requirements (p.p.) and on the y-axis the percentage change. Bank default and spreads are annualized.

When the 0.5 p.p. increase in capital requirements targets mortgage loan exposures only, bank resilience of the affected banks improves, while the relative pricing of mortgage loans increases, leading to lower mortgage credit in the steady state (Figure 2 and Table 2). Higher capital requirements push the cost of equity for mortgage banks up while lower bank defaults reduce the cost of deposit funding. This results in a slight increase in the lending rates of HH loans and a decline of the rate of NFC loans in the long run (the order of magnitude is still below the basis point). As a result, credit to HH declines 0.13% while credit to NFC is mostly unchanged. Moreover, HH consumption increases, thanks to the reduction of deposit insurance costs and a shift from houses to consumption of borrowers, leading to a slight positive effect on GDP.

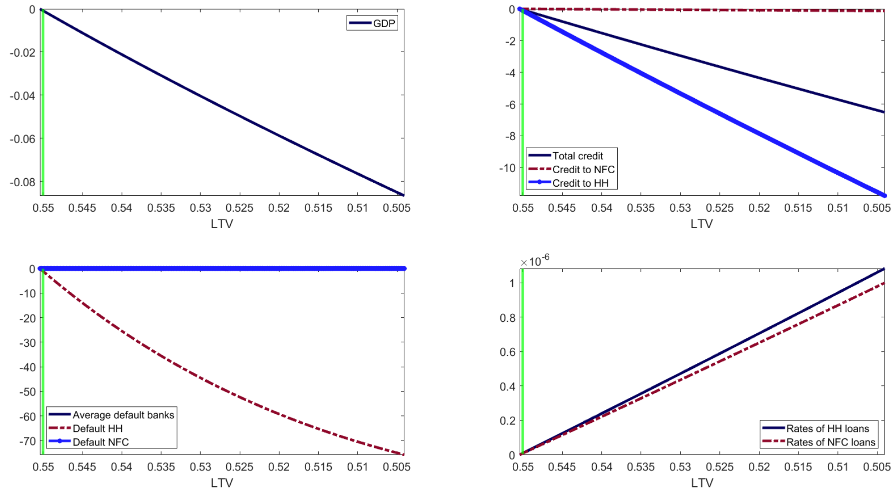
Figure 2: Long-run effects (Steady State). Changes in key variables wrt. ceteris paribus changes in the level of sectoral capital requirements on household loans.



Note: the green line identifies the calibrated steady state level of sectoral capital requirements for mortgage loans. On the x-axis we plot the level of sectoral capital requirements (p.p.) and on the y-axis the percentage change. Bank default and spreads are annualized.

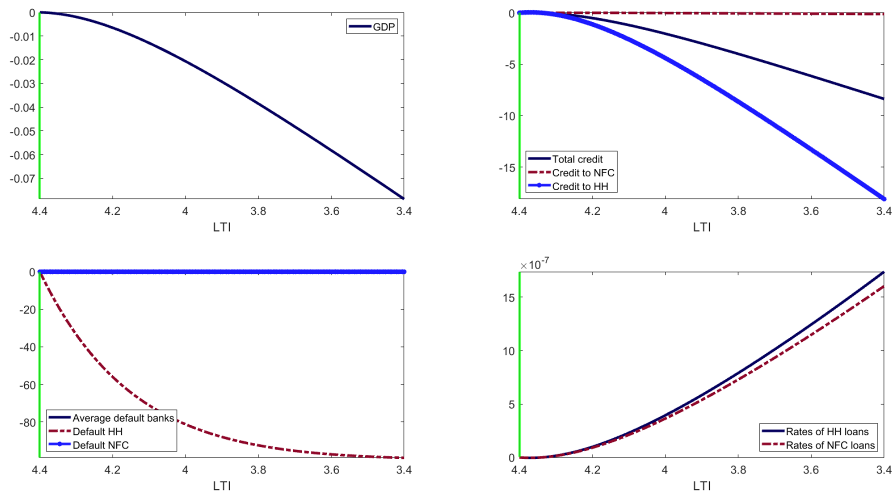
In the long-run, borrower-based measures such as LTV and LTI limits improve borrowers' resilience, however at the expense of a reduction in mortgage credit to the household sector and a reduction in economic activity. Figures 3 and 4 present the steady state effects of tightening, respectively, the LTV limits by 5 p.p. and the LTI limit by 1 point. In the steady state, LTV and LTI limits apply to the entire stock of loans. As the limits are tightened, credit to households and households' leverage decline significantly, with positive effects on borrowers' resilience (probability of default). It is interesting to notice that the reduction in HH credit due to a tightening in the LTV limit of around 12% is slightly above the percentage reduction of the LTV $\frac{5\%}{55\%} = 9\%$. This implies that borrowers are reducing leverage but also to a lesser extent the quantity of housing and hence, residential investment also declines. This results in a slight decrease of GDP while mortgage lending rates are almost unaffected by the decline in credit.

Figure 3: Long-run effects (Steady State). Changes in key variables wrt. ceteris paribus changes in the LTV level.



Note: the green line identifies the calibrated steady state level of LTV. On the x-axis we plot the level of LTV (p.p.) and on the y-axis the percentage change. Bank default and spreads are annualized.

Figure 4: Long-run effects (Steady State). Changes in key variables wrt. ceteris paribus changes in the LTI level.



Note: the green line identifies the calibrated steady state level of LTI. On the x-axis we plot the level of LTI and on the y-axis the percentage change. Bank default and spreads are annualized.

4.2 Transmission of macroprudential policy instruments

In this section, we examine the transmission of a permanent tightening of capital requirements (both broad and sectoral) and borrower-based measures, and their interaction with monetary

	Lending (%)			Int. rate spread (bp)		Leverage (bp)		Def. Banks (%)	GDP (%)
	HH	NFC	Total	HH	NFC	HH	NFC		
CR	-0.04	-0.19	-0.11	0.4	0.8	-0.03	-0.07	-29.38	-0.01
sSyRB CR	-0.13	-0.03	-0.08	0.79	0.00	-0.058	0.01	-28.37	0.03
LTV	-11.77	-0.12	-6.51	0.00	0.00	-11.69	0.00	0.02	-0.09
LTI	-18.11	-0.12	-8.38	0.00	0.00	-18.04	0.00	0.04	-0.08

Table 2: Long-run effects (Steady State): 0.5 p.p. higher capital requirements in the first row, 5 p.p. higher mortgage loan capital requirements in the second row, 5 p.p. lower LTV in the third row and 1 point lower LTI in the fourth row. Changes in key variables wrt. ceteris paribus changes in the different macroprudential instrument level.

policy. We particularly focus on the channels through which the instruments work to achieve the intended objectives. We further show the impact of the modelling novelties we introduce on the transmission of macroprudential instruments. Since we are interested in assessing the impact of *permanently* tighter macroprudential policy, we do not perform a standard impulse-response analysis (which would imply that macroprudential measures return to the steady-state level after the initial shock). Rather, we fix the path for the policy variable of interest (e.g. an increase in capital requirements of 0.5 p.p. over 4 quarters) and we feed such path to the model and obtain the resulting adjustment of the model variables.

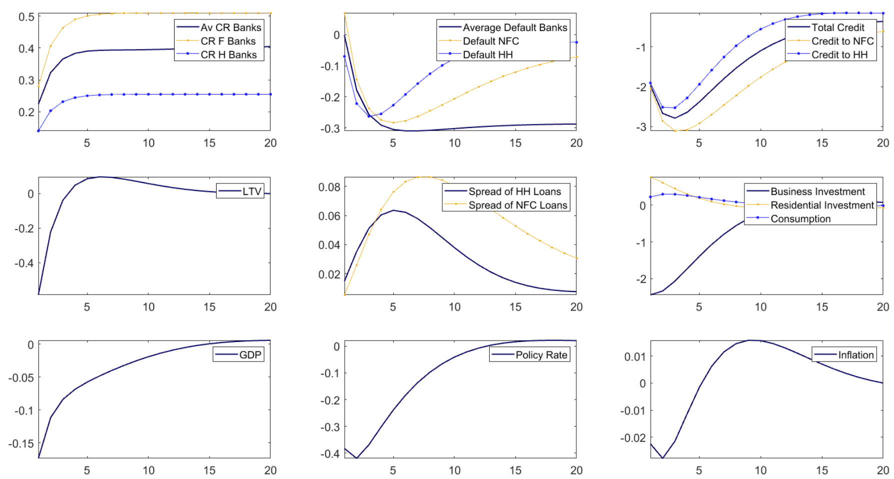
4.2.1 Transmission of capital requirements

Tighter broad capital requirements result in a permanent improvement in bank resilience, with only short-lived effects on credit. A permanent 0.5 p.p. increase in broad capital requirements implemented over 4 quarters[15] results in an increase in overall bank resilience, in line with its intended objective (figure 5). In light of the higher risk weights, the cost of equity increases relatively more for corporate banks, which pass it on to customers through higher leading rates. This leads to a relatively stronger increase in lending spreads on corporate loans than mortgage loans, which is reflected in a more marked decline in credit to NFCs (-3.10% after four quarters) than credit to households (-2.4% after four quarters), see Tables 3 and 4 for a summary of the impact on the main macroeconomic variables after four and eight quarters. As lower NFC credit leads to a decline in business investment, the price of capital and the rental rate of capital also fall, implying lower production costs which, in turn, translate in a decline in inflation (0.03% after four quarters). This is partly offset by a slight

[15] This reflects the practice for setting the CCyB, which becomes fully effective 4 quarters after the decision is published by the macroprudential authority.

increase in demand for consumption goods by patient households, driven by the decrease in the costs of bank default resulting from more resilient banks, which is reflected in lower costs for deposit insurance. The slight expansion of the residential real estate sector also results from the lower deposit insurance costs for households, which use part of the additional funds to purchase housing expenditure. The decline in inflation prompts the monetary policy to lower the policy rate, and this has a twofold effect. First, the decline in the risk-free rate lowers the cost of banks' deposit funding, thereby mitigating the increase in the cost of equity funding due to the higher capital requirements and further improving bank resilience. On the other hand, the lower policy rate mitigates the impact of capital requirements on bank lending rates and credit. Although lower policy rates counteract the effect of tighter macroprudential limits on credit, they contribute to fostering financial stability by reducing the repayment burden on the existing stock of loans. Furthermore, the magnitude of monetary accommodation is not strong enough to fully offset the macroprudential policy tightening. Appendix D shows the effects of degree of interest spread stickiness on the behaviour of credit and lending spreads after an increase in capital requirements.

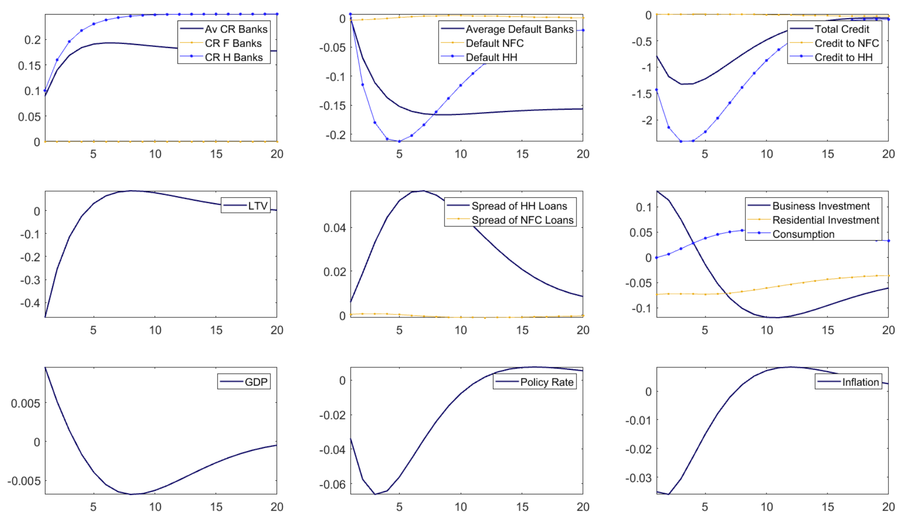
Figure 5: Transition to 0.5 p.p. higher capital requirements over 4 quarters.



Note: we plot, over the first 20 quarters, the annualized percentage deviation from the steady state for the spread on HH and NFC loans, the average default of banks, HH and NFC, the policy rate and the inflation rate; the deviation from the steady state for capital requirements of corporate and mortgage banks and LTV (in percentage points); the percentage deviation from the steady state for all other macroeconomic variables).

