Bank of England

The positive neutral countercyclical capital buffer

Staff Working Paper No. 1,128

May 2025

Manuel A. Muñoz and Frank Smets

Bank of England

Staff Working Paper No. 1,128

The positive neutral countercyclical capital buffer

Manuel A. Muñoz[(1)] and Frank Smets[(2)]

Abstract

We reconcile theory and recent evidence on the benefits of building releasable bank capital buffers when there is headroom for doing so by building a quantitative macro-banking model that provides a rationale for static bank capital requirements and dynamic capital buffers due to externalities arising from bank risk failure and collateral constraints. Optimal dynamic capital buffers gradually build in response to expected upward shifts in bank net interest margins. In the absence of pecuniary externalities due to collateral constraints, such capital buffers are ineffective. The model also captures previous empirical findings such as the negative effect of a capital requirement tightening on short-term lending and the optimality of setting static bank capital requirements at relatively conservative levels. We present an application of our quantitative analysis in the form of a simple framework for calibrating the so-called 'positive neutral counter-cyclical capital buffer' (PN-CCyB).

Key words: Macroprudential policy, pecuniary externalities, borrowing limits, bank default risk, bank lending spread.

JEL classification: E3, E44, E6, G21.

---

(1) Bank of England. Email: manuel.munoz@bankofengland.co.uk

(2) Bank for International Settlements, Ghent University and CEPR. Email: frank.smets@bis.org

The views expressed in this paper are those of the authors and do not necessarily reflect the views of the Bank for International Settlements or the Bank of England. For helpful comments, we thank Iñaki Aldasoro, Neil Esho, Jorge Galan, Todd Keister, Seho Kim, Caterina Mendicino, Matthias Rottner, Valerio Scalone, Rhiannon Sowerbutts, Javier Suárez, Nikola Tarashev, Alejandro Van der Ghote, Matt Waldron, staff members from the macroprudential policy departments of the BoE, BIS, European Commission and ECB and participants at numerous conferences and seminars including those at the 28th Conference 'Theories and Methods in Macroeconomics' (T2M), Banco de España, Bank for International Settlements, Bank of England, Central Bank of Ireland-UCD 2024 Workshop on Macro-finance and financial stability policies, ECB conference on financial stability and macroprudential policy 2024, International Monetary Fund, Spanish Treasury, Universitat de Valencia (MARVEL Workshop 2024), and the VII Workshop of the Spanish Macroeconomics Network. We acknowledge financial support from the European Union and Spanish government grants PID2020-116242RB-I00, PID2023-152348NB-I00 and TED2021-132629B-I00. We are responsible for all remaining errors.

Bank of England, Threadneedle Street, London, EC2R 8AH
Email: enquiries@bankofengland.co.uk

ISSN 1749-9135 (on-line)

1 Introduction

Supported by evidence (Jiménez et al. 2017) and theory (e.g., Elenev et al. 2021), there is a wide consensus that releasing (releasable) bank capital buffers in extraordinary crisis times helps sustain lending to the real economy. In contrast, the question of when and how to build such buffers in normal times (i.e., over a business-cycle frequency) has been subject to intense debate in recent years. Based on the evidence that financial crises are preceded by credit booms (Schularick and Taylor 2012; Jordà et al. 2017; Mian et al. 2017), in 2016 the Basel III Accords gave birth to the countercyclical capital buffer (CCyB); a releasable capital buffer whose adjustments over the cycle were expected to take the credit-to-GDP gap as a key common reference. However, a large number of competent national authorities started to build their capital buffers during the recent tightening cycle as net interest margins began to soar and despite the fact that these and other contractionary shocks were exerting a downward pressure on aggregate demand and credit-gaps were in negative territory (Figure 1).[1]

These actions were generally preceded by a revision of the corresponding national CCyB frameworks and motivated by a series of events.[2] First, the approach to the CCyB based on credit gaps led to inaction; Very few jurisdictions had a positive CCyB in place by the time the COVID-19 shock hit the economy.[3] Second, evidence based on the COVID-19 experience has reconfirmed the benefits of releasing capital buffers in extraordinary crisis times (see Section 2). Third, recent evidence finds that gradually building the CCyB when banks have headroom for doing so has no significant (negative) impact on lending in the very short-term and increases lending over the medium-term through improved banks' resilience (e.g., Bedayo and Galán 2024).

Standard business-cycle macro-banking models that provide a convincing rationale for prudential bank capital regulation by featuring bank risk failure, limited liability and deposit insurance generally find that there are little to no macroeconomic and welfare gains from having a dynamic capital buffer when the optimal static capital requirement is already in place (e.g., Canzoneri et al. 2021; Abad et al. 2024). This is so as the externality they feature (i.e., agents do not internalize the consequences of their individual decisions on the aggregate economic cost of bank risk failure, modelled as a deadweight loss) is most effectively corrected with fixed capital requirements. The

[1] For further details, see the IMF's Macroprudential Policy Survey and BCBS' CCyB Dashboard.

[2] These revisions of national CCyB frameworks have been oriented to ensure the existence of sufficient macroprudential space ahead of the build-up of financial cycle vulnerabilities by introducing a positive CCyB rate in the neutral phase of the cycle or PN-CCyB (e.g.; Check Republic, Cyprus, Estonia, Ireland, Latvia, Lithuania, Netherlands, Slovenia, Spain, Sweden) or by adopting an early activation strategy for the CCyB (Denmark and Norway). A few other countries, including the UK, had already introduced a PN-CCyB before the COVID-19 crisis. For further details and a more comprehensive list, see BCBS (2024). Range of practices in implementing a positive neutral countercyclical capital buffer.

[3] Out of the 89 countries that currently have a CCyB framework in place, only 15 countries had a positive CCyB rate by the time the COVID-19 shock hit the world economy (Edge and Liang 2020).

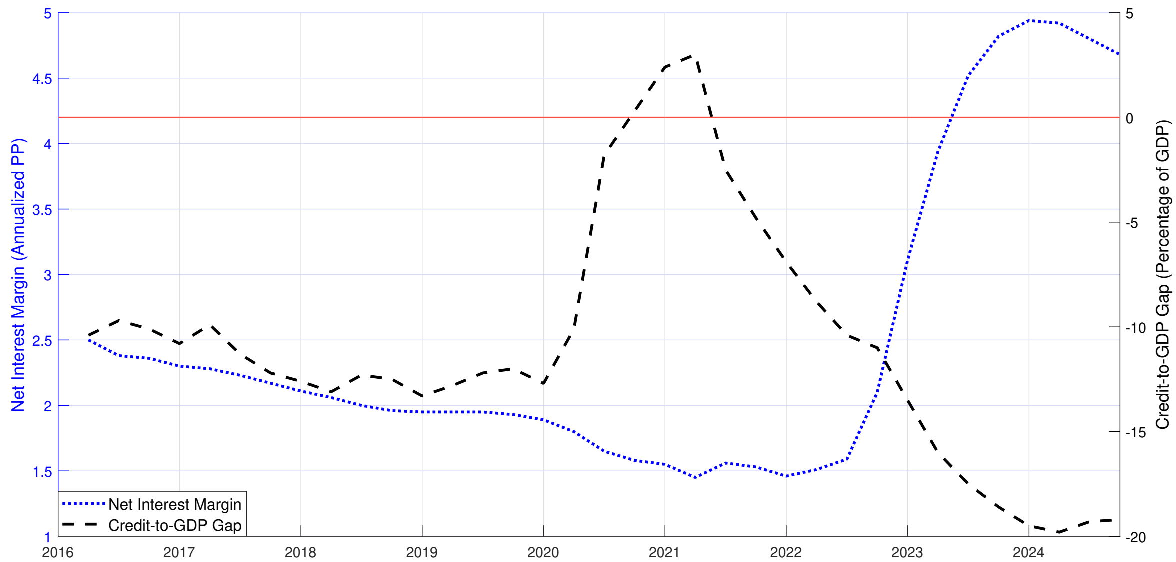
very few exceptions to this result typically find that optimal dynamic capital requirements should respond to macroeconomic indicators such as credit and output (e.g., Davydiuk 2017) and do generally not inspect the role for building such buffers gradually (i.e., capital buffer smoothing). In general, these models do not feature pecuniary externalities due to collateral constraints either because the borrowing limits are not (occassionally) binding or because there are no endogenous price/s entering the constraints.

The main contribution of this paper is to build a simple version of the above mentioned class of quantitative macro-banking models that provides a rationale not only for optimal static capital requirements but also for dynamic capital buffers optimally being built gradually and in response to expected upward shifts in the net interest margin (i.e., when there is headroom for doing so). We distill the full transmission mechanism of these buffers into three main channels that we refer to as the "bank profitability channel", the "aggregate economic cost channel" and "the collateral channel". In the absence of pecuniary externalities originated by collateral constraints, the latter remains inactive, the transmission mechanism does not operate, and dynamic capital buffers are ineffective. By considering different specifications of the collateral market, we identify the different market features that contribute to the stabilization and welfare gains of dynamic capital buffers through the "collateral channel". We show how capital buffer smoothing amplifies these gains and how that matters to the actual calibration of these buffers.

First, we build a quantitative general equilibrium saver-borrower type of model that features collateral constraints and property markets a la Iacoviello (2005) and a banking sector as in Mendicino et al. (2020). Beyond abstracting from nominal rigidities and monetary policy, our model only fundamentally differs from the latter in that entrepreneurs and the collateral market are modelled differently. To focus on the role of pecuniary externalities originated by collateral constraints, we: (i) deviate from the assumption that the asset pledged as collateral (to access bank funding) by entreprenuers is physical capital to allow for empirically-relevant property collateral constraints, and (ii) abstract from the assumption that bank borrowers also face idiosyncratic asset return shocks (Bernanke et al. 1999). We show that - for the purpose of our analysis - there is no "cost" in doing so as we match the same banking data targets with similar calibrated parameter values, capture the same empirical findings, and find the same mechanisms, welfare trade-offs and optimal static capital requirements. That is, to reach the same conclusions on optimal static capital requirements it is sufficient to assume that only banks are subject to the same type of idiosyncratic shocks.[4] Since borrowers (entrepreneurs) discount the future more heavily than savers (households), these borrowing limits are binding in a neighbourhood of the steady state.

[4]This follows from the fact that - for tractability purposes - these models typically assume these shocks to affect bank asset returns independently of the performance of individual loans. For a model that studies the implications of this standard but simplifying assumption for optimal static capital requirements by simultaneously capturing high firm and bank failures, see Mendicino et al. (2024).

Figure 1: Net interest margin and credit-to-GDP gap in the euro area



Notes: Bank net interest margin in the euro area computed as the difference between the NFC loans interest rate and the household deposits interest rate and expressed in annualized percentage points. Credit-to-GDP in the euro area (secondary y-axis), constructed by the BIS (using the the standard methodology made available on its webpage) and expressed as a percentage of GDP. The horizontal red line indicates the level below which the gap is negative. For further details on the data, see Appendix B). Data sources: European Central Bank (MFI Interest Rate Statistics) and BIS statistics.

Then, we study the macroeconomic and welfare consequences of dynamic capital buffers through the lens of a simple policy rule according to which dynamic bank capital requirements comprise a steady state component (i.e., static capital requirements) and a time-varying component that adjusts with a macro-financial indicator of the choice of the regulator (i.e., dynamic capital buffer). Following a similar approach to the one proposed in Schmitt-Grohé and Uribe (2007) for the case of optimal simple monetary and fiscal rules, we assess the welfare effects of these buffers for a large number of candidates for such indicator. As opposed to macroeconomic indicators (e.g., credit-to-GDP gap), bank profitability metrics enable dynamic capital buffers to induce significant welfare gains. Welfare-maximizing dynamic capital requirements are built in response to expected upward shifts in the net interest margin (also referred to as the bank lending spread).

To better understand what is behind this finding, we distill the channels through which adjustments in optimal dynamic capital buffers transmit to the real economy. According to the "bank profitability channel", by adjusting capital requirements in response to expected shifts in the net interest margin, the competent authority has great control over the dynamics of banks'resilience (proxied by the bank default probability). This follows from the fact that the expected threshold for the idiosyncratic bank asset return shocks below which intermediaries default is determined by the dynamic capital requirement and the one period-ahead net interest margin. In the event of adverse exogenous shocks that precede the expected recovery in the net interest margin (which leads to the accumulation of the capital buffer), such mechanism enables adjustments in optimal dynamic capital buffers to have real effects through two channels that feed one another. Through the "aggregate economic cost channel", the corresponding decline in the bank default probability causes bank resolution costs and taxes collected to fund the deposit insurance scheme to recede. Such reduction in the "macroeconomic cost of bank risk failure" frees up resources that help sustain aggregate demand. Through the "collateral channel", certain empirically-relevant features of collateral markets strengthen the pass-through that allows dynamic capital buffers to induce stabilization and welfare gains through improved banks' resilience. In the case of collateral constraints in which property plays a role, these market features include a sufficiently inelastic real estate supply (i.e., a market that predominantly adjusts via prices), households deriving utility from housing services and commercial real estate entering the production function.

The first two channels are standard in this class of macro-banking models with bank risk failure. The third one (i.e., the "collateral channel") is generally not present in those models that find little to no gains from adjusting capital buffers over the cycle (i.e., outside extraordinary crisis times). This suggests that this third channel - which revolves around borrowers (modelled in this set up as entrepreneurs) - needs to be active for the entire transmission mechanism to be operative.

This is confirmed throughout the paper from different angles. First, we find that optimal dynamic capital requirements induce welfare gains across the different types of shocks that hit this model economy. However, stabilization and welfare gains are only significant in response to financial (collateral) and TFP shocks, which are those borrowers are more exposed to and those that more directly impact the property collateral held by entrepreneurs. Second, due to the key role played by the "collateral channel", borrowers are those who reap most of the benefits (i.e., welfare gains) from optimal dynamic capital buffers. Third, by considering four different versions of the model that differ from one another in one or more of the key collateral market features, we are able to distill each of the sub-channels around the "collateral channel" and their contribution to the welfare and stabilization gains of optimal dynamic capital buffers. The elasticity of the collateral asset supply fundamentally determines the effectiveness of dynamic capital buffers. Under our baseline case that real estate supply is inelastic (which allows us to match the empirical property price volatility) adjustments in the collateral (property) market in response to exogenous shocks and policy responses (e.g., the accumulation of capital buffers) are made via prices, which makes ample room for the correction of the resulting pecuniary externalities via macroprudential policy. Additional assumptions that housing services enter the utility function and commercial real estate serves as a productive factor strengthen the mechanism through which dynamic capital buffers guided by net interest margins stabilize the economy and induce welfare gains. Given our specification of property markets, dynamic capital buffers yield significant welfare gains under the two most empirically-relevant types of collateral constraints in the real economy; property (or mortgage)-based and earnings-based collateral constraints (Lian and Ma 2021) modelled as in Drechsel (2023) and Drechsel and Kim (2024).

Then, we inspect the interactions between static capital requirements and dynamic capital buffers. While the former permits to more effectively correct the externality due to bank risk failure by managing the steady state level of bank default risk, the latter allows to correct the pecuniary externality due to collateral constraints by managing banks' resilience over the cycle. That is, there are complementarities between the two - as they provide stability to the system through different mechanisms - but also a trade-off. This trade-off makes the initial level of static capital requirements crucial to the question of whether having dynamic capital buffers is optimal or not. If this level is sufficiently high (i.e., the steady-state default probability is sufficiently low), the space to stabilize the economy further by strengthening banks' resilience via capital buffer accumulation is limited. In fact, we find an effective lower bound for the long-run bank default probability below which dynamic capital buffers are ineffective. As the initial level of static capital requirements goes down, welfare gains of capital buffers soar (with the headroom for strengthening banks'resilience over the cycle). There is an initial level of steady-state capital requirements below which having dynamic capital buffers is optimal as their benefits outweigh the cost of having low static capital requirements (i.e., lower than optimal static capital requirements).

Lastly, we assess the role for capital buffer smoothing by incorporating persistence in the policy rule according to which dynamic capital requirements are set. We find that adjusting capital buffers gradually is optimal. It amplifies the welfare gains of dynamic capital buffers and materially improves the trade-off between such buffers and static capital requirements. Under the baseline calibration, the optimal rule with buffer smoothing features even lower static capital requirements and yields substantially larger welfare gains than in the absence of it. By more gradually building the capital buffer, the decline in the bank default probability is more persistent and the real effects more sizable and long-lasting.

As an application of our quantitative analysis, we present a simple framework for calibrating micro and macro-prudential capital requirements - including the so-called "positive neutral CCyB" (PN-CCyB) - to give a sense of how our optimal rules would map into capital requirements and buffers typically calibrated by regulators in practice. Under the optimal rule with buffer smoothing, the calibrated optimal PN-CCyB - and, more generally speaking, calibrated optimal dynamic capital buffers - is larger (1.84%) than without it (0.37%) mainly because the volatility of the underlying indicator (i.e., the expected growth rate of the net interest margin) is higher. The reason for this is twofold. First, due to lower static capital requirements that make aggregates more volatile (from the bank lending spread to private consumption). Second, more gradual responses to expected shifts in the net interest margin cause such variable itself to fluctuate more than in the absence of buffer smoothing.

The paper is organized as follows. Section 2 reviews the literature. Section 3 describes the quantitative macro-banking model. Section 4 studies static capital requirements. Section 5 conducts a detailed welfare analysis of dynamic capital buffers. Section 6 distills the sub-channels around the "collateral channel" through which dynamic capital buffers induce welfare gains. Section 7 presents an application of the quantitative analysis in the form of a simple framework for calibrating the PN-CCyB. Section 8 concludes.

2 Related Literature

This paper belongs to the literature that studies the effects of bank capital regulation (e.g., Admati and Hellwig 2013; Admati et al. 2013; Repullo 2004; Repullo and Suarez 2013; Repullo 2013; He and Krishnamurthy 2012; De Nicolò et al. 2014; Gersbach and Rochet 2017; Lang and Menno 2023) and, more precisely, those of optimal capital requirements through the lens of quantitative macroeconomic models (e.g., Collard et al. 2017; Mendicino et al. 2024). Many of these models focus on the study of static capital requirements. In doing so, some papers abstract from bank failure to focus on other frictions that also matter to optimal bank capital levels (e.g., Van den Heuvel 2008; Begenau 2020; Begenau and Landvoigt 2022). Some others, explicitly allow for bank default. Within this strand of the literature, there is a general class of macro-banking models that features bank failure, limited liability and deposit insurance. To capture bank failure, they assume that banks and bank borrowers face idyosincratic asset return shocks modelled as in Bernanke et al. (1999) (e.g., Clerc et al. 2015; Mendicino et al. 2018; Abad 2019; Mendicino et al. 2020).[5] Our set-up belongs to this general class of macroeconomic models but differs from the rest by allowing for a pecuniary externality due to collateral constraints that can be corrected by building dynamic capital buffers in response to expected upward shifts in the bank lending spread.

More specifically, our paper contributes to the strand of the literature that considers this class of macro-banking models to study dynamic capital requirements. Given the growing empirical literature on the effects of releasing capital buffers in crisis times and the still scant one on when and how to accumulate these buffers, this literature has mainly focused on the former.[6] In a model of the same class that features large financial crises due to occasionally binding constraints in the intermediation and productions sectors, Elenev et al. (2021) show that releasing a dynamic capital buffer when the economy switches to the bad state of the nature is optimal. This result also

[5] The cross-sectional dispersion of these shocks evolves stochastically over time, driven by some aggregate risk shocks (Christiano et al. 2014).