Higher sectoral capital requirements allow to increase the resilience of the banking sector to specific exposures, while limiting spillover effects to other sectors. A permanent 0.5 p.p. increase in capital requirements on mortgage lending (over 4 quarters) induces a permanent improvement in the resilience of the affected banks, leading to a 14% decline in the average bank default over the first four quarters (Figure 6 and Table 3). The higher cost of equity for mortgage loan exposures is passed on to borrowers through higher spreads on mortgage loans (4 bp), leading to a 2.47% decline in credit to households after four quarters. In addition to increasing banks' resilience, sectoral capital requirements may also contribute to addressing vulnerabilities related to the real estate sector and borrower indebtedness. Higher capital requirements on mortgage loans entail higher mortgage rates and lower mortgage credit demand. The residential real estate sector is also affected through lower demand for housing, prompting a decline in residential investment and house prices. Moreover, as households' leverage (and indebtedness) declines, so does the average LTV and their resilience (i.e. their probability of default) improves. As the NFC sector is not affected by the measure, the overall impact on GDP is negligible. Actually, the reduced cost of bank default exerts a positive effect on GDP after some quarters, due to a slight increase in demand for consumption goods by patient households, which benefit from the lower costs of deposit insurance.

Figure 6: Transition to 0.5 p.p. higher capital requirements on mortgage loan exposures over 4 quarters.

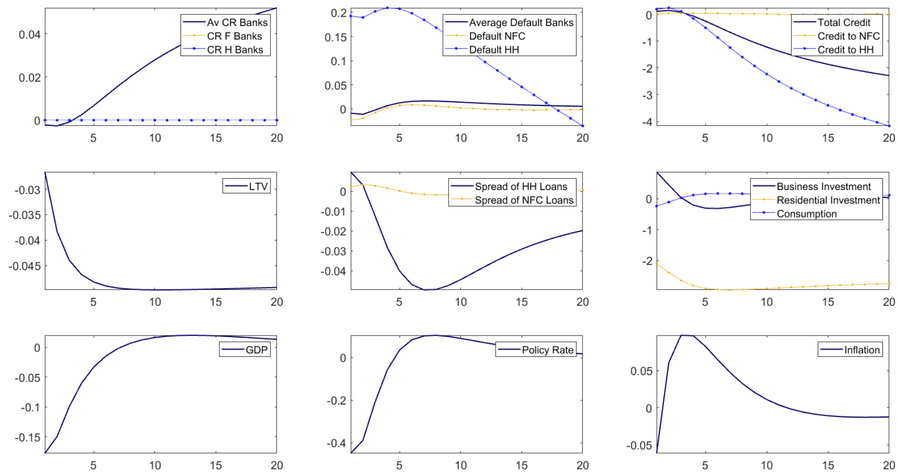


Note: we plot, over the first 20 quarters, the annualized percentage deviation from the steady state for the spread on HH and NFC loans, the average default of banks, HH and NFC, the policy rate and the inflation rate; the deviation from the steady state for capital requirements of corporate and mortgage banks and LTV (in percentage points); the percentage deviation from the steady state for all other macroeconomic variables.

4.2.2 Transmission of borrower-based measures

A permanent tightening of the aggregate LTV limit by 5 p.p. over 4 quarters tightens the mortgage loan market and reduces house prices, however with mixed effects on borrower-resilience (Figure 7). Tighter LTV limits are obtained by lowering the target LTV limit, therefore causing the LTV penalty function for banks to kick-in for lower values of the LTV. As a result, banks curtail their credit supply, thereby reducing mortgage credit to households and leading to a decline in housing expenditure by borrowing households. This, in turn, leads to a drop in residential investment and house prices. The drop in house prices leads to an increase in households' defaults while banks' and entrepreneurs' defaults are less affected. This stems from the fact that, in this model, household default is a function of the collateral value (see equation 3.5). In addition, lower residential investment negatively affects GDP in the first quarters (0.06% drop in the first four quarters) while business investment increases as households partly substitute housing with consumption. The combination of higher monitoring costs stemming from higher household defaults and higher business investments leads to an increase in inflation for the first quarters (0.1% increase after the first four quarters). However, inflation goes back slightly below the steady state level when monitoring costs reduce due to the improving household resilience. Monetary policy reacts by decreasing the policy rate in the first quarters and then increasing it as the GDP recovers. This partially counters the LTV effects on credit in the first quarters. Moreover, the effect of the LTV tightening on household credit can be observed only after some quarters because the LTV limit is applied only to new loans and it takes some time to pass-through to the stock. Appendix E shows the transmission of tighter LTV and LTI limits according to different calibrations of the penalty parameter.

Figure 7: Transition to 5 p.p. tighter LTV limit over 4 quarters.



Note: we plot, over the first 20 quarters, the annualized percentage deviation from the steady state for the spread on HH and NFC loans, the average default of banks, HH and NFC, the policy rate and the inflation rate; the deviation from the steady state for capital requirements of corporate and mortgage banks and LTV (in percentage points); the percentage deviation from the steady state for all other macroeconomic variables.

Similar results hold for the transmission of a permanent tightening of the aggregate LTI limit by 1 point (from 4.5 to 3.5) over 4 quarters (Figure 8). Similarly to the LTV case, tighter LTI limits are obtained by lowering the target LTI limit, therefore causing the LTI penalty function for banks to kick-in for lower values of the LTI. As a result, banks curtail their credit supply, thereby reducing credit to households and household indebtedness, and leading to a decline in housing expenditure by borrowing households. This, in turn, leads to a drop in residential investment and house prices. On the one hand, the drop in house prices leads to an increase in households' defaults while banks' and entrepreneurs' defaults are not affected. On the other hand, GDP drops slightly in the first quarters (0.01% drop in the first four quarters). The combination of higher monitoring costs stemming from higher household defaults leads to an increase in inflation for the first quarters (0.03% increase after the first four quarters). However, inflation goes back slightly below the steady state level when monitoring costs reduce due to the improving household resilience. Monetary policy reacts by decreasing the policy rate in the first quarters and then increasing it as the GDP recovers. In general the volatility of GDP inflation and monetary policy is significantly below the LTV case. Moreover, the effect of the LTI tightening on HH credit can be observed only after some quarters because the LTI limit is applied only to new loans and it takes some time to pass-through to the stock.

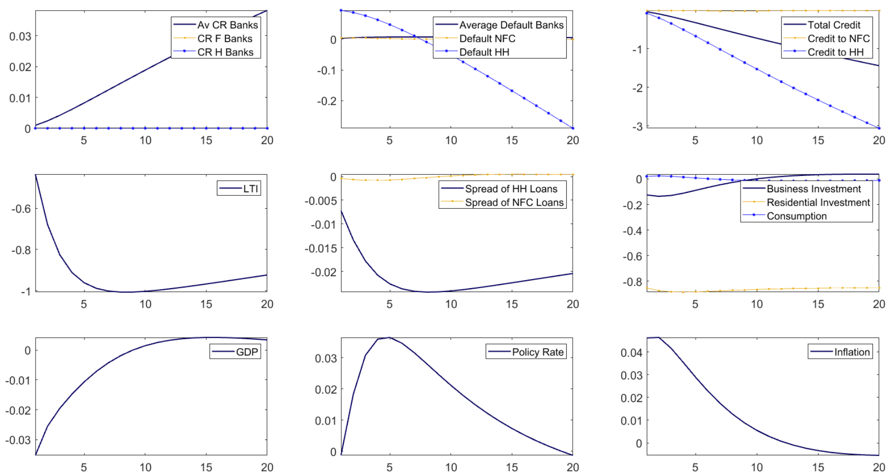
	Lending (%)			Int. rate spread (bp)		Leverage (bp)		Def. Banks (%)	GDP (%)	Inf. (%)
	HH	NFC	Total	HH	NFC	HH	NFC			
CR	-2.40	-3.10	-2.71	6.1	6.0	-2.33	-3.03	-29	-0.07	-0.03
sectoral CR	-2.47	0.01	-1.37	4.08	0	-2.48	0	-14	-0.01	-0.02
LTV	-0.14	0.048	-0.05	-1.8	0	-0.08	0.10	1	-0.06	0.1
LTI	-0.50	-0.018	-0.24	-2.1	0	-0.48	0.00	1	-0.01	0.03

Table 3: Short-run effects of tighter macroprudential instruments: 0.5 p.p. higher capital requirements in the first row, 0.5 p.p. higher sectoral capital requirements in the second row, 5 p.p. lower LTV in the third row and one point lower LTI in the last row. Impact of higher capital requirements/lower LTV/LTI limits over 4 quarters relative to starting levels, annualized deviation from steady state for interest rate spreads, bank defaults and inflation. The effects over credit, spreads and bank defaults are more relevant in the CR case over 4 quarters. In the LTV and LTI case, effects on credit are delayed because the LTV/LTI limits are applied only on new loans.

	Lending (%)			Int. rate spread (bp)		Leverage (bp)		Def. Banks (%)	GDP (%)	Inf. (%)
	HH	NFC	Total	HH	NFC	HH	NFC			
CR	-0.87	-2.11	-1.43	10.41	14.22	-0.84	-2.08	-31	-0.03	0.01
sectoral CR	-1.34	0.01	-0.74	9.2	0	-1.33	0	-16	-0.01	0.01
LTV	-1.52	0.04	-0.82	-6.6	0	-1.53	0.04	2	0.01	0.03
LTI	-1.18	-0.02	-0.55	-2.4	0	-1.18	-0.02	1	0.00	0.01

Table 4: Short-run effects of tighter macroprudential instruments: same as table 3 but over 8 quarters.

Figure 8: Transition to 1 point tighter LTI limit over 4 quarters.



Note: we plot, over the first 20 quarters, the annualized percentage deviation from the steady state for the spread on HH and NFC loans, the average default of banks, HH and NFC, the policy rate and the inflation rate; the deviation from the steady state for capital requirements of corporate and mortgage banks and LTI (in percentage points); the percentage deviation from the steady state for all other macroeconomic variables.

4.3 Exogenous shocks

In this section, we use impulse-response analysis to investigate the effectiveness of different macroprudential instruments in addressing emerging broad and sectoral vulnerabilities. To this end, we analyse the response of the economy to two shocks which stimulate the demand of credit, one more broadly (monetary policy shock) and one affecting household credit (housing preference shock).

Monetary policy shock

Figure 9 depicts the impulse-responses to a 0.5 p.p. exogenous decline in the monetary policy rate. In the absence of countercyclical capital requirements and LTV limits[16], a monetary policy expansion contributes to financial stability by decreasing the cost of funding with a positive effect on bank defaults; at the same time, it results in higher leverage in both the corporate and household sector. In the baseline case (solid blue line in figure 9), the decline in the monetary policy rate immediately lowers the cost of banks' deposit funding, thereby reducing banks' default probability and lending rates to both households and firms. Lower costs of borrowing encourage borrowing households' demand for housing, thereby pushing residential investment upwards. At the same time, lower interest rates on bonds and deposits reduce savings by patient households thereby stimulating consumption (and consequently stimulating NFC investment) and further encouraging housing investment.[17] Higher consumption and investment in both the corporate and housing sector exert a positive effect on GDP. As GDP growth outpaces household credit growth in the first quarters, households' indebtedness initially decreases, becoming positive after three quarters. Overall, the shock results in an increase in total credit and in higher business and residential investment which lead to higher asset prices and higher inflation. The economic expansion comes at the expense of a build-up of leverage in both the corporate and household sector, however, default probabilities decrease in light of the more favourable loan repayment costs and higher asset prices.

Broad countercyclical capital requirements (i.e. the CCyB) improve bank resilience and limit credit procyclicality without compromising the expansionary effect of monetary policy on GDP and inflation, however, they suffer from important design

[16]Banks still face minimum fixed capital requirements.

[17]Consumption is further encouraged by a decrease of the cost of deposit insurance due to lower bank defaults.

drawbacks. In fact, after the expansionary monetary policy shock, the credit-to-GDP gap turns negative, as GDP is increasing more than credit. Therefore, when the CCyB is active (dashed red line in figure 9), as the macroprudential authority responds to deviations of the credit-to-GDP gap from the steady state and GDP increases after the monetary policy shock, in the first periods, capital requirements decrease. Therefore, the effect of the CCyB in fostering banks' resilience and in reducing credit procyclicality only emerges after a four quarters lag. In addition, in light of the higher risk weights on corporate loans and the resulting stronger increase in capital requirements for corporate banks, the CCyB exerts a stronger effect on corporate than household credit.

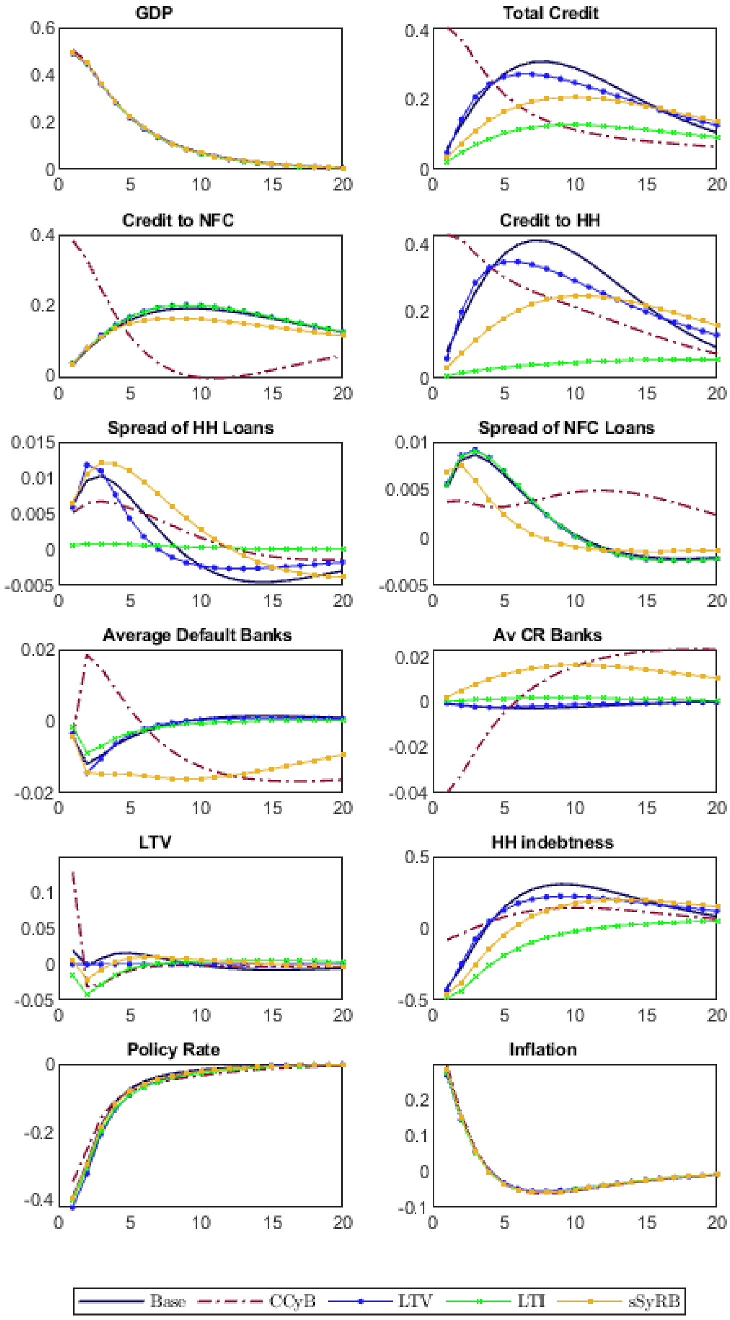
These results show that relying on the credit-to-GDP gap as a main indicator to guide the setting the CCyB may not be appropriate in certain circumstances. While the Basel Committee on Banking Supervision[18] had put forward the use of this indicator to inform the calibration of the CCyB in light of its good early-warning performance after the great financial crisis[19], since then, the evidence gathered and the experience observed in recent years have shown that the credit-to-GDP gap has several shortcomings.[20] Among these is the dependence of the credit to GDP gap on past GDP performance (see e.g., Repullo and Saurina Salas 2011, Drehmann and Tsatsaronis 2014). In its response to the European Commission's call for advice on the Review of the Macroprudential framework, the ECB also highlighted the need to reduce the prominent role of the credit to-GDP gap in the CCyB framework (see European Central Bank 2022, and the related Annex 1).

[18] See Basel Committee on Banking Supervision (2010).

[19] See Drehmann *et al.* (2010).

[20] For a discussion of the shortcomings of the Basel gap, see Lang and Welz (2017), Lang *et al.* (2019), Castro *et al.* (2016), Edge and Meisenzahl (2011)

Figure 9: Impulse-responses to a monetary policy shock.



Note: we plot, over the first 20 quarters, the annualized percentage deviation from the steady state for the spread on HH and NFC loans, the average default of banks, HH and NFC, the policy rate and the inflation rate; the deviation from the steady state for capital requirements of corporate and mortgage banks and LTV (in percentage points); the percentage deviation from the steady state for all other macroeconomic variables.

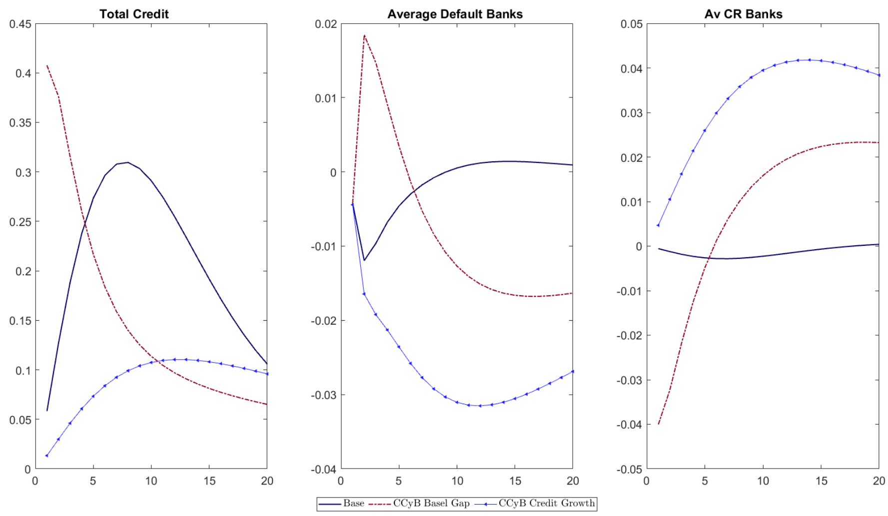
Therefore, in Figure 10 we display the impulse response function to the same monetary policy shock as above, considering also an alternative rule for the setting of the CCyB whereby the macroprudential authority reacts to the deviation of total credit from the steady state. The alternative macroprudential rules for mortgage and corporate banks become respectively :

$$\phi_t^h = RW_t \left(\phi_{Fs} + \varphi_F \log \frac{b_t}{b_0} + \varphi_S \log \frac{b_t^m}{b_0^m} \right)$$

$$\phi_t^f = \left(\phi_{Fs} + \varphi_F \log \frac{b_t}{b_0} \right)$$

As shown in the figure, the alternative CCyB rule does a much better job in improving bank resilience and reducing the procyclicality of credit in the event of a monetary policy shock. As total credit rises in response to the shock, the macroprudential authorities increases the CCyB, which immediately reduces average bank default.

Figure 10: Impulse-responses to a monetary policy shock - alternative CCyB rule.



Note: we plot, over the first 20 quarters, the percentage deviation from steady state of total credit, of the average default of banks (annualized), and the deviation from the steady state of the average capital requirements of banks.

Sectoral countercyclical capital requirements targeting mortgage loan exposures (i.e. the sSyRB) allow the monetary policy stimulus to transmit to the corporate sector and the broader economy, while addressing emerging vulnerabilities in the residential real estate sector. A cyclical sSyRB reacting counter-cyclically to deviations of credit to households from the steady state (yellow line with diamonds in Figure 9) tightens capital requirements for mortgage banks only. Therefore, mortgage banks charge a higher spread on mortgage borrowers, which depresses the demand for mortgage credit and also limits the buildup of households indebtedness. Therefore, while having the primary objective to increase the resilience of the banking sector to losses in the mortgage loan portfolios, sectoral capital-based measures may also be effective in addressing vulnerabilities emerging from the residential real estate sector and limiting the procyclicality of mortgage credit. It is important to note that the design of the instrument (which reacts to deviations of sectoral credit from the steady state and does not depend on credit-to-GDP gaps as the CCyB) implies that the capital requirements increase as soon as sectoral credit starts growing.

Following an expansionary monetary policy shock, LTV limits are less effective than sectoral capital requirements in slowing the expansion in mortgage credit and reducing borrowers' indebtedness, in light of their procyclicality. As the monetary policy shock encourages consumption (of both housing and consumption goods), the LTV limit puts a brake on credit to households. At the same time, the increased demand for housing from saving households (who do not rely on mortgage credit for their house purchases) pushes real estate prices upwards. However, rising house prices actually bring the LTV down through their effects on the collateral value, thereby making the LTV limit less binding (see e.g., Lo Duca *et al.* 2023). While LTV limits results in lower credit to households compared to the baseline case, in this exercise they do not outperform sectoral capital requirements in addressing emerging vulnerabilities in the real estate sector.

LTI limits are the most effective instrument to prevent exuberant mortgage credit developments to materialise and to ensure that household debt remains sustainable. While containing the increase in the demand for mortgage credit resulting from the monetary policy shock, LTI limits are not influenced by house prices and do not suffer from the procyclicality which affects LTV limits. Therefore, LTI limits are much more effective in constraining the rise in mortgage credit and in borrowers' indebtedness. Interestingly, as borrowers' resilience improves as a result of lower leverage, LTI instruments also have positive spillovers on bank resilience, which also improves compared to the baseline case.

Overall, it is important to note that macroprudential instruments do not seem to interfere with the transmission of monetary policy to its two main objective variables, namely inflation and output.

Housing preference shock

We now consider a shock affecting the residential real estate sector. Specifically, we simulate a housing preference shock, which shifts households' preferences towards purchasing housing goods. The shock is calibrated to yield a 1% increase in house prices on impact. In the absence of macroprudential policy reaction (solid blue line in Figure 9) the increased demand for mortgage credit drives developments in total credit, and leads to an increase in residential investment and house prices. While the residential real estate sector expands, business investment and production decline with the demand for consumption goods, leading to a decline in inflation. As, overall, GDP increases driven by residential investment, the central bank reacts by only marginally reducing the policy rate, which is then mirrored by lower rates on mortgage and corporate loans. Therefore, the central bank is accommodating the initial shock, as lower mortgage interest rates reinforce the initial effect of the shock on credit demand. While higher housing valuation and lower mortgage rates reduce the probability of households' default, household leverage increases.