[6] For recent evidence on the effectiveness of releasing (releasable) capital buffers to sustain lending supply to the real economy in crisis times, see Couaillier et al. (2022); Bergant and Forbes (2023); Dursun-de Neef et al. (2023); Mathur et al. (2023); Bedayo and Galán (2024).

applies to the case in which banks face idyosincratic funding shocks (Corbae and D'Erasmo 2021).[7] Canzoneri et al. (2021) show that in a model of this class that does not capture this type of non-linear financial crises (i.e., outside extraordinary crisis times), optimal static capital requirements are hard to beat. Abad et al. (2024) come to similar conclusions and find mixed effects for the release of a capital buffer in a banking crisis as it moderately alleviates the credit crunch but also induces more systemic risk-taking ex-ante (by mitigating rents ex-post). Very few models of this class find that adjusting capital requirements over the cycle (i.e., outside extraordinary crisis times) is optimal (Davydiuk 2017).[8] These exceptions typically find optimal adjustments in capital requirements to be guided by macroeconomic indicators such as output and credit gaps.[9]

Our paper also relates to recent work on the effects of tightening bank capital requirements on bank lending. The model captures both, the negative short-term effects of an exogenous tightening of static capital requirements (e.g., Aiyar et al. 2014; Gropp et al. 2019) and the positive medium-term effects of accumulating dynamic capital buffers when there is headroom for doing so (e.g., Bedayo and Galán 2024). Accounting for the implicit subsidy to banks that government guarantees generate, Bahaj and Malherbe (2020) study through the lens of a one-period representative bank model, a mechanism through which a bank may optimally respond to higher capital requirements by increasing lending (i.e., the "forced safety effect").

Our work connects with the literature on macroprudential policies that correct pecuniary externalities due to collateral constraints (e.g., Lorenzoni 2008; Bianchi and Mendoza 2018; Dávila and Korinek 2018; Van der Ghote 2021). Different from theirs, in our model there is also an externality caused by economic agents not internalizing the consequences for the aggregate economic cost of bank risk failure of their individual decisions (Section 3). Similar to theirs, collateral constraints are the engine of financial amplification that gives rise to welfare and stabilization gains from macroprudential policies. This key feature obviously follows from initial work on the financial accelerator (Bernanke et al. 1999; Kiyotaki and Moore 1997) and subsequent literature (e.g., Jermann and Quadrini 2012; Boissay et al. 2016). We show that by allowing for binding property-based collateral constraints as in Iacoviello (2005), this financial amplification mechanism is particularly powerful.[10] We show further that, as long as property markets retain several of these empirically-relevant features (e.g., fixed property supply and commercial real estate entering the production

[7] In a similar vein, macro-banking models in which the economy is prone to bank runs, find significant gains from releasing capital buffers when the bad equilibrium occurs (Angeloni and Faia 2013; Faria-e Castro 2021).

[8] Malherbe (2020) would be another example, although in this case the modelling of bank failure and the dynamics of the economy is somewhat different.

[9] On the basis of a normative criterion that builds on a welfare function that incorporates the volatility of various aggregates in the economy, Aguilar et al. (2019) also find that optimal dynamic capital buffers respond to credit.

[10] The assumption of binding borrowing constraints faced by firms is empirically relevant. At the aggregate level the NFC sector is credit constrained (Banerjee and Duflo 2014), firms that are credit constrained are found across the entire firm-size distribution (Ferreira et al. 2023), and such financial constraints have large real effects (Campello et al. 2010).

function), our findings remain qualitatively unchanged also in the case of the other main class of empirically-relevant collateral constraints; earnings-based borrowing limits (Lian and Ma 2021) modelled as in Drechsel (2023) and Drechsel and Kim (2024).

In essence, our work reconciles recent evidence and theory on the benefits of building capital buffers when there is headroom for doing so (i.e., when net interest margins are expected to improve) by connecting the literature on optimal bank capital regulation in macro-banking models featuring bank failure, limited liability and deposit insurance with that on pecuniary externalities stemming from collateral constraints as the engine of financial amplification. By combining the externality from bank risk failure and the associated "bank profitability channel" and "aggregate economic cost channel" of the former with the pecuniary externality and the related "collateral channel" of the latter, we simultaneously provide a rationale for both having static capital requirements to manage the bank default risk in the steady state and gradually accumulating dynamic capital buffers in response to expected upward shifts in net interest margins to manage banks' resilience dynamics over the cycle.

Contrary to what other set-ups show in this strand of the literature, by capturing the empirical observations such as the correlation between net interest margins and credit gaps, we are able to show that building a countercyclical capital buffer in response to expected improvements in bank profitability is optimal even when credit gaps are in negative territory.

3 The Model

Consider a real, closed, decentralized and time-discrete economy populated by savers and borrowers. Savers are households that provide consumption insurance to two types of members: workers and bankers. Workers supply labor and return their wage income to the household. Bankers devote their net worth to provide equity financing to the banks they manage and transfer their accumulated earnings back to the household. Borrowers are entrepreneurs - also referred to as non-financial corporations (NFCs) - who accummulate commercial real estate (CRE) to obtain bank lending by pledging such property holdings as collateral and to combine it with labor to produce a homogeneous final good. Entrepreneurs discount the future more heavily than households (i.e., $\beta_e < \beta_h$) which effectively implies that, in the aggregate, the former are net borrowers and the latter are net savers (Iacoviello 2005). This key assumption ensures that the borrowing constraint faced by entrepreneurs is binding in a neighbourhood of the steady state.

Banks finance their loans to NFCs with equity from bankers and deposits held by households, and have to comply with a regulatory capital requirement. Banks operate under limited liability and default when the value of their assets falls below that of their debt obligations. A fraction κ of these bank deposits is insured by a deposit insurance scheme, which is funded with lump-sum taxes.

The remaining deposits are uninsured and depositors price them based on the expected potential losses associated with the risk of failure of an average bank. Hence, deposit valuation does not depend on leverage and risk taking choices of each bank, which are assumed to be unobservable to small and dispersed depositors (Dewatripont et al. 1994). This friction implies that the risk of bank default is not priced at the margin and banks have incentives to lever up excessively (i.e., the capital adequacy constraint is binding) and to underprice the risk involved in lending to NFCs (Mendicino et al. 2020).

The presence of these two frictions (binding property-based collateral constraints in the real economy and lending risk underpricing that makes capital requirements binding in the financial sector) provides a strong rationale for both static capital requirements and dynamic capital buffers. The next subsection describes the main features of the model in greater detail. The full list of equilibrium conditions of the model is available in Appendix A.

3.1 Main Features

3.1.1 Households: Savers

Let $c_{h,t}$, $n_{h,t}$, $h_{h,t}$ represent consumption, hours worked and housing demand by households in period t, respectively. The representative household seeks to maximize

$$E_0 \sum_{i=0}^{\infty} \beta_h^i \left\{ \frac{1}{1-\sigma_u} \left[c_{h,t+i} - \frac{n_{h,t+i}^{1+\phi}}{(1+\phi)} \right]^{1-\sigma_u} + j_{h,t+i} \log h_{h,t+i} \right\}, \tag{1}$$

where $\beta_h \in (0,1)$ is the households' subjective discount factor, ϕ refers to the inverse of the Frisch elasticity, and $j_{h,t}$ denotes a possibly time-varying preference parameter for housing. More precisely, $j_{h,t} = j_h \varepsilon_t^h$ is the exogenously time-varying households' preference parameter for housing services, where $j_h > 0$ and ε_t^h captures exogenous housing preference shocks.[11]

The maximization of (1) is subject to the sequence of budget constraints

$$c_{h,t} + q_t(h_{h,t} - h_{h,t-1}) + d_{h,t} + b_{h,t} + T_t = \widetilde{R}_t^d d_{h,t-1} + R_{t-1}^b b_{h,t-1} + w_t n_{h,t} + \Omega_t, \tag{2}$$

where $d_{h,t}$ denotes bank deposits, $b_{h,t}$ holdings of the risk-free asset (which is in zero net supply), T_t lump-sum taxes, and Ω_t net transfers received from bankers. q_t denotes the price of housing, w_t

[11]Households have GHH preferences in consumption and hours worked (see Greenwood et al. 1988). This type of preferences - under which wealth effects on labor supply are arbitrarily close to zero - has been extensively used in the business cycle literature as a useful device to match several empirical regularities. As in this paper, GHH preferences have been formulated by other authors when evaluating macroeconomic policies to prevent a counterfactual increase in labor supply in response to adverse shocks (see, e.g., Bianchi and Mendoza 2018).

the wage rate, and R_t^b the gross interest rate on the risk-free asset. The gross interest rate on bank deposits is $\widetilde{R}_t^d = R_{t-1}^d - (1-\kappa)\Psi_t$, where R_t^d is the promised gross bank deposit return that the fraction κ of insured deposits always yields and Ψ_t is the average per unit loss rate on the fraction of uninsured deposits.

3.1.2 Banking Groups

As in Gertler and Karadi (2011), in each period bankers become workers with probability $1-\theta_b$ (and workers become bankers with probability θ_b). Thus, in each period a fraction $(1-\theta_b)$ of bankers retires, they transfer their terminal net worth to the household, and they are replaced by new bankers who continue business with an endowment (that is assumed to be a constant fraction χ_b of retiring bankers' net worth) received from the household. Therefore, the size of bankers' population remains constant over time and the (joint) aggregate accumulated net worth of (surviving and new) bankers is prevented to grow excessively and is devoted to provide equity financing to banks and pay dividends to the household.