In the event of a shock affecting the residential real estate sector only, the CCyB is a too broad instrument to address the emerging vulnerabilities and results in an excessive and unnecessary penalisation of the corporate sector. The macroprudential authority reacts to the initial shock by raising capital requirements in response to the widening credit to GDP gap (c.f. dashed red line in Figure 9). Since the deviation of the credit-to-GDP gap from the steady state is positive, the CCyB implies an additional positive capital requirement for both banks, which reduces their default rates. However, due to the higher risk weights on corporate loans, the increase in capital requirements is particularly strong for banks lending to NFCs, leading to a strong contraction in corporate credit compared to the baseline case. As a result, business investment drops, with negative consequences on GDP compared to the baseline case.[21]

Sectoral countercyclical capital requirements targeting mortgage credit, on the other hand, allow to affect specific exposures, thereby yielding the desired increase

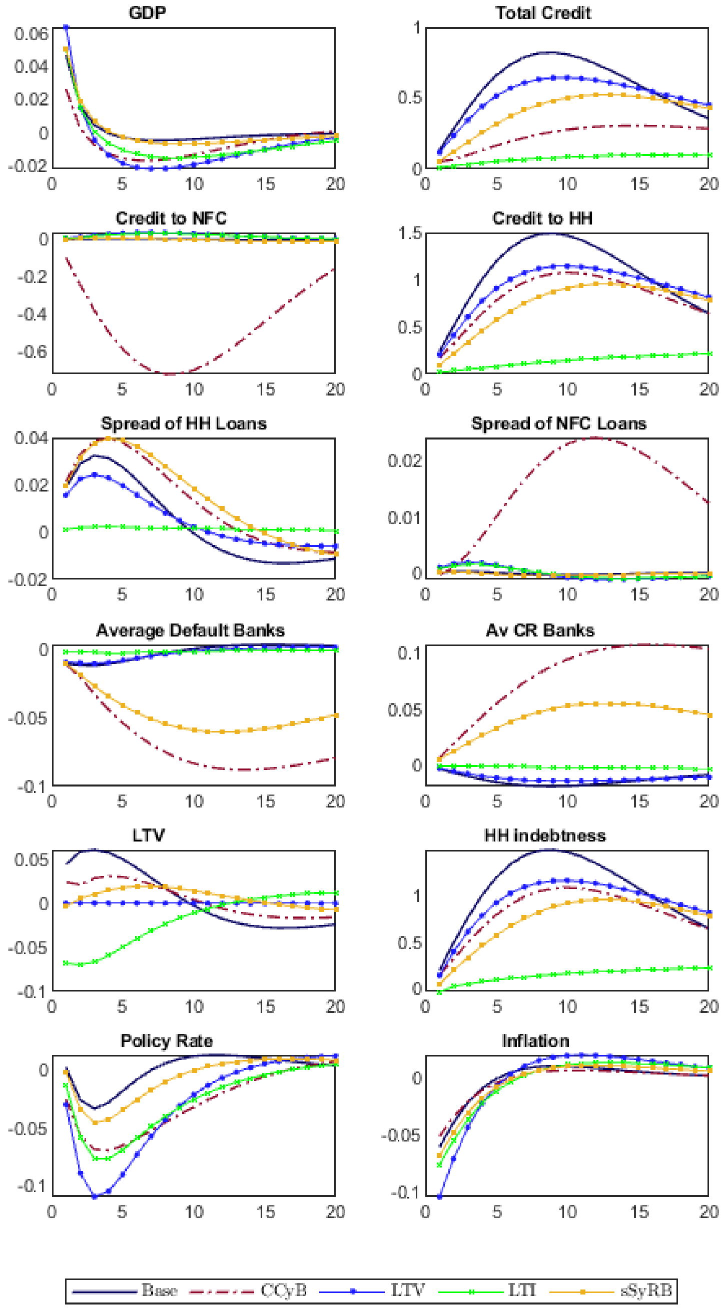
[21] In this case, the CCyB based on the credit-to-GDP gap and the CCyB based on the credit growth have a similar effect on the economy because the shocks affect credit more than GDP.

in banks' resilience while limiting adverse spillovers to other sectors of the economy. Compared to the broad CCyB, the sSyRB imposes higher capital requirements only on banks lending to households. Therefore, the resilience of these banks increases, as reflected in he lower probability of default. At the same time, the policy leads to higher lending spreads, which curtail the demand for mortgage credit. However, since the sSyRB does not affect the banks lending to firms, lending spreads to NFCs remain broadly constant and so does credit to firms. Therefore, with sectoral capital requirements, the (mild) decline in business investment is entirely driven by the change in households' appetite for consuming consumption goods. Overall, the milder decline in business investment coupled with the stronger decline in the cost of bank defaults lead to a higher GDP throughout the entire horizon, compared to the case where the CCyB is active.

LTV limits are successful in containing the rise of vulnerabilities in the residential real estate sector compared to the baseline case, however they exhibit a degree of procyclicality which undermines their effectiveness in containing the growth of mortgage credit and household indebtedness compared to other policy options. As the shock entails an increase in house prices on impact, the LTV constraint in place becomes less binding and therefore less successful in limiting the expansion in mortgage credit after the shock. As the figure shows, LTV limits seem to be less effective than LTI and even sectoral capital requirements in containing the growth in mortgage credit and household indebtedness. The procyclicality of LTV limits was also found in a recent paper as one of the drawbacks of this policy instruments (see Lo Duca *et al.* 2023). In addition, LTV limits effectively shift housing demand from borrowers to savers, thereby still leading to a similar increase in residential investment and house prices as in the baseline case.

Finally, LTI limits seem to be the most effective instruments in containing the growth of mortgage credit and household indebtedness. LTI limits are not influenced by changes in house prices, therefore they remain binding even after house prices increase after the shock. This implies that they are most successful in limiting excessive developments in mortgage credit. In fact, they lead to a negligible impact of the shock on credit spread on mortgage loans and household credit dynamics. Surely, as these instruments have no impact on the resilience of the banking sector, they are mostly appropriate when the policy-maker's objective is to tame excessive mortgage credit and residential real estate price developments.

Figure 11: Impulse-responses to a housing preference shock.



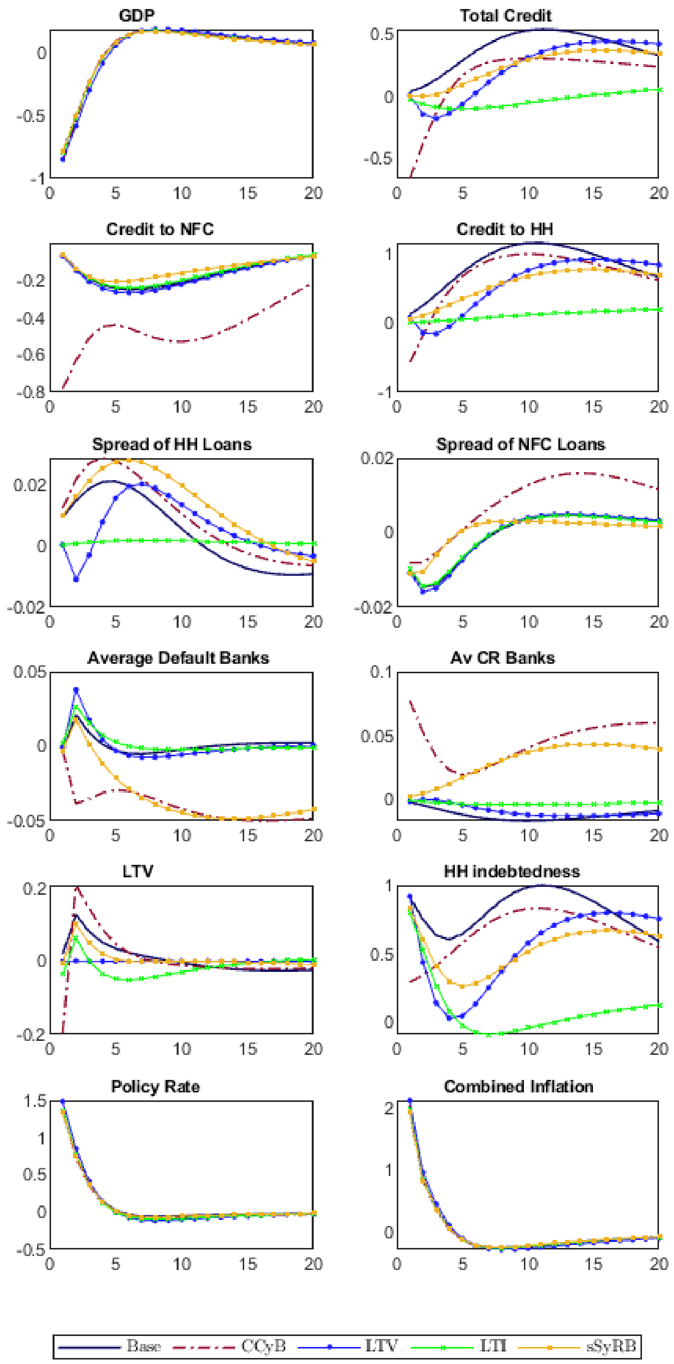
Note: we plot, over the first 20 quarters, the annualized percentage deviation from the steady state for the spread on HH and NFC loans, the average default of banks, HH and NFC, the policy rate and the inflation rate; the deviation from the steady state for capital requirements of corporate and mortgage banks and LTV (in percentage points); the percentage deviation from the steady state for all other macroeconomic variables.

Monetary policy and house prices

In this section, We explore the question as to whether monetary policy would be effective in containing residential real estate imbalances, if the Harmonised Index of Consumer Prices (HICP) were broadened to include housing costs. Figure 12 presents the impulse responses to the same housing preference shock considered in the previous section when house prices are included in the inflation index.

When the monetary authority also reacts to developments in house prices, the reaction to the sectoral shock leads to costs in terms of GDP due to a stronger effect on consumption and an unnecessary penalisation of the corporate sector. In the baseline case, the shock increases the demand for mortgage credit, which drives the increase in total credit, and fuels residential investment. The increases of household credit and house prices are less pronounced than in the case with no house prices in inflation. The reason is that, while goods price inflation decreases as demand for consumption goods declines along with business investment and production, the combined inflation including house prices increases significantly. Therefore, a tighter monetary policy stance is required to bring inflation down, which also leads to higher rates on mortgage and corporate loans. While the monetary policy tightening dampens the effect of the initial shock on credit demand, it also leads to an economic contraction in light of its strong effect on consumption. This affects negatively credit and GDP. While higher housing valuation and lower mortgage rates reduce the probability of households' default, household leverage increases. Macroprudential policy reacts similarly to what happens in the case with no house prices in the inflation index (cf. figure 11).

Figure 12: Impulse-responses to a housing preference shock when house prices are included in HICP.



Note: we plot, over the first 20 quarters, the annualized percentage deviation from the steady state for the spread on HH and NFC loans, the average default of banks, HH and NFC, the policy rate and the inflation rate; the deviation from the steady state for capital requirements of corporate and mortgage banks and LTV (in percentage points); the percentage deviation from the steady state for all other macroeconomic variables.

5 Conclusion

In this paper, we address the question of appropriate selection of macroprudential instruments according to the vulnerabilities identified and the policymakers' objective using a calibrated DSGE model for the euro area in the spirit of Mendicino *et al.* (2020) and Hinterschweiger *et al.* (2021). We focus on a rich set of macroprudential instruments, including broad and sectoral countercyclical capital requirements, as well as limits to the LTV and LTI ratios of borrowers. The analysis provides valuable conclusions for macroprudential policy.

First, we confirm previous results regarding the effectiveness of capital regulation in improving bank's resilience, with negligible effects on economic activity. Sectoral capital requirements are preferable when vulnerabilities are limited to specific sectors, as the prevent the occurrence of undesired spill-over effects to sectors where vulnerabilities are not present. In the long-term, borrower-based measures such as LTV and LTI limits are effective in improving the resilience of borrowers, reducing their probability of default, however at the expense of a reduction in mortgage credit to the household sector and a reduction in economic activity.

Second, we find that, in response to a monetary policy shock increasing vulnerabilities on both the household and firms' side in the form of increased leverage, broad countercyclical capital requirements (i.e. the CCyB) improve bank resilience and limit credit procyclicality without compromising the expansionary effect of monetary policy on GDP and inflation. However, we show that policy rules whereby the CCyB is set according to the evolution of total credit from the steady state are more effective than rules reacting to the credit-to-GDP gap in improving bank resilience and reducing the procyclicality of credit in the event of a broad shock. Among borrower-based instruments, LTI limits are the most effective instrument to prevent exuberant mortgage credit developments to materialise and to ensure that household debt remains sustainable, as LTV limits become less binding due to the expansionary effect of the shock on house prices. The results further highlight the superiority of sectoral capital requirements over their broad counterparts in addressing vulnerabilities in specific sectors. We show that, in the event of a shock affecting the residential real estate sector only, sectoral countercyclical capital requirements yield the desired increase in banks' resilience while limiting adverse spillovers to other sectors of the economy. Among borrower-based measures, LTV limits are successful in containing the rise of vulnerabilities in the residential real estate sector compared to the baseline case, however they exhibit a degree of procyclicality which undermines their effectiveness in containing the growth of mortgage credit and household indebtedness compared to other policy options. Finally, LTI limits seem to be the most effective instruments in containing the growth of mortgage credit and household indebtedness.

Lastly, we show that macroprudential policy is superior to monetary policy in addressing vulnerabilities building up in the real estate sector. When the monetary authority also reacts to developments in house prices, the policy rate needs to increase substantially to bring composite (goods and house price) inflation down, leading to more severe costs in terms of GDP due to a stronger effect on consumption and an unnecessary penalisation of the corporate sector.