Bankers The representative banker solves

$$V_{b,t} = \max_{e_{b,t},\ \mathrm{div}_{b,t}} \left\{ \mathrm{div}_{b,t} + E_t \Lambda_{h,t+1} \left[(1-\theta_b) N_{b,t+1} + \theta_b V_{b,t+1} \right] \right\}, \tag{3}$$

subject to

$$N_{b,t} = e_{b,t} + \mathrm{div}_{b,t}\,, \tag{4}$$

$$N_{b,t+1} = \int_0^\infty \rho_{b,t+1}(\omega_b) dF(\omega_b) e_{b,t}, \tag{5}$$

$$\mathrm{div}_{b,t} \geq 0, \tag{6}$$

where $\mathrm{div}_{b,t}$ is the dividend payed to the household, $\Lambda_{h,t+1} = \beta_h \dfrac{\lambda_{h,t+1}}{\lambda_{h,t}}$ the stochastic discount factor of the household (with $\lambda_{h,t}$ being the Lagrange multiplier of the households' optimization problem), $N_{b,t}$ the banker's aggregate net worth, $e_{b,t}$ the net worth invested in the continuum of banks, and $\rho_{b,t}(\omega)$ is the return on equity invested in a bank with return shock ω_b.

Given that individual banks operate under constant returns to scale (see below) and bankers take returns on bank equity as given, $\rho_{b,t}$, the value function of bankers is linear in their level of net worth. Thus, assuming that bankers always fully reinvest their wealth as bank equity, the marginal value of one unit of net worth can be defined as $\upsilon_{b,t} = E_t \left[\Lambda_{b,t+1} \left(1-\theta_b + \theta_b \upsilon_{b,t+1}\right) \rho_{b,t+1} \right]$ and expression (3) can be re-written as

$$\upsilon_{b,t} N_{b,t} = \max_{e_{b,t},\ \mathrm{div}_{b,t}} \left[\mathrm{div}_{b,t} + E_t \Lambda_{h,t+1} \left(1 - \theta_b + \theta_b \upsilon_{b,t+1}\right) N_{b,t+1} \right]. \tag{7}$$

Provided that the shadow value of one unit of bank equity satisfies $\upsilon_{b,t} > 1$, it is optimal for bankers to fully reinvest their net worth in bank equity and only distribute a terminal dividend when they retire. Expression (7) allows us to conveniently define the banker's stochastic discount factor as $\Lambda_{b,t+1} = \Lambda_{h,t+1} \left(1 - \theta_b + \theta_b \upsilon_{b,t+1}\right)$.

The law of motion of bankers' aggregate net worth is given by

$$N_{b,t} = \underbrace{\theta_b \rho_{b,t} e_{b,t-1}}_{\substack{\text{Retained Earnings} \\ \text{Surviving Bankers}}} + \underbrace{\left(1 - \theta_b\right) \chi_b \rho_{b,t} N_{b,t-1}}_{\substack{\text{Initial Endowment} \\ \text{New Bankers}}}, \tag{8}$$

where χ_b is the fraction of retiring bankers' net worth with which the representative household endows new bankers. In this regard, it is useful to define transfers from retiring bankers to the household net of the initial endowment received by new bankers as $\Omega_t = \left(1 - \theta_b\right) \rho_{b,t} \left(e_{b,t-1} - \chi_b N_{b,t-1}\right)$.

Banks The representative bank maximizes the net present value of bankers' equity share

$$E_t \left[\Lambda_{b,t+1} \max \left(\omega_{b,t+1} R^l_{t+1} l_{b,t} - R^d_t d_{b,t}, 0 \right) \right] - \upsilon_{b,t} e_{b,t}, \tag{9}$$

subject to a balance sheet identity and a regulatory capital requirement, respectively:

$$l_{b,t} = e_{b,t} + d_{b,t}, \tag{10}$$

$$e_{b,t} \geq \gamma_t l_{b,t}, \tag{11}$$

where $\omega_{b,t}$ is the bank-idiosyncratic asset return shock, R^l_t the gross interest rate on bank loans to NFCs, $l_{b,t}$ bank loans to NFCs, and $d_{b,t}$ bank deposit funding. Expression (9) indicates that bank equity, $e_{b,t}$, is valued at its equilibrium opportunity cost, $\upsilon_{b,t}$, and the max operator captures bank shareholders' limited liability. Equation (10) stipulates that bank assets (i.e., loans to NFCs) are fully financed with equity, $e_{b,t}$, and bank deposit funding. Expression (11) states that, for regulatory reasons, bank equity cannot fall below a possibly time-varying fraction γ_t of bank assets. This regulatory capital requirement, γ_t, is binding in equilibrium since uninsured (or "partially covered") deposits are comparatively "less costly" to banks than equity.

Idiosyncratic return shocks, $\omega_{b,t}$: (i) are the driver of idiosyncratic bank default risk in the model, (ii) capture any exogenous sources that may affect banks' profitability, (iii) follow a log-normal distribution with a mean of one and a distribution function $F(\omega_{b,t})$ and are i.i.d. across banks (Bernanke et al. 1999), and (iv) its cross-sectional dispersion, $\sigma_{\omega,t}$, evolves stochastically over time, driven by some aggregate risk shocks (Christiano et al. 2014). The bank operates across two consecutive dates. If positive, the bank transfers its terminal net worth back to the bankers. If the bank's terminal net worth is negative the bank defaults, its equity is written down to zero and its assets are repossessed by the deposit insurance scheme. The condition for the bank not to default requires $\omega_{b,t+1}R^l_{t+1}l_{b,t} - R^d_t d_{b,t} \geqslant 0$, which allows us to rearrange and define the threshold for the value of $\omega_{b,t}$ below which the bank defaults as $\overline{\omega}_{b,t+1} = \left(R^d_t d_{b,t}\right) \big/ \left(R^l_{t+1} l_{b,t}\right)$. Then, we can define the probability of bank default as

$$F(\overline{\omega}_{b,t}) = \int_0^{\overline{\omega}_{b,t}} f\left(\omega_b; \sigma_{\omega,t}\right) d\omega_b = \digamma \left[\frac{\log(\overline{\omega}_{b,t}) + \sigma^2_{\omega,t}/2}{\sigma_{\omega,t}}\right], \tag{12}$$

where $f\left(\omega_b; \sigma_{\omega,t}\right)$ and $\digamma\,[.]$ denote the probability density function and the cumulative distribution function of the bank-idiosyncratic asset return shock $\omega_{b,t}$, respectively. Given that the risk weight of loans to NFCs is normalized to one for simplicity, it can be rearranged in expressions (10) and (11) to define the bank's leverage ratio as $d_{b,t}/l_{b,t} = (1-\gamma_t)$. Thus, we can redefine the threshold for the value of $\omega_{b,t}$ below which the bank defaults as

$$\overline{\omega}_{b,t+1} = (1-\gamma_t)\,\frac{R^d_t}{R^l_{t+1}}. \tag{13}$$

From expressions (12) and (13) it follows that the bank default probability fundamentally depends on the capital requirement and components of the net interest margin (i.e., the lending and deposit rates). As it will become clearer in Sections 4 and 5, this is important to understand the transmission and effectiveness of static capital requirements and dynamic capital buffers in the model.

3.1.3 Entrepreneurs: Borrowers

Let $c_{e,t}$ represent consumption by entrepreneurs in period t. Then, entrepreneurs seek to maximize

$$E_0 \sum_{i=0}^{\infty} \beta_e^i \left[\frac{\left(c_{e,t+i}\right)^{1-\sigma_u}}{1-\sigma_u}\right], \tag{14}$$

subject to a sequence of budget constraints

$$c_{e,t} + q_t(h_{e,t} - h_{e,t-1}) + R^l_t l_{e,t-1} + w_t n_{e,t} = Y_{e,t} + l_{e,t}, \tag{15}$$

where $\beta_e \in (0,1)$ is the entrepreneurs' subjective discount factor, $l_{e,t}$ denotes bank loans extended to NFCs, $h_{e,t}$ refers to commercial real estate or CRE, $n_{e,t}$ makes reference to labor demand and Y_t is total output (or sale revenues). According to (15), in each period, entrepreneurs devote their available resources in terms of loans and sale revenues to repay their debt, remunerate workers, accumulate commercial real estate and consume.

The homogeneous final good is produced by using a Cobb-Douglas technology that combines labor and CRE as follows:

$$Y_{e,t} = A_t h^{\nu}_{e,t-1} n^{(1-\nu)}_{e,t}, \tag{16}$$

The maximization of (14) is also subject to a collateral constraint that ties the borrowing capacity of the entrepreneur to the value of her commercial real estate collateral:

$$l_{e,t} \leq \phi_t q_t h_{e,t}, \tag{17}$$

where $\phi_t = \phi \varepsilon^{\phi}_t$ is a possibly time-varying fraction (or multiple) of the aggregate against which the entrepreneur gets indebted, with $\phi \geq 0$ and ε^{ϕ}_t capturing exogenous shocks to the entrepreneurs' borrowing capacity.

3.1.4 Public Authorities

Prudential Authority The prudential authority sets the regulatory capital requirement according to a rule

$$\gamma_t = \gamma + \gamma_x \widetilde{X}_t, \tag{18}$$

where γ captures static (i.e., steady-state) capital requirements and the term $\gamma_x \widetilde{X}_t$ measures dynamic capital buffers, with the capital buffer parameter γ_x capturing the two-sided degree of responsiveness of γ_t to changes in a macro-financial indicator of the choice of the regulator, $\widetilde{X}_t$.

Deposit Insurance Scheme The DIS operates as follows to ensure that, upon default of a bank, households are fully refunded for the losses associated with their insured deposit holdings. When a bank defaults its assets are transferred to the DIS. However, due to a proportional repossession cost μ_b (also interpretable as bank resolution costs) only $(1 - \mu_b)\, \omega_{b,t+1} R^l_{t+1} l_{b,t}$ is effectively repossessed by the DIS. Insured deposits are fully covered by complementing a fraction κ of repossessed bank assets with lump-sum taxes. Thus, lump-sump taxes collected by the DIS are given by

$$T_t = \kappa \Psi_t d_{h,t-1}, \tag{19}$$

where the term $\Psi_t d_{h,t-1} = \left[\left(R^d_{t-1} d_{b,t-1}\right) F(\overline{\omega}_{b,t}) - (1-\mu_b) R^l_t l_{b,t-1} G_t(\overline{\omega}_{b,t})\right]$ refers to the total losses incurred by households on deposits that are not covered with repossessed bank assets. $G(\overline{\omega}_{b,t})$ refers to the share of total bank assets that end up in default.[12] Remaining repossessed bank asset returns, $(1-\kappa)(1-\mu_b) R^l_t l_{b,t-1} G_t(\overline{\omega}_{b,t})$, are devoted to partially cover the losses incurred by households for their holdings of uninsured deposits.

3.1.5 Aggregation, Market Clearing and Net Output

In equilibrium, all markets clear. The supply is endogenous in all markets with the exception of real estate supply, which is specified as a fixed endowment that is normalized to one

$$\overline{H} = h_{h,t} + h_{e,t}., \tag{20}$$

In the case of the final goods market, the aggregate resource constraint dictates that the income generated in the production process is fully spent in the form of aggregate final consumption, C_t, and resolution costs, which represent a deadweight loss for society:

$$Y_t = C_t + \mu_b R^l_t l_{b,t-1} G_t(\overline{\omega}_{b,t}), \tag{21}$$

where $C_t = c_{h,t} + c_{e,t}$. As standard in this strand of the literature, we differentiate between total output (expression 21) and net output, defined as total output net of the deadweight loss:

$$\widetilde{Y}_t = Y_t - \mu_b R^l_t l_{b,t-1} G_t(\overline{\omega}_{b,t}), \tag{22}$$

The definition of real GDP given by expression 22 is convenient for the purpose of "uncovering" the real effects of capital requirements, which under expression 21 may be blurred by the fact that the bank default probability (and bank resolution costs) is countercyclical and determined, to a large extent, by the capital requirement itself. Note that in this model, net output is equal to aggregate consumption.

[12] See Appendix A for the analytical expression of $G(\overline{\omega}_{b,t})$.

3.2 Calibration

We follow a three-stage strategy in order to calibrate the model to quarterly data of the euro area economy. Data targets have been taken from three recent macro-banking models that are calibrated to quarterly euro area data for a similar period; Mendicino et al. (2020), Muñoz (2021) and Burlon et al. (2024).

Table 1: Baseline calibration

Parameter	Description	Value	Target ratio/Source
(A) Preset Parameters			
σ_u	Risk aversion parameter	2.0000	Standard
φ	Inverse of the Frisch elasticity	1.000	Standard
σ_ω	Std. bank risk shock	0.0290	Mendicino et al. (2020)
ν	Property share in production	0.030	Iacoviello (2005)
ϕ	Borrowing limit param.	0.600	Standard
(B) First moments			
β_h	Savers' discount factor	0.9942	$(\beta_h^{-1} - 1)x\ 400 = 2.320$
β_e	Borrowers' discount factor	0.9840	$\overline{l_b}/\overline{Y} = 1.682$
j	Savers' housing services weight	0.0708	$\overline{q}\overline{h}_h/\overline{Y} = 2.802$
γ	Regulatory capital requirements	0.0800	$\overline{e}_b/\overline{l}_b = 0.080$
κ	Share of insured deposits	0.5400	$\kappa = 0.540$
μ_b	Complementary of recovery rate	0.300	$\mu_b = 0.300$
θ_b	Survival rate of bankers	0.9062	$\overline{\upsilon_b} = 1.148$
$\overline{\sigma_b}$	Mean std. of iid bank shocks	0.0286	$\overline{F}(\overline{\omega})x\ 400 = 0.665$
χ_b	Transfer from HH to bankers	0.8150	$(\overline{\rho_b} - 1)\,x\ 400 = 7.066$
(C) Second moments			
σ_A	Std. TFP shock	0.0047	$\sigma_Y\ x\ 100 = 2.631$
σ_h	Std. housing pref. shock	0.0098	$\sigma_q\ /\ \sigma_Y = 2.429$
σ_ϕ	Std. NFC financial shock	0.0010	$\sigma_l/\sigma_Y = 6.473$

Notes: All series in Euros are seasonally adjusted and deflated. Data targets for quarterly data of the euro area have been taken from Mendicino et al. (2020), Muñoz (2021) and Burlon et al. (2024). The standard deviation of GDP is in quarterly percentage points. Abbreviations HH, NFC and TFP refer to households, non-financial corporations (entrepreneurs) and total factor productivity, respectively.

First, we set several parameters following convention (Table 1A). The risk aversion parameter is set to a value of 2, whereas the inverse of the Frisch elasticity of labor is fixed to a value of 1. The standard deviation of bank asset return shocks is set to 0.029 (Mendicino et al. 2020) and the property share in production to a conventional value of 0.03 (Iacoviello 2005). Based on existing legislation and available evidence for the euro area, the loan-to-value on commercial (real estate) mortgages, ϕ, is set to a value of 0.6.

Table 2: Model fit

Variable	Description	Data	Model
(A) First moments			
$(\beta_h^{-1}-1)x\ 400$	Real risk-free rate	2.320	2.334
$(\overline{\rho_b}-1)\ x\ 400$	Bank equity return	7.066	7.064
$\overline{F}(\overline{\omega})x\ 400$	Bank default rate	0.665	0.672
$\overline{\upsilon_b}$	Bank price-to-book ratio	1.148	1.141
$\overline{e}_b/\overline{l_b}$	Regulatory capital requirements	0.080	0.080
κ	Share of insured deposits	0.540	0.540
μ_b	Complementary of recovery rate	0.300	0.300
$\overline{l_b}/\overline{Y}$	Bank lending-to-GDP ratio	1.682	1.683
$\overline{q}\overline{h}_h/\overline{Y}$	HH property wealth-to-GDP ratio	2.802	2.803
(B) Second moments			
$\sigma_Y\ x\ 100$	Std(GDP) x 100	2.631	2.650
$\sigma_q\ /\ \sigma_Y$	Std property prices/Std(GDP)	2.429	2.513
$\sigma_{l_b}\ /\ \sigma_Y$	Std. bank lending/Std(GDP)	6.473	6.928
$\sigma_{e_b}\ /\ \sigma_Y$	Std. bank equity/Std(GDP)	6.554	6.928
$\sigma_{r^l}\ /\ \sigma_Y$	Std. bank lending rate/Std(GDP)	0.122	0.226
$\sigma_{r^d}\ /\ \sigma_Y$	Std. bank deposit rate/Std(GDP)	0.043	0.151
$\sigma_\mu\ /\ \sigma_Y$	Std. bank lending spread/Std(GDP)	0.087	0.159
(C) Correlations			
ρ_{μ,l_b}	Corr(bank lending spread, bank lending)	0.064	0.209
$\rho_{\mu,l_b/Y}$	Corr(bank lending spread, bank lending-to-GDP)	0.278	0.195

Notes: All series in Euros are seasonally adjusted and deflated and their log value has been linearly detrended before computing standard deviation and correlation targets. Data targets for quarterly data of the euro area have been taken from Mendicino et al. (2020), Muñoz (2021) and Burlon et al. (2024). The exceptions are the empirical correlations, which have been explicitly computed for the purpose of this analysis, using the same methodology and time series for the period 2003:I-2024I. The standard deviation of GDP is in quarterly percentage points. Abbreviation HH refers to households. Data sources are Eurostat and Bloomberg.

Second, another group of parameters is calibrated by using steady state targets (Tables 1B and 2A). Importantly, the first seven data targets reported in Table 2A (which include all steady-state bank data targets) have been taken from Mendicino et al. (2020). The households' discount factor, $\beta_h = 0.9942$, is chosen such that the annual interest rate on the risk free asset equals 2.32%. The entrepreneurs' discount factor is set to 0.984, in order to generate an annualized bank lending-to-GDP ratio of 1.68. Households' weight on housing utility, j_h, has been calibrated to match the households' property wealth-to-GDP ratio. Based on the Basel III Accords, we set the regulatory (static) capital requirement, γ, to 8%. In line with existing evidence for the euro area, the share of insured deposits is fixed to a value of 0.54. The bank bankruptcy cost parameter is set to 0.3 in order to generate a recovery rate of around 70% of assets held by banks upon default (Mendicino et al. 2020, 2024).[13] The survival rate of bankers, $\theta_b = 0.9062$, is chosen to match a bank price-to-book ratio of 1.148; whereas the mean standard deviation of i.i.d. bank-idiosyncratic return shocks is set to a value of 0.0286 such that the annual bank default rate equals 0.665. The fraction χ_b of retiring bankers' net worth is fixed to a value of 0.815 to match the annual bank return on equity (RoE).

Third, the size of TFP shocks, housing preference shocks, financial (NFC collateral) shocks, and bank risk shocks is calibrated to match the second moments (in terms of relative standard deviations) of GDP, property prices and bank assets, respectively (Tables 1C and 2B).

Lastly, we use quarterly euro area data for the period 2003:I-2024I (that includes the full tightening cycle discussed in Section 1) to compute the empirical correlations between the net interest margin and, on the one hand, bank lending to NFCs and, on the other hand, the lending (to NFCs)-to-GDP ratio. In both cases, the model correlation is approximately equal to 20%, which lies between the data correlation between the bank lending spread and lending to NFCs and that between the net interest margin and the credit-to-GDP ratio and captures the empirical observation that these historical correlations are positive but low.

The autoregressive coefficients in the AR(1) processes followed by all shocks are set equal to 0.90 in both versions of the model. Importantly, under the baseline scenario, dynamic capital buffers remain inactive (i.e., $\gamma_x = 0$).