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Appendix A First order conditions

$U_{c_t^s}$ ($U_{c_t^m}$) is the per-period utility derived from consumption for savers (borrowers).

$$U_{c_t^s} = \log(c_t^s - \theta c_{t-1}^s) \ , \tag{A.1}$$

where c_t^s is the consumption of savers and θ the preference parameter.

$$U_{c_t^m} = \log(c_t^m - \theta c_{t-1}^m) \ , \tag{A.2}$$

where c_t^m is the consumption of borrowers and θ the consumption preference parameter.

$U_{l_t^s}$ ($U_{l_t^m}$) is the per-period dis-utility derived from labour for savers (borrowers).

$$U_{l_t^s} = \frac{\varphi_s \, (l_t^s)^{1+\eta}}{1+\eta} \ , \tag{A.3}$$

where l_t^s is the labour of savers, φ_s the labour preference parameter of savers, and η the inverse of the Frisch elasticity of labour supply.

$$U_{l_t^m} = \frac{\varphi_m \, (l_t^m)^{1+\eta}}{1+\eta} \ , \tag{A.4}$$

where l_t^m is the labour of borrowers, φ_m the labour preference parameter of borrowers.

$U_{h_t^s}$ ($U_{h_t^m}$) is the per-period utility derived from housing for savers (borrowers).

$$U_{h_t^s} = \epsilon_t^J \, v_s \, \log(h_t^s) \ , \tag{A.5}$$

where h_t^s is the quantity of housing owned by savers, ϵ_t^J the housing preference shock and v_s the housing preference parameters of savers.

$$U_{h_t^m} = \epsilon_t^J \, v_m \, \log(h_t^m) \ , \tag{A.6}$$

where h_t^m is the quantity of housing owned by borrowers and v_m the housing preference parameters of borrowers.

The per-period utility of savers is

$$U_t^s = U_{c_t^s} - U_{l_t^s} + U_{h_t^s} \quad . \tag{A.7}$$

The utility of borrowers is

$$U_t^m = U_{c_t^m} - U_{l_t^m} + U_{h_t^m} \quad . \tag{A.8}$$

The marginal utilities are

$$U_c^s(t) = \frac{1}{c_t^s - \theta\, c_{t-1}^s} \quad , \tag{A.9}$$

$$U_c^m(t) = \frac{1}{c_t^m - \theta\, c_{t-1}^m} \quad , \tag{A.10}$$

$$U_l^s(t) = \varphi_s (l_t^s)^\eta \quad , \tag{A.11}$$

$$U_l^m(t) = \varphi_m (l_t^m)^\eta \quad , \tag{A.12}$$

$$U_h^s(t) = \frac{v_s}{h_t^s} \quad , \tag{A.13}$$

$$U_h^m(t) = \frac{v_m}{h_t^m} \quad . \tag{A.14}$$

The stochastic discount of savers from t to $t+1$ is

$$\Lambda_{t,t+1} = \beta_s \frac{U_c^s(t+1)}{U_c^s(t)} \quad , \tag{A.15}$$

where β_s is the deterministic discount factor of savers.

The value function of savers or borrowers can be written recursively.

$$V_t^s = U_t^s + \beta_s\, V_{t+1}^s \quad . \tag{A.16}$$

$$V_t^m = U_t^m + \beta_m V_{t+1}^m \quad , \tag{A.17}$$

where β_m is the deterministic discount factor of borrowers.

The value function of entrepreneurs and bankers is entrepreneurs and bankers net worth.

$$V_e = n_t^e \quad , \tag{A.18}$$

where n_t^e is entrepreneurs' net worth.

$$V_b = n_t^b \quad , \tag{A.19}$$

where n_t^b is bankers' net worth.

The first order condition (FOC) for savers wrt. consumption is

$$\lambda_t^s \, P_t = U_c^s(t) \quad , \tag{A.20}$$

where P_t is the goods price and λ_t^s the Lagrange multiplier for the budget constrain.

The FOC for savers wrt. labour is

$$U_l^s(t) = w_t \, \lambda_t^s \quad , \tag{A.21}$$

where w_t is the wage rate.

The FOC for savers wrt. deposit is

$$\lambda_t^s = \beta_s \, \lambda_{t+1}^s R_{DD}^{t+1} \quad , \tag{A.22}$$

where R_{DD}^{t+1} is the net deposit rate defined in (A.24).

The FOC for savers wrt. the risk free bond is

$$\lambda_t^s = \beta_s \, \lambda_{t+1}^s R_t \quad , \tag{A.23}$$

where R_t is the risk free rate.

The net rate paid at time t for deposit at time $t-1$ is

$$R_t^{DD} = R_{t-1}^D (1 - pp \; PD_t^b/4) \tag{A.24}$$

where R_t^D is the deposit rate, PD_t^b the average (yearly) default of banks and pp a parameter that takes into account the cost of recovering insured deposit.

The FOC for savers wrt. housing is

$$\lambda_t^s \, q_t^h = U_h^s(t) + \beta_s \lambda_{t+1}^s (1 - \delta_{t+1}^h) q_{t+1}^h \quad , \tag{A.25}$$

where q_t^h is the price of housing and δ_t^h the rate at which housing units depreciated defined in

(A.123).

The FOC for savers wrt. capital is

$$\lambda_t^s(q_t^k + s_t^k) = \beta_s \lambda_{t+1}^s (1 - \delta_{t+1}^k) q_{t+1}^k \quad , \tag{A.26}$$

where q_t^k is the cost of capital, s_t^k the management firms revenues and δ_t^k the rate at which capital units depreciated defined in (A.122).

The budget constraint for savers is

$$\begin{aligned} &c_t^s\, P_t + k_t^s\,(q_t^k + s_t^k) - (C_t^e + C_t^b)/n_s + q_t^h(h_t^s - (1 - \delta_t^h)h_{t-1}^s) + D_t \\ =&w_t\, l_t^s + (r_t^k + (1 - \delta_t^k)q_t^k)k_{t-1}^s + R_t^{DD}\, D_{t-1} - T_t \frac{a_s}{n_s} + G_t^I + G_t^h + G_t^k \quad , \end{aligned} \tag{A.27}$$

where k_t^s is the quantity of capital, C_t^e and C_t^e are respectively the dividends of entrepreneurs and bankers, n_s is the number of savers, D_t is the quantity of deposits, r_t^k is the rental rate of capital, T_t is the deposit insurance payment, a_s is the parameter that regulates how the deposit insurance cost is divided between savers and borrowers, G_t^I is the flow of profits from investments, G_t^h is the flow of profits from housing investment and G_K the flow of profits from capital management firms.

The default cut-off for borrowers is

$$\bar{w}_t^m = \frac{x_{t-1}^m}{R_t^h} \quad , \tag{A.28}$$

where x_{t-1}^m is the borrowers leverage

$$x_t^m = \frac{b_t^m R_t^m}{h_t^m q_t^h} \quad , \tag{A.29}$$

R_t^h is the rate of return on housing

$$R_t^h = \frac{(1 - \delta_t^h) q_t^h}{q_{t-1}^h} \quad , \tag{A.30}$$

and R_t^m is the borrowers' interest rate on loans.

The FOC for borrowers wrt. consumption is

$$\lambda_t^m\, P_t = U_c^m(t) \quad , \tag{A.31}$$

where λ_t^m is the borrowers' Lagrange multiplier for the budget constrain.

The FOC for borrowers wrt. labour is

$$U_l^m(t) = w_t\,\lambda_t^m + \xi_t^m \frac{f_{LTI}\zeta_{LTI}}{l_t^m} \quad . \tag{A.32}$$

The FOC for borrowers wrt. housing is

$$\begin{aligned}
&U_h^m(t) - \lambda_t^m q_t^h + \beta_m \lambda_{t+1}^m \left((1-\Gamma_{t+1}^m)R_{t+1}^h q_t^h - (\Gamma_{t+1}^m)'\left(-\bar{\omega}_{t+1}^m R_{t+1}^h q_t^h\right)\right)\\
&+\xi_t^m \frac{f_{LTV}\zeta_{LTV}}{h_t^m - (1-\delta_t^h)h_{t-1}^m} - \xi_{t+1}^m \beta_m (1-\delta_{t+1}^h)\frac{f_{LTV}\zeta_{LTV}}{h_{t+1}^m - (1-\delta_{t+1}^h)h_t^m}\\
&+\xi_t^m \left((1-\Gamma_{t+1}^h)R_{t+1}^h q_t^h\left((\Gamma_{t+1}^m - \mu_m\,G_{t+1}^m) + \left((\Gamma_{t+1}^m)' - \mu_m\,(G_{t+1}^m)'\right)(-\bar{\omega}_{t+1}^m)\right)\right) = 0 \quad ,
\end{aligned} \tag{A.33}$$

where Γ_t^m and $(\Gamma_{t+1}^m)'$ are defined in (A.103, A.107), G_t^m and $(G_t^m)'$ are defined in (A.111, A.115), Γ_t^h is defined in (A.106), ξ_t^m is the Laplace multiplier for the bank participation constraint, f_{LTV} is the flag that activates the LTV, ζ_{LTV} the LTV penalty constant and μ_m the proportional verification cost incurred in the repossession of the fraction G_{t+1}^m of housing units.

The FOC for borrowers wrt. the debt level is

$$\begin{aligned}
&\lambda_t^m - \beta\lambda_{t+1}^m(\Gamma_{t+1}^m)'\frac{\bar{\omega}_{t+1}^m}{b_m}R_{t+1}^h q_t^h h_t^m - \xi_t^m \frac{f_{LTV}\zeta_{LTV}}{b_t^m - (1-\delta_B)b_{t-1}^m} + \xi_{t+1}^m \beta_m(\delta_B)\frac{f_{LTV}\zeta_{LTV}}{b_{t+1}^m - (1-\delta_B)b_t^m}\\
&\xi_t^m \frac{f_{LTI}\zeta_{LTI}}{b_t^m - (1-\delta_B)b_{t-1}^m} + \xi_{t+1}^m \beta_m(\delta_B)\frac{f_{LTI}\zeta_{LTI}}{b_{t+1}^m - (1-\delta_B)b_t^m}\\
&-\xi_t^m \left(\rho_{t+1}^h \phi_H\right) - \left(1-\Gamma_{t+1}^h\right)\left(\Gamma_{t+1}^m - \mu_m\,G_{t+1}^m\right)\frac{\bar{\omega}_{t+1}^m}{b_m}R_{t+1}^h q_t^h h_t^m \quad .
\end{aligned} \tag{A.34}$$

where b_t^m is the debt level of borrowers, δ_B is the fraction of loans that expire every quarter, ρ_{t+1}^h is the return on equity of banks that lends of retail banks and ϕ_H is the capital requirement of retail banks.

The budget constraint borrowers is

$$c_t^m\,P_t + q_t^h\,h_t^m - (1-\Gamma_t^m)R_t^h\,q_{t-1}^h h_{t-1}^m = w\,l_t^m + b_t^m - T_t\frac{a_m}{n_m} \quad , \tag{A.35}$$

where a_m is the share of deposit insurance paid by borrowers and n_m the number of borrowers.

The rate of return on capital is

$$R_t^k = (r_K + (1-\delta_t^k)q_t^k)/q_{t-1}^k \quad . \tag{A.36}$$

The default cut-off for entrepreneurs is

$$\bar{\omega}_t^e = x_{t-1}^e / R_t^k \quad , \tag{A.37}$$

where x_t^e is entrepreneurs' leverage

$$x_t^e = \frac{R_t^f (q_t^k\, k_t^e - n_e)}{q_t^k\, k_t^e} \quad , \tag{A.38}$$

k_t^e is the entrepreneurs capital and R_t^f is the rate on entrepreneurs' loans.

The FOC for entrepreneurs wrt. capital is

$$\begin{aligned} &(1-\Gamma_{t+1}^e)R_{t+1}^k - (\Gamma_{t+1}^e)' k_t^e\, R_{t+1}^k \frac{R_t^f n_e}{q_t^k (k_t^e)^2 R_{t+1}^k} \\ &+\xi_t^e \left((1-\Gamma_{t+1}^f)R_{t+1}^k \left((\Gamma_{t+1}^e - \mu_e G_{t+1}^e) + ((\Gamma_{t+1}^e)' - \mu_e (G_{t+1}^e)') \frac{R_t^f n_e}{q_t^k (k_t^e)^2 R_{t+1}^k} k_t^e \right) - \rho_{t+1}^f \phi_t^f \right) \quad , \end{aligned} \tag{A.39}$$

where ξ_t^e is the Laplace multiplier for the corporate bank participation constraint, Γ_t^e and $(\Gamma_t^e)'$ are defined in (A.104, A.108), G_t^e and $(G_t^e)'$ are defined in (A.112, A.116), Γ_t^f is defined in (A.105), μ_e is the proportional verification costs incurred by the bank on its portfolio of loans to entrepreneurs, ρ_f is the return on equity for corporate banks and ϕ_t^f the regulatory capital for corporate banks.