4 Static Capital Requirements

First, we inspect the individual and social welfare consequences of static capital requirements, γ. To do so, we propose a measure of social welfare specified as a weighted average of the expected life-time utility of savers and borrowers. This measure is maximized with respect to the relevant policy parameter/s. Formally:

$$\arg\max_{\Theta} V_0 = \zeta_h V_0^h + \zeta_e V_0^e, \tag{23}$$

where $V_0^h = E_0 \sum_{i=0}^{\infty} \beta_h^i u\left(c_{h,t+i}, h_{h,t+i}, n_{h,t+i}\right)$ and $V_0^e = E_0 \sum_{i=0}^{\infty} \beta_e^i u\left(c_{e,t+i}\right)$ are the expected life-time utility functions of households (savers) and entrepreneurs (borrowers), respectively. ζ_h and ζ_e denote the utility weights of each agent type; and Θ refers to the vector of policy parameters within policy rule (18) with respect to which the objective function is maximized, which in this case restricts to γ. The Problem (23) is subject to all the competitive equilibrium conditions of

[13] Alderson and Betker (1995) estimate liquidation costs to represent 36% percent of assets, whereas Granja et al. (2017) find that the average FDIC loss from selling a failed bank is 28% of assets

the model. As in Schmitt-Grohé and Uribe (2007), welfare gains of each agent type are defined as the implied permanent differences in consumption between two different scenarios. Formally, and for the case of households, consumption equivalent gains can be specified as a constant λ_h, that satisfies:

$$E_0 \sum_{i=0}^{\infty} \beta_h^i u \left(c_{h,t+i}^a, h_{h,t+i}^a, n_{h,t+i}^a \right) = \sum_{i=0}^{\infty} \beta_h^i u \left[(1+\lambda_h)\, c_{h,t+i}^b, h_{h,t+i}^b, n_{h,t+i}^b \right] \tag{24}$$

where superscripts a and b refer to the corresponding alternative (capital requirement) scenario and the baseline (calibration) scenario, respectively. As standard in the macro-banking literature, $\zeta_h = (1-\beta_h)$ and $\zeta_e = (1-\beta_e)$, which ensures the same utility weights across agent types discounting future utility at different rates.[14] For reporting purposes, welfare weights are normalized, $\widehat{\zeta}_x = \frac{(1-\beta_x)}{[(1-\beta_h)+(1-\beta_e)]}$, for $x = h, e$ to ensure that $\widehat{\zeta}_h + \widehat{\zeta}_e = 1$.[15]

Figure 2 plots the individual and social welfare gains of changing the value of parameter γ under the baseline calibration. These are mainly driven by the trade-off faced by the economy from hiking these capital requirements. On the one hand, a higher capital ratio lowers the bank default probability. This effect promotes aggregate demand and real economic activity through two channels; by fostering bank lending and by lowering the aggregate economic cost of bank risk failure (i.e., the deadweight loss in equation 21) as well as lump-sum taxes. On the other hand, the increase in the relatively more expensive bank funding source (i.e., equity) encourages banks to exert an upward pressure on lending rates by restricting lending supply. At the macroeconomic level, beyond a certain capital requirement threshold the second effect dominates the first one.[16] At the individual level, borrowers are directly affected by such trade-off and more vulnerable to the negative level effect on bank lending supply. In contrast, savers' welfare increases with γ for the entire range of such parameter values as they are more affected by the decline in bank default risk, which results in smaller losses on deposit holdings and lower lump-sum taxes and resolution costs.

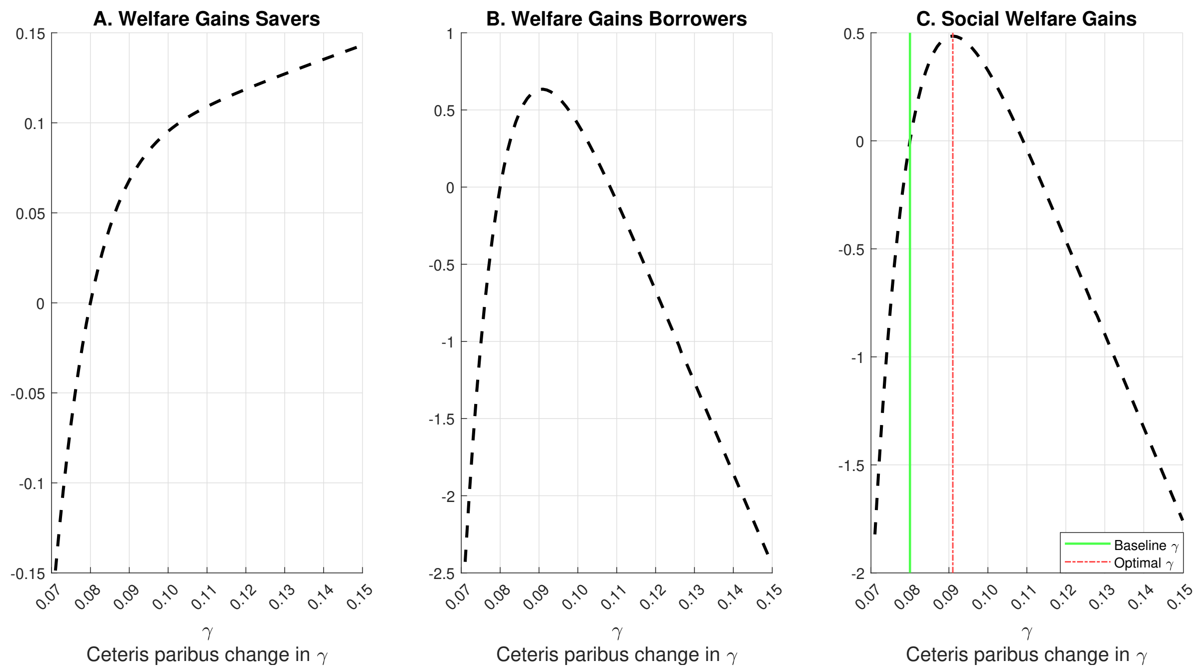
Table 3 reports the optimal static capital requirement - which under the baseline calibration is equal to 9.10% - and the resulting individual and social welfare gains.

[14] This is a welfare weighting criterion typically considered in the macro-banking literature to prevent an overweight of savers' welfare related to a higher discount factor (see, e.g., Lambertini et al. 2013; Alpanda and Zubairy 2017; Burlon et al. 2024).

[15] Under the baseline calibration this normalization implies that $\widehat{\zeta}_h = 0.2661$ and $\widehat{\zeta}_e = 0.7339$.

[16] For further details on the transmission and macroeconomic effects of permanent and transitory hikes in bank capital requirements in this model economy, see Appendix C.

Figure 2: Welfare gains of static capital requirements



Notes: Second-order approximation to the unconditional individual welfare gains of savers and borrowers as well as to the unconditional social welfare gains (expressed in percentage permanent consumption), both as a function of static capital requirement parameter, γ. The vertical solid and dashed lines indicate the value for such parameter under the baseline calibration and the optimal static capital requirement scenarios, respectively.

Table 3: Optimal static capital requirements and welfare gains

	SCR ($\gamma x100$)	WG Saver ($\lambda_h x100$)	WG Borrower ($\lambda_e x100$)	Social WG ($\lambda x100$)
A. $\{\gamma^*\}$				
	9.10%*	0.0719%	0.6344%	0.4847%

Notes: Second-order approximation to the welfare gains (expressed in percentage permanent consumption) and the corresponding optimized policy parameter value resulting from solving Problem (23) for γ. Abbreviations SCR and WG refer to static capital requirements and welfare gains, respectively. λ_h, λ_e and λ denote households', entrepreneurs' and social consumption equivalent gains, respectively. The policy parameter marked with an asterisk is the one for which social welfare is maximized.

In summary, the set-up matches the same key bank data targets (with similar calibrated parameter values), captures the same empirical observations, reveals the same transmission mechanisms and trade-off, yields the same type of capital requirement-induced individual and social welfare effects (e.g., Mendicino et al. 2018) and finds similar optimal static capital requirements (Mendicino et al. 2020) as in the literature.[17]

[17]On the empirical observations, see Appendix C for the mechanisms through which an exogenous tightening of static capital requirements reduces the bank default probability, increases the weighted average cost of capital and

5 A Dynamic Capital Buffer

Next, we study the welfare consequences of a dynamic capital buffer by allowing for changes in γ_x. In the first instance, this requires making a choice for the indicator that enters the simple capital requirement rule within the class (18), $\widetilde{X}_t$.

5.1 Macro-Financial Indicators

We consider two standard cases for the specification of such macro-financial indicator that we refer to as growth rate-based rules and gap-based rules

$$\widetilde{X}_{r,t} = \left(\frac{x_{t+i}}{x_{t+i-1}} - 1 \right), \qquad i = -1, 0, 1 \tag{25}$$

$$\widetilde{X}_{g,t} = \left(\frac{x_{t+i}}{\overline{x}} - 1 \right), \qquad i = -1, 0, 1$$

where sub-index $j = \{r, g\}$ indicates whether the rule is growth-rate based or gap-based and sub-index $i = -1, 0, 1$ informs about whether the rule is backward-looking, contemporaneous, or forward-looking, respectively. For each of these six cases, we consider six different options for the variable, x_t, that enters indicator (25):

$$x_t = \left\{ l_{b,t}/\widetilde{Y}_t;\ q_t;\ \widetilde{Y}_t;\ \rho_{b,t};\ \alpha_{b,t};\ R_t^l \right\}, \tag{26}$$

where the first three variables ($l_{b,t}/\widetilde{Y}_t$; q_t; $\widetilde{Y}_t$) are macroeconomic aggregates (the credit-to-GDP ratio, property prices, and real GDP) and the last three ($\rho_{b,t}$; $\alpha_{b,t}$; R_t^l) are bank profitability indicators (bank RoE, bank lending spread, and bank RoA), with $\alpha_{b,t} = (r_t^l - r_{t-1}^d)$.[18]

Figures 3 and 4 display the welfare gains of changing the value of parameter γ_x under the baseline calibration for the case of the above outlined macroeconomic and bank profitability indicators, respectively.[19] Regardless of the type of macroeconomic indicator under consideration, attainable welfare gains via a dynamic capital buffer are negligible to non-existent and, in most of the cases, the best the competent authority can do is to refrain from having such a buffer in place. In contrast, a capital buffer guided by a forward-looking growth rate-based bank profitability indicator has the potential to yield significant welfare gains. From the 36 indicators under consideration, the

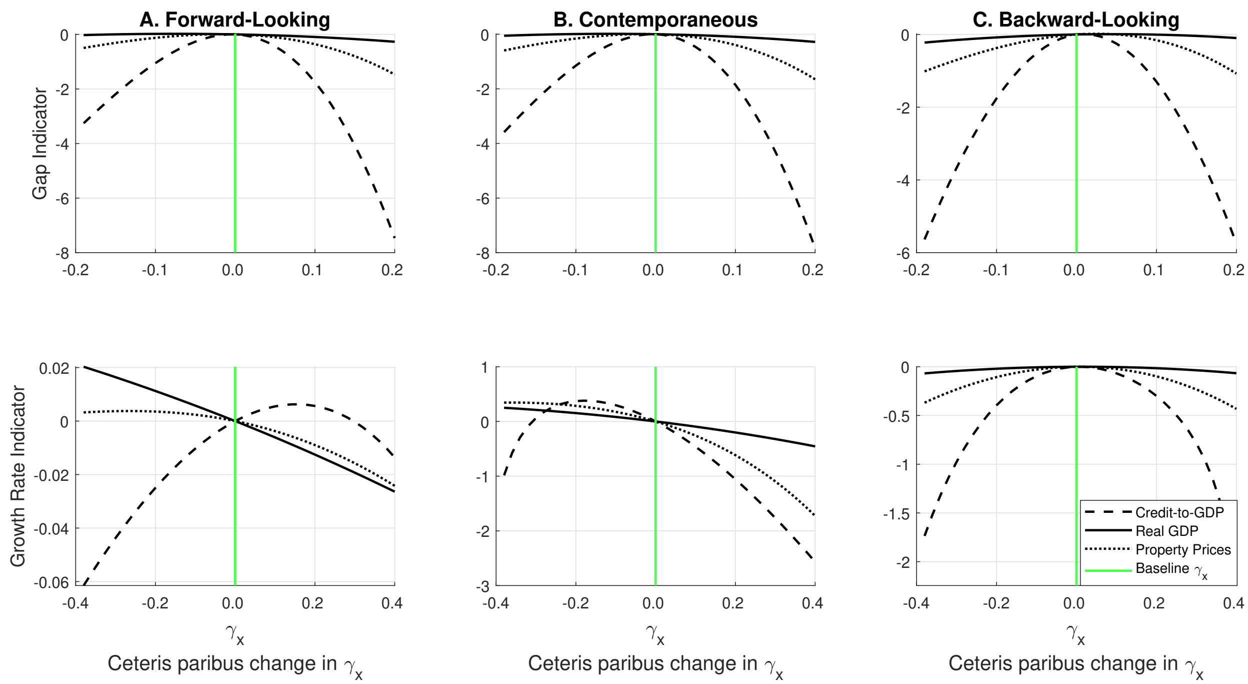
negatively affects short-term lending.

[18] Recall from Subsection 3.1 that, as standard in this strand of the literature, in the quantitative analysis we consider net output as a proxy for real GDP.

[19] The welfare gains of changing the value of parameter γ_x under contemporaneous and backward-looking gap-based and growth rate-based rules cannot be displayed as there is no stable equilibrium (i.e., Blanchard-Kahn conditions are not satisfied) in these cases.

forward-looking growth rate of the bank lending spread is by far the one that allows for the CCyB to yield the largest welfare gains (4B).

Figure 3: Welfare gains of a dynamic capital buffer: Macroeconomic indicators



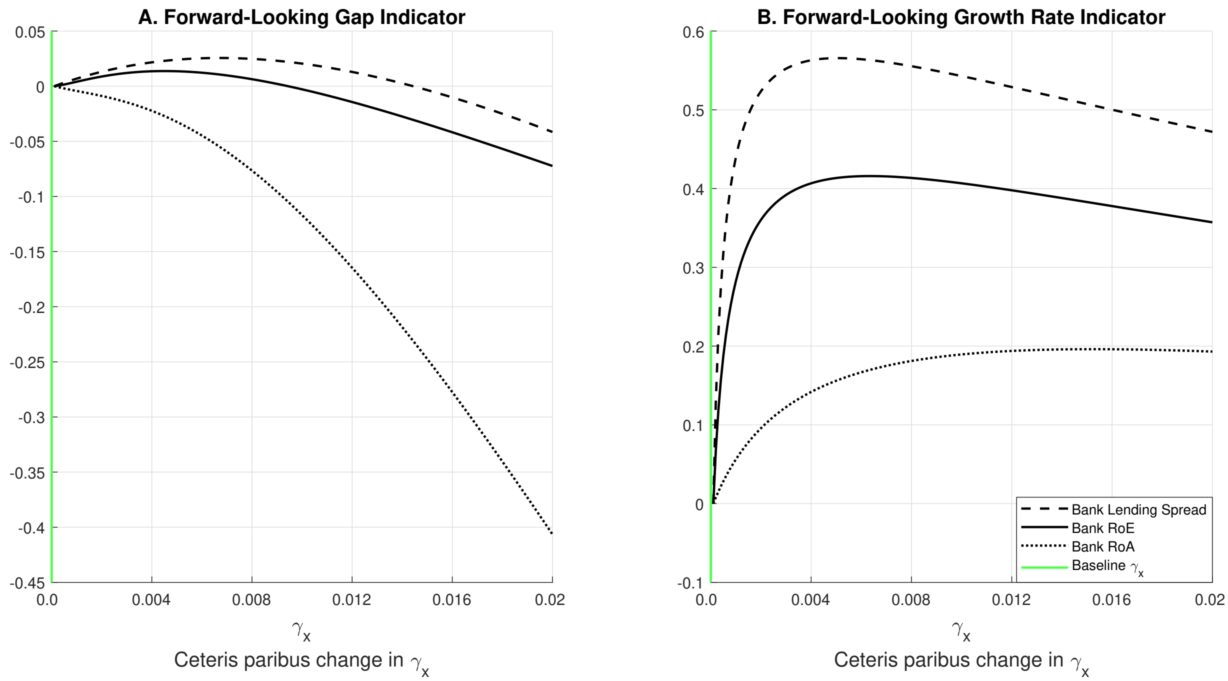
Notes: Second-order approximation to the unconditional social welfare gains (expressed in percentage permanent consumption) as a function of parameter γ_x for the 18 cases under consideration in which $\widetilde{X}_t$ is a macroeconomic indicator. The figure differentiates between gap-based and growth rate-based indicators, between forward-looking, contemporaneous and backward looking indicators, and across candidates for x_t (i.e., credit-to-GDP, real GDP and property prices). The vertical solid line indicates the value for such parameter under the baseline calibration.

Indicators based on expected changes in bank profitability metrics perform significantly better than macroeconomic indicators, with the one based on the bank lending spread being the best performer. This result ultimately follows from expressions (12) and (13). According to the latter, the expected threshold below which a bank defaults is determined by the one-period ahead bank lending spread and by the capital requirement, γ_t. This implies that the competent authority can have great control over the dynamics of banks' resilience (proxied by the bank default probability) by adjusting capital requirements in response to forward-looking changes in the net interest margin.

The macroeconomic and welfare effects that can be attained via dynamic capital buffers through this mechanism also apply to other indicators of the bank's profit generation capacity (e.g., bank RoE and RoA). Not surprisingly, the magnitude of the welfare gains induced by a dynamic capital buffer guided by any of these indicators will be directly related to the correlation between such indicator and the net interest margin.

However, the literature shows that even if this mechanism is in place, dynamic capital buffers may not necessarily yield significant stabilization and welfare gains. This suggests that there are other

Figure 4: Welfare gains of a dynamic capital buffer: Bank profitability indicators



Notes: Second-order approximation to the unconditional social welfare gains (expressed in percentage permanent consumption) as a function of parameter $\gamma_{x,1}$ for the 6 (out of the 18 cases under consideration) in which $\widetilde{X}_t$ is a financial (bank profitability) indicator and there is a stable equilibrium. The figure differentiates between forward-looking gap-based and growth rate-based indicators and across candidates for x_t (i.e., bank lending spread, bank RoE and bank RoA). The solid line indicates the value of such parameter under the baseline calibration.

key channels in the transmission mechanism that are equally important. We turn to this in the next subsection.

5.2 Transmission

Without loss of generality, we describe the full transmission of a dynamic capital buffer that builds in response to expected upward shifts in the net interest margin by inspecting the responses of selected aggregates to a negative financial (collateral) shock that constrains the borrowing capacity of entrepreneurs (Figure 5). In order to do so, we distill the full transmission mechanism into three main channels. The "bank profitability channel" described in Subsection 5.1. The "collateral channel", which allows for dynamic capital buffers to have real effects through a collateral constraint that acts as the nexus between financial intermediation and the real economy (expression 17). The "aggregate economic cost channel", by which shifts in the bank default probability have a direct impact on aggregate demand by altering the aggregate resources devoted to mitigate the impact of bank failure (i.e., bank resolution costs and taxes levied on households to fund the deposit insurance mechanism).

The "Bank Profitability Channel" As bank lending demand is negatively affected, under the baseline scenario (solid line) the bank lending rate and the lending spread fall on impact (in the first quarter), causing the bank default probability to go up. Banks respond by tightening credit conditions, inducing an increase in the lending rate and the lending margin in subsequent quarters by restricting lending supply.