The wealth of entrepreneurs before dividend is

$$W_t^e = (1-\Gamma_t^e)R_t^k q_t^k k_{t-1}^e \quad . \tag{A.40}$$

The net worth of entrepreneurs is

$$n_t^e = (1-\chi_e)W_t^e \quad , \tag{A.41}$$

where χ_e is the portion of paid dividends.

Corporate dividends are

$$C_t^e = \chi_e W_t^e \quad . \tag{A.42}$$

The inflation is defined as

$$\Pi_t = \frac{P_t}{P_{t-1}} \quad . \tag{A.43}$$

The housing inflation is

$$\Pi_t^h = \frac{q_t^h}{q_{t-1}^h} \quad . \tag{A.44}$$

Monetary policy is enforced with a Taylor rule

$$\frac{R_t}{R_0} = \left(\frac{R_{t-1}}{R_0}\right)^{\phi_R} \left(\frac{\Pi t}{\Pi_0}\left(\frac{C_t}{C_t + H_t}\right)^{f_{hi}} + \frac{\Pi_t^h}{\Pi_h^0}\frac{H_t}{C_t + H_t} f_{hi}\right)^{\phi_\Pi} \left(\frac{GDP_t}{GDP_0}\right)^{\phi_{GDP}} + \epsilon_{IR} \quad , \tag{A.45}$$

where GDP_{acc} is the GDP, ϕ_R, ϕ_Π, ϕ_{GDP} are the three Taylor rule parameters, f_{hi} the flag that add housing inflation to the Taylor rule, C_t the total consumption, H_t the total quantity of houses, and ϵ_{IR} is a monetary policy shock.

The optimal inflation is

$$\Pi_t^* = \frac{\epsilon_p}{\epsilon_p - 1}\frac{X_t^1}{X_t^2} \quad , \tag{A.46}$$

where ϵ_p is the Calvo pricing parameter,

$$X_t^1 = \frac{P_t^w}{P_t} Y_t + \Lambda_{t,t+1}\phi_I \Pi_{t+1}^{\epsilon_p} X_{t+1}^1 \quad , \tag{A.47}$$

$$X_t^2 = Y_t + \Lambda_{t,t+1}\phi_I \Pi_{t+1}^{\epsilon_p - 1} X_{t+1}^2 \quad , \tag{A.48}$$

P_t^w is the wholesale price, ϕ_I is the proportion of firm not able to adjust optimally the price and Y_t the output.

The staggered prices are set by

$$1 = (1 - \phi_I)(\Pi_t^*)^{1-\epsilon_p} + \phi_I \Pi_t^{\epsilon_p - 1} \quad . \tag{A.49}$$

The wealth of NFC bankers before dividends is

$$W_t^{bf} = \rho_t^f n_{t-1}^{bf} \quad , \tag{A.50}$$

and the wealth of HH bankers before dividends is

$$W_t^{bh} = \rho_t^h n_{t-1}^{bh} \quad , \tag{A.51}$$

where

$$n_t^{bf} = (1 - \chi_b) W_t^{bf} \tag{A.52}$$

is the net worth of NFC bankers allocated to lending,

$$n_t^{bh} = (1 - \chi_b) W_t^{bh} \tag{A.53}$$

is the net worth of NFC bankers allocated to lending and χ_b is the fraction of wealth distributed as dividend. The market clearing in corporate bank equity market is

$$n_t^{bf} = \phi_t^F (q_t^k K_t^t - n_t^e) \tag{A.54}$$

and the market clearing in HH bank equity market

$$n_t^{bh} = \phi_t^H (b_t^m) \quad . \tag{A.55}$$

The total wealth of bankers is

$$W_t^b = W_t^{bf} + W_t^{bh} \tag{A.56}$$

and the total bankers net worth allocated to lending

$$n_t^b = n_t^{bf} + n_t^{bh} \quad . \tag{A.57}$$

The banks dividends are

$$C_t^b = \chi_b W_t^b \quad . \tag{A.58}$$

The default threshold for corporate banks is

$$\bar{\omega}_t^f = (1 - \phi_{t-1}^f) \frac{R_{t-1}^D}{\tilde{R}_f^t} \quad , \tag{A.59}$$

where $\tilde{R}_f^t$ is the rate of return of corporate loans. The default threshold for retail banks is

$$\bar{\omega}_t^h = (1 - \phi_{t-1}^h) \frac{R_{t-1}^D}{\tilde{R}_t^h} \quad , \tag{A.60}$$

where $\tilde{R}_t^h$ is the rate of return of mortgage loans.

The rate of return of corporate bank equity is

$$\rho_t^f = (1 - \Gamma_t^f) \frac{\tilde{R}_t^e}{\phi_t^f} \quad . \tag{A.61}$$

The rate of return of retail bank equity is

$$\rho_t^h = (1 - \Gamma_t^h) \frac{\tilde{R}_t^h}{\phi_t^h} \quad . \tag{A.62}$$

The rate of return of mortgage loans is

$$\tilde{R}_t^h = (\Gamma_t^m - \mu_m G_t^m) \frac{R_t^h \, q_{t-1}^h h_{t-1}^m}{b_{t-1}^m} - f_{LTV} \zeta_{LTV} \log \frac{LTV_{t-1}^m}{E_{LTV}} - f_{LTI} \zeta_{LTI} \log \frac{LTI_{t-1}^m}{E_{LTI}} \quad , \tag{A.63}$$

where LTV_t^m is the LTV of borrowers in (A.66), E_{LTV} is the LTV threshold, LTI_t^m is the LTV of borrowers in (A.68) and E_{LTI} is the LTI threshold.

The rate of return of corporate loans is

$$\tilde{R}_t^e = (\Gamma_t^e - \mu_e G_t^e) \frac{R_t^k \, q_{t-1}^k k_{t-1}^e}{q_{t-1}^k k_{t-1}^e - n_{t-1}^e} \quad . \tag{A.64}$$

The balance sheet of bank is

$$n_t^b + n_s D = n_m b_t^m + (q_t^k k_t^e - n_e^t) \quad . \tag{A.65}$$

The LTV of new loans is

$$LTV_t^m = \frac{b_t^m - (1 - \delta_B) b_{t-1}^m}{(h_t^m - (1 - \delta_t^h) h_{t-1}^m) q_t^h} \quad . \tag{A.66}$$

The LTV on the stock is

$$LTV_t^{tot} = \frac{b_t^m}{h_t^m q_t^h} \quad . \tag{A.67}$$

The LTI of new loans is

$$LTI_t^m = \frac{b_t^m - (1-\delta_B)b_{t-1}^m}{\delta_B w_t l_t^m} \quad . \tag{A.68}$$

The LTI on the stock is

$$LTI_t^{tot} = \frac{b_t^m}{w_t l_t^m} \quad . \tag{A.69}$$

Marginal cost retail banks is

$$MC_t^h = 1 + \phi_t^h(\rho_t^h - 1) \quad . \tag{A.70}$$

Marginal cost corporate banks is

$$MC_t^f = 1 + \phi_t^f(\rho_t^f - 1) \quad . \tag{A.71}$$

The optimal borrowers spread is

$$(S_t^h)^* = \frac{Z_t^1}{Z_t^2}\frac{\epsilon_{Sh}}{\epsilon_{Sh} - 1} \quad , \tag{A.72}$$

where ϵ_{S_m} is the retail banks Calvo pricing parameter,

$$Z_t^1 = MC_t^h (S_t^h)^{\epsilon_{Sh}} b_t^m + \Lambda_{t,t+1}\phi_{S_h} Z_{t+1}^1 \quad , \tag{A.73}$$

ϕ_{S_h} is the fraction of banks that adjust interest rate spreads, and

$$Z_t^2 = (S_t^h)^{\epsilon_{Sh}} b_t^m + \Lambda_{t,t+1}\phi_{S_h} Z_{t+1}^2 \quad . \tag{A.74}$$

Finally, the staggered spread is

$$S_t^h = \Big((1-\phi_{Sm})(S_{t-1}^h)^{1-\epsilon_{Sm}} + \phi_{S_h}((S_t^h)^*)^{1-\epsilon_{Sm}}\Big)^{1/(1-\epsilon_{Sm})} \quad . \tag{A.75}$$

The optimal firms interest rate spread is

$$(S_t^f)^* = \frac{W_t^1}{W_t^2}\frac{\epsilon_{Sf}}{\epsilon_{Sf} - 1} \quad , \tag{A.76}$$

where ϵ_{R_e} is the corporate banks Calvo pricing parameter,

$$W_t^1 = MC_t^e (S_t^f)^{\epsilon_{Sf}} b_t^e + \Lambda_{t,t+1}\phi_{S_f} W_{t+1}^1 \quad , \tag{A.77}$$

ϕ_{S_f} is the fraction of banks that adjust interest rate spreads, and

$$W_t^2 = (S_t^f)^{\epsilon_{Sf}} b_t^e + \Lambda_{t,t+1}\phi_{S_f} W_{t+1}^2 \quad . \tag{A.78}$$

The staggered spread is

$$S_t^f = \left((1-\phi_{Re})(S_{t-1}^e)^{1-\epsilon_{Se}} + \phi_{S_f}((S_t^f)^*)^{1-\epsilon_{S_e}}\right)^{1/(1-\epsilon_{S_e})} \quad . \tag{A.79}$$

Finally, the household interest rate is the average cost of deposits plus the spread

$$R_t^m = S_t^h - 1 + R_t^D(1-\phi_t^h) + \phi_t^h \quad , \tag{A.80}$$

and the corporate interest rate is

$$R_t^e = S_t^f - 1 + R_t^D(1-\phi_t^f) + \phi_t^f \quad , \tag{A.81}$$

The wholesale output is

$$Y_t^w = \epsilon_t^A K_{t-1}^\alpha, L_t^\alpha \quad , \tag{A.82}$$

where ϵ_t^A is a technology shock, K_t is the total capital, L_t the total labour and α the elasticity parameter.

The rental rate of capital is

$$r_t^k = \frac{\alpha Y_t^w P_t^w}{K_{t-1}} \quad . \tag{A.83}$$

The wage rate is

$$w_t = \frac{(1-\alpha)Y_t^w P - w_t}{L_t} \quad . \tag{A.84}$$

The price dispersion is

$$\nu_t = (1-\phi_I)(\Pi_t^*)^{-\epsilon_p} + \phi_I \Pi_t^{\epsilon_p} \nu_{t-1} \quad . \tag{A.85}$$

The real output is

$$Y_t \nu_t = Y_t^w \quad . \tag{A.86}$$

The capital price evolution is

$$q_t^k (\delta_t^k)^{1/\psi_i} \left(\frac{I_t}{K_{t-1}}\right)^{-1/\psi_i} = 1 \quad , \tag{A.87}$$

where ψ_i is the Jermann (1998) concavity cost parameter for investment and I_t is the investment. The capital stock evolution is

$$K_t = (1-\delta_t^k)K_{t-1} + \left(\frac{(\delta_t^k)^{1/\psi_i}}{1-1/\psi_i} \left(\frac{I_t}{K_{t-1}} \right)^{1-1/\psi_i} + \frac{(\delta_t^k)^{1/\psi_i}}{1-1/\psi_i} (\delta_t^k)^{1-1/\psi_i} \right) K_{t-1} \tag{A.88}$$

The flow of profit from investment is

$$G_t^I = q_t^k \left(\frac{(\delta_t^k)^{1/\psi_i}}{1-1/\psi_i} \left(\frac{I_t}{K_{t-1}} \right)^{1-1/\psi_i} + \left(\delta_t^k - \left(\frac{I_t}{K_{t-1}} \right)^{1-1/\psi_i} (\delta_t^k)^{1-1/\psi_i} \right) \right) K_{t-1} - I_t \ . \tag{A.89}$$

The capital market clearing is

$$K_t = k_t^s + k_t^e \ . \tag{A.90}$$

The flow of profits from capital management firms is

$$G_t^k = s_t^k k_t^s - z_t^k \ , \tag{A.91}$$

where

$$s_t^k = \xi_k (k_t^s)^{\phi_k - 1} \ , \tag{A.92}$$

ξ_k is the management cost multiplicative parameter, ϕ_K is management cost convexity parameter and

$$z_t^k = \frac{\xi_k}{\phi_k} (k_t^s)^{\phi_k} \ . \tag{A.93}$$

The aggregate consumption is

$$C_t = c_t^s n_s + c_t^m n_m \ . \tag{A.94}$$

The aggregate labour supply is

$$L_t = l_t^s n_s + l_t^m n_m \ . \tag{A.95}$$

The housing price evolution is

$$q_t^h (\delta_t^h)^{1/\psi_h} \left(\frac{IH_t}{H_{t-1}} \right)^{-1/\psi_h} = 1 \ , \tag{A.96}$$

where ψ_h is the Jermann (1998) concavity cost parameter for housing investment and IH_t is the housing investment.

The housing stock evolution is

$$H_t = (1-\delta_t^h)H_{t-1} + \left(\frac{(\delta_t^h)^{1/\psi_h}}{1-1/\psi_h} \left(\frac{IH_t}{H_{t-1}} \right)^{1-1/\psi_h} + \frac{(\delta_t^h)^{1/\psi_h}}{1-1/\psi_h} (\delta_t^h)^{1-1/\psi_h} \right) H_{t-1} \tag{A.97}$$

The flow of profit from housing investment is

$$G_{IH}^t = q_t^h \left(\frac{(\delta_t^h)^{1/\psi_h}}{1-1/\psi_h} \left(\frac{IH_t}{H_{t-1}} \right)^{1-1/\psi_h} + \left(\delta_h - \left(\frac{IH_t}{H_{t-1}} \right)^{1-1/\psi_h} (\delta_t^h)^{1-1/\psi_h} \right) \right) H_{t-1} - IH_t \ . \tag{A.98}$$

The housing market clearing is

$$H_t = h_t^m n_m + h_t^s n_s \ . \tag{A.99}$$

The deposit insurance transfers to corporate bank depositors is

$$T_f^t = (\bar{\omega}_t^f - \Gamma_t^f + \mu_f G_t^f)\tilde{R}_t^f (q_{t-1}^k k_{t-1}^e - (1-\chi_e)W_{t-1}^e) \ , \tag{A.100}$$

where G_t^f is defined in (A.113).

The deposit insurance transfers to retail bank depositors is

$$T_h^t = (\bar{\omega}_t^h - \Gamma_t^h + \mu_h G_t^h)\tilde{R}_t^h \frac{n_m h_{t-1}^m q_{t-1}^h x_{t-1}^m}{R_{t-1}^m} \ , \tag{A.101}$$

where G_t^h is defined in (A.114).

The aggregate deposit insurance is

$$T_t = T_t^h + T_t^f - f_{LTV}\zeta_{LTV} \log \frac{LTV_t^m}{E_{LTV}} - f_{LTI}\zeta_{LTI} \log \frac{LTI_t^m}{E_{LTI}} \ . \tag{A.102}$$

The different distribution functions follows:

$$\Gamma_t^m = N\left(\frac{log\left(\bar{\omega}_t^m\right) - \frac{(\epsilon_t^{Sm}\sigma_{m1})^2}{2}}{\epsilon_t^{Sm}\sigma_{m1}}\right) + \bar{\omega}_t^m\left(1 - N\left(\frac{log\left(\bar{\omega}_t^m\right) + \frac{(\epsilon_t^{Sm}\sigma_{m1})^2}{2}}{\epsilon_t^{Sm}\sigma_{m1}}\right)\right) \tag{A.103}$$

$$\Gamma_t^e = N\left(\frac{log\left(\bar{\omega}_t^e\right) - \frac{(\epsilon_t^{Se}\sigma_{e1})^2}{2}}{\epsilon_t^{Se}\sigma_{e1}}\right) + \bar{\omega}_t^e\left(1 - N\left(\frac{log\left(\bar{\omega}_t^e\right) + \frac{(\epsilon_t^{Se}\sigma_{e1})^2}{2}}{\epsilon_t^{Se}\sigma_{e1}}\right)\right) \tag{A.104}$$

$$\Gamma_t^f = N\left(\frac{log\left(\bar{\omega}_t^f\right) - \frac{(\epsilon_t^{Sf}\sigma_{f1})^2}{2}}{\epsilon_t^{Sf}\sigma_{f1}}\right) + \bar{\omega}_t^f\left(1 - N\left(\frac{log\left(\bar{\omega}_t^f\right) + \frac{(\epsilon_t^{Sf}\sigma_{f1})^2}{2}}{\epsilon_t^{Sf}\sigma_{f1}}\right)\right) \tag{A.105}$$

$$\Gamma_t^h = N\left(\frac{log\left(\bar{\omega}_t^h\right) - \frac{(\epsilon_t^{Sh}\sigma_{h1})^2}{2}}{\epsilon_t^{Sh}\sigma_{h1}}\right) + \bar{\omega}_t^h\left(1 - N\left(\frac{log\left(\bar{\omega}_t^h\right) + \frac{(\epsilon_t^{Sh}\sigma_{h1})^2}{2}}{\epsilon_t^{Sh}\sigma_{h1}}\right)\right) \tag{A.106}$$

$$(\Gamma_t^m)' = \left(N'\left(\frac{log\left(\bar{\omega}_t^m\right) - \frac{(\epsilon_t^{Sm}\sigma_{m1})^2}{2}}{\epsilon_t^{Sm}\sigma_{m1}}\right) - \bar{\omega}_t^m N\left(\frac{log\left(\bar{\omega}_t^m\right) + \frac{(\epsilon_t^{Sm}\sigma_{m1})^2}{2}}{\epsilon_t^{Sm}\sigma_{m1}}\right)\right) / (\epsilon_t^{Sm}\sigma_{m1}\bar{\omega}_t^m) \tag{A.107}$$

$$+ \left(1 - N\left(\frac{log\left(\bar{\omega}_t^m\right) + \frac{(\epsilon_t^{Sm}\sigma_{m1})^2}{2}}{\epsilon_t^{Sm}\sigma_{m1}}\right)\right)$$

$$(\Gamma_t^e)' = \left(N'\left(\frac{log\left(\bar{\omega}_t^e\right) - \frac{(\epsilon_t^{Se}\sigma_{m1})^2}{2}}{\epsilon_t^{Se}\sigma_{e1}}\right) - \bar{\omega}_t^e N\left(\frac{log\left(\bar{\omega}_t^e\right) + \frac{(\epsilon_t^{Se}\sigma_{m1})^2}{2}}{\epsilon_t^{Se}\sigma_{e1}}\right)\right) / (\epsilon_t^{Se}\sigma_{e1}\bar{\omega}_t^e) \tag{A.108}$$

$$+ \left(1 - N\left(\frac{log\left(\bar{\omega}_t^e\right) + \frac{(\epsilon_t^{Se}\sigma_{e1})^2}{2}}{\epsilon_t^{Se}\sigma_{e1}}\right)\right)$$

$$(\Gamma_t^f)' = \left(N'\left(\frac{log\left(\bar{\omega}_t^f\right) - \frac{(\epsilon_t^{Sf}\sigma_{f1})^2}{2}}{\epsilon_t^{Sf}\sigma_{hf}}\right) - \bar{\omega}_t^f N\left(\frac{log\left(\bar{\omega}_t^f\right) + \frac{(\epsilon_t^{Sf}\sigma_{h1})^2}{2}}{\epsilon_t^{Sf}\sigma_{f1}}\right)\right) / (\epsilon_t^{Sf}\sigma_{f1}\bar{\omega}_t^f) \tag{A.109}$$

$$+ \left(1 - N\left(\frac{log\left(\bar{\omega}_t^f\right) + \frac{(\epsilon_t^{Sf}\sigma_{f1})^2}{2}}{\epsilon_t^{Sf}\sigma_{f1}}\right)\right)$$

$$(\Gamma_t^h)' = \left(N'\left(\frac{log\left(\bar{\omega}_t^h\right) - \frac{(\epsilon_t^{Sh}\sigma_{h1})^2}{2}}{\epsilon_t^{S}\sigma_{m1}}\right) - \bar{\omega}_t^m N\left(\frac{log\left(\bar{\omega}_t^h\right) + \frac{(\epsilon_t^{Sh}\sigma_{h1})^2}{2}}{\epsilon_t^{Sh}\sigma_{h1}}\right)\right) / (\epsilon_t^{Sh}\sigma_{h1}\bar{\omega}_t^h) \tag{A.110}$$

$$+ \left(1 - N\left(\frac{log\left(\bar{\omega}_t^h\right) + \frac{(\epsilon_t^{Sh}\sigma_{h1})^2}{2}}{\epsilon_t^{Sh}\sigma_{h1}}\right)\right)$$

$$G_t^m = N\left(\frac{log\left(\bar{\omega}_t^m\right) - \frac{(\epsilon_t^{Sm}\sigma_{m1})^2}{2}}{\epsilon_t^{Sm}\sigma_{m1}}\right) \tag{A.111}$$

$$G_t^e = N\left(\frac{log\left(\bar{\omega}_t^e\right) - \frac{(\epsilon_t^{Se}\sigma_{e1})^2}{2}}{\epsilon_t^{Se}\sigma_{e1}}\right) \tag{A.112}$$

$$G_t^f = N\left(\frac{log\left(\bar{\omega}_t^f\right) - \frac{(\epsilon_t^{Sf}\sigma_{f1})^2}{2}}{\epsilon_t^{Sf}\sigma_{f1}}\right) \tag{A.113}$$

$$G_t^h = N\left(\frac{log\left(\bar{\omega}_t^h\right) - \frac{(\epsilon_t^{Sh}\sigma_{h1})^2}{2}}{\epsilon_t^{Sh}\sigma_{h1}}\right) \tag{A.114}$$

$$(G_t^m)' = N'\left(\frac{log\left(\bar{\omega}_t^m\right) - \frac{(\epsilon_t^{Sm}\sigma_{m1})^2}{2}}{\epsilon_t^{Sm}\sigma_{m1}}\right) / (\epsilon_t^{Sm}\sigma_{m1}\bar{\omega}_t^m) \tag{A.115}$$

$$(G_t^e)' = N'\left(\frac{log\left(\bar{\omega}_t^e\right) - \frac{(\epsilon_t^{Se}\sigma_{e1})^2}{2}}{\epsilon_t^{Se}\sigma_{e1}}\right) / (\epsilon_t^{Se}\sigma_{e1}\bar{\omega}_t^e) \quad , \tag{A.116}$$

where σ_{m1}, σ_{e1}, σ_{f1} and σ_{h1} are the Bernanke *et al.* (1999) standard deviations respectively for borrowers, entrepreneurs, corporate and retail banks. ϵ_t^{Sm}, ϵ_t^{Se}, ϵ_t^{Sf} and ϵ_t^{Sh} are shocks on the standard deviations respectively of borrowers, entrepreneurs, corporate and retail banks.

The capital requirements on retail banks are

$$\phi_t^h = (1 - f_{sec})\phi_t^f RW_t + f_{sec} RW_t \left(\phi_{Fs} + \varphi_S \log \frac{b_t^m}{b_0^m}\right) \quad , \tag{A.117}$$

where f_{sec} is the flag that activates and deactivates sectoral buffers, RW_t are the risk weights for mortgages loans φ_{Fs} is the baseline capital requirement for corporate loans and φ_S is the S-CCyB coefficient. The risk weights are

$$RW_t = (1 - \rho_r w)(rw + \epsilon_t^{rw}) + \rho_r w RW_{t-1} \quad , \tag{A.118}$$

where $\rho_r w$ is the risk weight autocorrelation parameter, rw risk weight parameter and ϵ_t^{rw} is a risk weight shock.

The capital requirements on corporate banks are

$$\phi_t^f = \rho_{CR}\phi_{t-1}^f + (1 - \rho_{CR})\left(\phi_{Fs} + (\epsilon_t^{CR} + \epsilon_{t-1}^{CR} + \epsilon_{t-2}^{CR} + \epsilon_{t-3}^{CR}) + \varphi_F \log \frac{b_t GDP_0}{b_0 GDP_t}\right) \quad , \tag{A.119}$$

where b_t is the total debt, ϵ_{CR} is a capital requirement shock and φ_F the CCyB coefficient.

The aggregate loans are

$$b_t = b_t^m + b_t^e \quad , \tag{A.120}$$

where

$$b_t^e = q_t^k k_t^e - n_t^e \quad . \tag{A.121}$$

The capital depreciation is

$$\delta_t^k = \bar{\delta}_k + \epsilon_t^{dk} \quad , \tag{A.122}$$

where $\bar{\delta}_k$ is a constant and ϵ_t^{dk} is a shock on capital depreciation. The housing depreciation is

$$\delta_t^h = \bar{\delta}_h + \epsilon_t^{dh} \quad , \tag{A.123}$$

where $\bar{\delta}_h$ is a constant and ϵ_t^{dh} is a shock on housing depreciation.

Appendix B BBMs as constraints on borrowers in the 3D model

In this appendix we show that, in the 3D model with banks facing capital requirements and borrower-based measures imposed as constraints on borrowers as in Iacoviello(2005), either the borrowers' constraint or the bank participation constraint is not binding.

Proof. We recall that borrowers optimizes their utility over consumption c_t^m,labour l_t^m, house quantity h_t^m, and debt b_t^m. We consider the bank participation constraints as in (3.6) but without the term depending from the LTV pecuniary cost

$$(1 - \Gamma_t^h)(\Gamma_t^m - \mu_m G_t^m) R_t^h q_t^h h_{t-1}^m = \rho_t^h \phi_t^h b_t^m \quad ,$$

and an LTV constraint as

$$LTV_t = E_{LTV} \quad .$$

For the sake of simplicity we work in the steady state and we consider $q_0^h = 1$ and $\delta_b = \delta_0^h$ but the same reasoning can be applied to any time t and any q_0^h or δ_b. We prove the thesis by contradiction by assuming that both constrains are binding.
In the steady state

$$LTV_t = \frac{b_0^m R_0^m}{h_0^m} = E_{LTV} \quad .$$

Moreover, Γ_0^m in A.103, G_0^m in (A.111), Γ_0^h in (A.106) and ρ_0^h depend from the ratio $\frac{b_0^m R_0^m}{h_0^m}$ and do not depend from consumption c_m^0 or labour l_0^m. Hence, we can rewrite the bank participation constraint in terms of E_{LTV}

$$(1-\Gamma_0^h(E_{LTV}))(\Gamma_0^m(E_{LTV})-\mu_m G_0^m(E_{LTV}))E_{LTV}=\rho_0^h((E_{LTV})(RW_0\phi_{Fs}) \ ,$$

where we have stressed the dependency of all terms from E_{LTV}. Then, the bank participation constraint does not depend from any of the quantities borrowers are optimizing from and it is not a feasible constraint. This proves the thesis □

Let us notice that the same holds in the case of an LTI constratint.

Appendix C Calibrated Parameters

In this appendix we report the model parameters and the first order moments used in the calibration. The model has been calibrated on quarterly EA macroeconomic time-series for a time-span that goes from 2001 to 2020 (included). All series are in real terms and we have de-trended their log value. We fix a number of parameters consistently with the literature and calibrate the rest on the macroeconomic time-series.[22] Model parameters are available in table 5.

In table 6, we report the first order moments used in the calibration and the steady state LTV and LTI (when the LTI and LTV constraint are active).

Appendix D Effects of staggered spreads on the transmission of capital requirements

Figure 13 depicts credit to NFC, credit to HH, the spread on HH loans and the spread on NFC loans when increasing capital requirements by 0.5 p.p, for different values of the parameter ϕ representing the degree of interest spread stickiness. Values $0 < \phi_{S_h} < 1$ result in different degrees of interest spread stickiness that tends asymptotically to the same long-run value. When $\phi_{S_h} = 1$, spreads are set without any degree of stickiness and banks immediately adjust the spread to the optimal one thanks to the forward-looking nature of the model. A higher degree

[22] Details are available upon request.

Description	Variable	Value
Savers Utility Weight of Housing	v^s	0.18
Borrowers Utility Weight of Housing	v^m	0.58
Variance of Household Idiosyncratic Shocks	σ^2_{m1}	0.2
Dividend Payout of Entrepreneurs	X^e	0.036
Number of borrowers	n_m	0.77
Variance of Entrepreneurial Risk Shock	σ^2_{e1}	0.38
Capital Requirement for Mortgage Loans	ϕ_{Hs}	0.07
Capital Requirement for Corporate Loans	ϕ_{Fs}	0.14
Borrowers discount factor	β_m	0.97
Housing Depreciation Rate	δ_h	0.08
Dividend Payout of Bankers	χ^b	0.02
Variance of Mortgage Bank Risk Shock	σ^2_h	0.3
Variance of Corporate Bank Risk Shock	σ^2_f	0.5
Management cost of capital	ξ_k	0.0113
Patient Household Discount Factor	β_s	0.995
Impatient Household Discount Factor	β_s	0.97
Patient Household Marginal Disutility of Labour	φ_s	1
Impatient Household Marginal Disutility of Labourr	φ_m	1
Inverse of Frisch Elasticity of Labour	η	1
Depositor Cost of Bank Default	pp	0.00025
Household Bankruptcy Cost	μ_m	0.3
Entrepreneur Bankruptcy Cost	μ_s	0.3
Mortgage Bank Bankruptcy Cost	μ_h	0.3
Corporate Bank Bankruptcy Cost	μ_h	0.3
Dividend Payout of Entrepreneur	X^e	0.036
Capital Share in Production	α	0.3
Capital Depreciation Rate	δ^k	0.03
Capital Adjustment Cost Parameter	ψ_i	5
Housing Depreciation Rate	δ^k	0.008
Housing Adjustment Cost Parameter	ψ_h	2

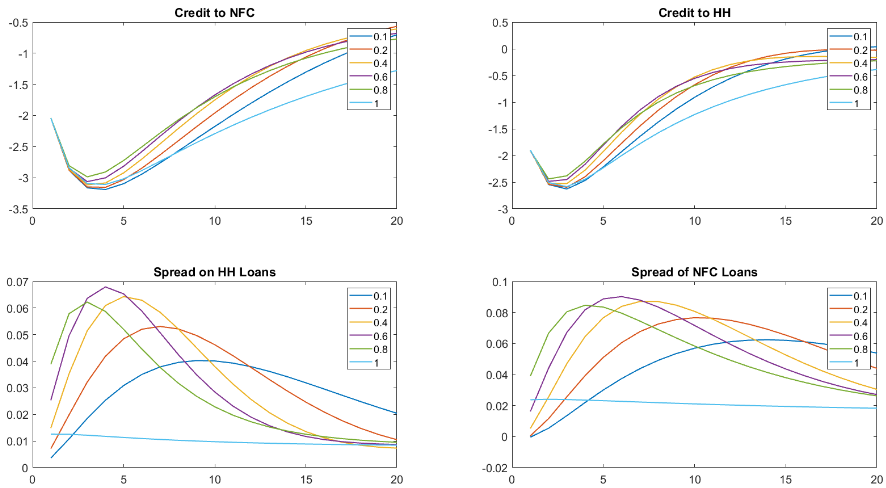
Table 5: Model parameters.

Description	Value
Fraction of borrowers	43.7%
Return on average Equity	6.4%
Capital Requirement Ratio	14.1%
Write-off for households (annualized)	0.4%
Write-off for entrepreneurs (annualized)	0.7%
NFC loans to GDP ratio	1.7
Mortgages to GDP ratio	2.1
Investment in Housing to GDP ratio	0.1
Housing wealth held by borrowers	0.5
Spread corporate loans (annualized)	1.3%
Spread retail loans (annualized)	0.7%
LTV	0.55
LTI	4.4

Table 6: First order moments used for the calibration and steady state LTV and LTI.

of stickiness (i.e. lower values of ϕ) results in a slower adjustment of interest rate spreads. While the impact effect on credit is not materially affected, a higher degree of stickiness results in more sluggishness in the response of credit, which takes longer to reach its peak and to return to the initial levels.

Figure 13: Sensitivity to interest spread stickiness parameter.

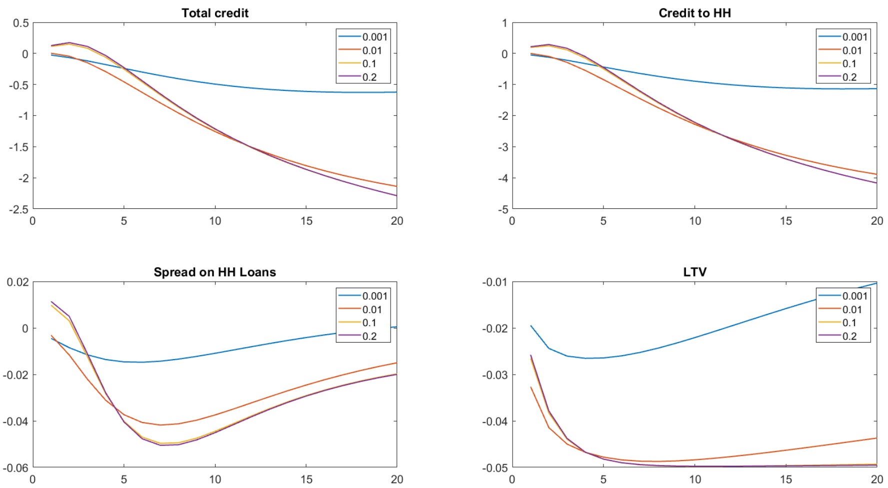


Note: effect of tightening capital requirements for different degrees of interest spread stickiness. X-axis: quarters; y-axis: annualized percentage deviation from the steady state for the spread on HH and NFC loans; percentage deviation from the steady state for credit to HHs and to NFCs. Transition path of total credit, credit to HH, spread on HH loans and NFC loans when increasing capital requirements by 0.5 p.p. for different spread stickiness (from 0.1 to 1). In the baseline model we set the stickiness parameter to 0.4.

Appendix E Effects of LTI and LTI penalty on BBM transmission

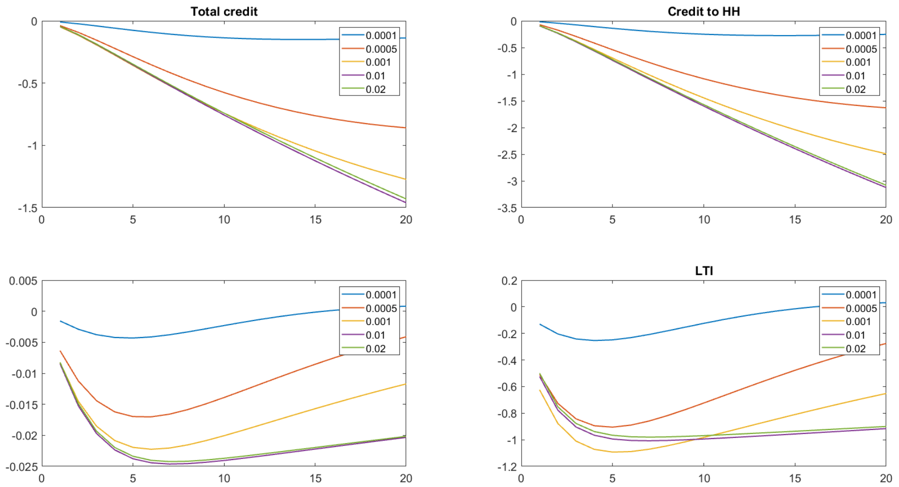
Figures 14 and 15 depict the impact on total credit, credit to households, the spread on mortgage loans and the LTV (LTI) when tightening LTV (LTI) limit by 5 p.p. (1 point) for different penalty parameters.

Figure 14: Sensitivity to LTV penalty parameter.



Note: effect of tightening LTV for different values of the penalty parameters. X-axis: quarters; y-axis: percentage deviation from the steady state for totalcredit, credit to HHs and spread (annualized), deviation from steady state of LTV. Transition path of total credit, credit to HH, spread on HH loans and LTV when tightening LTV limit by 5 p.p. for different penalty parameters. In the baseline model we set the penalty parameter to 0.1.

Figure 15: Sensitivity to LTI penalty parameter.



Note: effect of tightening LTI for different values of the penalty parameters. X-axis: quarters; y-axis: percentage deviation from the steady state for total credit, credit to HHs and spread (annualized), deviation from steady state of LTI. Transition path of total credit, credit to HH, spread on HH loans and LTI when tightening LTI limit by 1 point for different penalty parameters. In the baseline model we set the penalty parameter to 0.01.

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