Under the alternative scenario (dashed line), the capital buffer starts being built one period ahead of the one in which the net interest margin is expected to start recovering. Through this channel, a dynamic capital buffer smooths bank profitability over the cycle and ensures that bank resilience gets strengthened (i.e., the bank default probability declines) when it is needed the most (i.e., during the period in which the credit and output gaps are in negative territory).

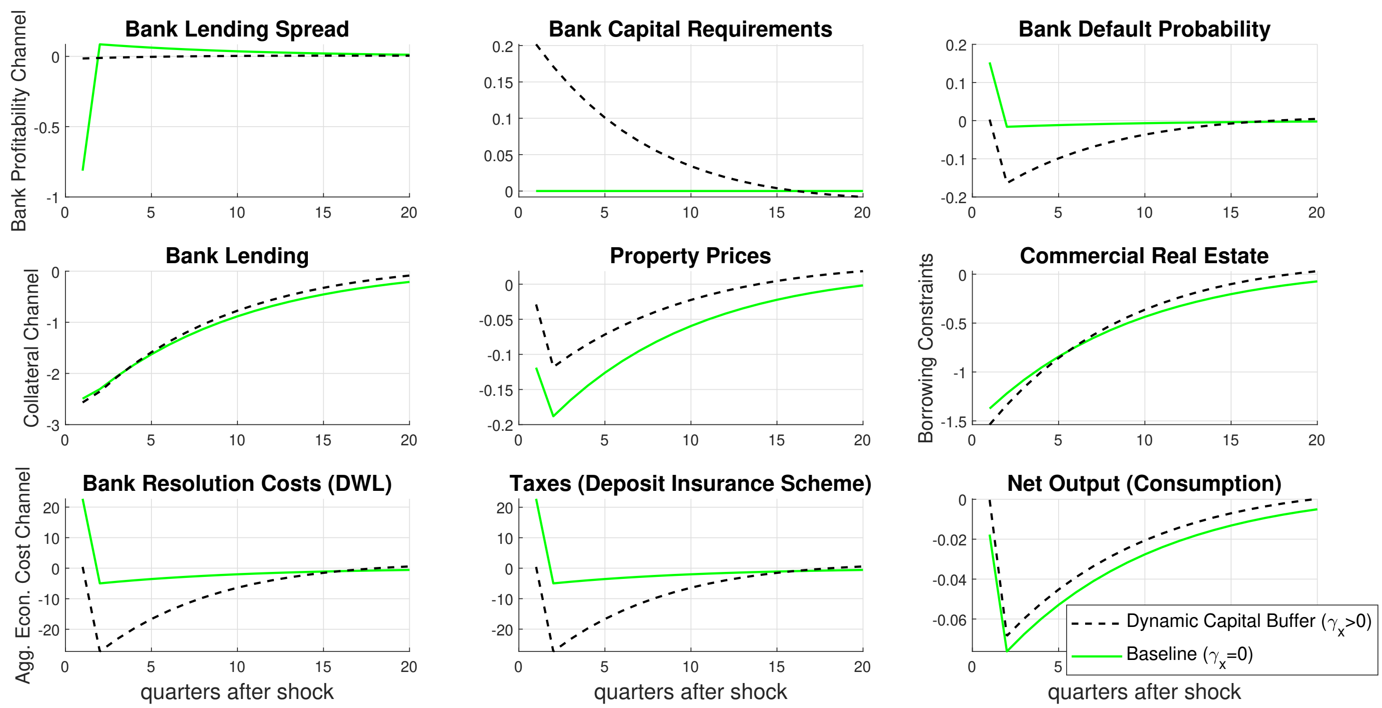
By altering the bank default probability, a dynamic capital buffer can have real effects through the "collateral channel" and the "aggregate economic cost channel".

The "Collateral Channel" The borrowers' collateral constraint (i.e., expression 17) is the nexus between financial intermediation and the real economy. It ensures that the downward adjustment in the bank default probability stabilizes real economic activity by sustaining lending to firms and by smoothing property prices.

As explained in greater detail in Section 6, the magnitude of any macroeconomic and welfare effects generated by dynamic capital buffers crucially depends on the market features of the asset that entrepreneurs pledge as collateral to obtain lending. In this model economy, such market (i.e., the property market) has three key distinctive (and empirically-relevant) features. First, supply is exogenous and fixed (equation 29). That is, adjustments in this market are fully made via prices, which provides stability for property holdings and implies that any stabilization of CRE holdings transmits to RRE through this channel (since the volatility of the two classes of real estate are identical by construction). Second, housing services enter the utility function of households, which - in conjunction with the previous market feature - also implies that a dynamic capital buffer indirectly improves households' welfare by smoothing RRE holdings (expression 1). Third, CRE enters the production function as an input (equation 16); a dynamic capital buffer also stabilizes real economic activity directly from the supply side of the economy.

The "Aggregate Economic Cost Channel" As the default probability recedes, so do bank resolution costs (i.e, the deadweight loss in expression 21) and taxes (levied on households) required to fund the deposit insurance scheme (equation 19). This frees up resources that help sustain consumption as well as housing investments (which favours a smoothing effect on property prices), and a more rapid economic recovery.

Figure 5: IRFs to a negative financial (collateral) shock



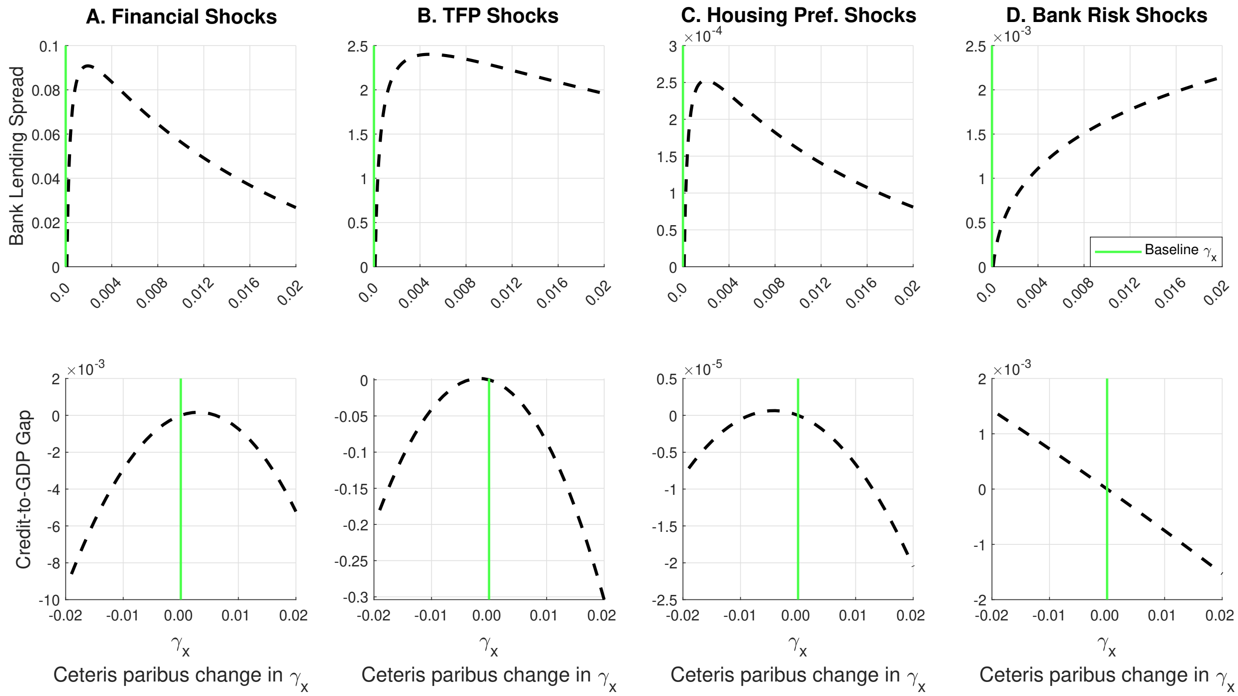
Notes: Variables are expressed in percentage deviations from the steady state with the exceptions of bank capital requirements, the lending spread and the bank default probability, which are shown as absolute deviations from the steady state and are expressed in percentage points, with all of them except for the first one being annualized. The solid line refers to the baseline calibration scenario. The dashed line makes reference to an alternative scenario that differs from the baseline one in that γ_x is set to a value of 0.2, with $\widetilde{X}_t$ being the forward-looking growth rate of the bank lending spread. The size of the shock, σ_ϕ, is set to 0.01.

5.3 Shocks

Although the size of the gains vary across them, the findings presented in Subsections 5.1 and 5.2 apply to the different shocks that hit this model economy. To illustrate this, Figure 6 plots the social welfare gains of changing the value of γ_x for each of the four different types of shocks across two indicators that are representative of the two main classes previously described. The contemporaneous change in the credit-to-GDP and the expected growth rate of the bank lending spread. In each panel, only one type of shock is active, with the size of such shock having been set to a value of 0.01. Regardless of the shock type, a dynamic capital buffer: (i) guided by the credit-to-GDP gap does not induce any significant welfare gains; (ii) optimally builds in response to expected upward shifts in the net interest margin, and (iii) induces particularly large welfare gains in response to financial and TFP shocks (under the bank lending spread indicator).

The first two findings confirm the robustness of the results presented in the two previous subsections. The third one does not come as a surprise either since collateral and TFP shocks are those

Figure 6: Welfare gains of a dynamic capital buffer: Shocks



Notes: Second-order approximation to the unconditional social welfare gains (expressed in percentage permanent consumption) as a function of parameter γ_x under the case in which indicator $\widetilde{X}_t$ is the forward-looking growth rate of the bank lending spread (first row) and the contemporaneous credit-to-GDP gap (second row). Under Panels A, B, C and D, only financial (collateral), TFP, housing preference and bank risk shocks are active, respectively. In each case, the size of shocks is set to 0.01. The vertical solid line indicates the value for γ_x under the baseline calibration.

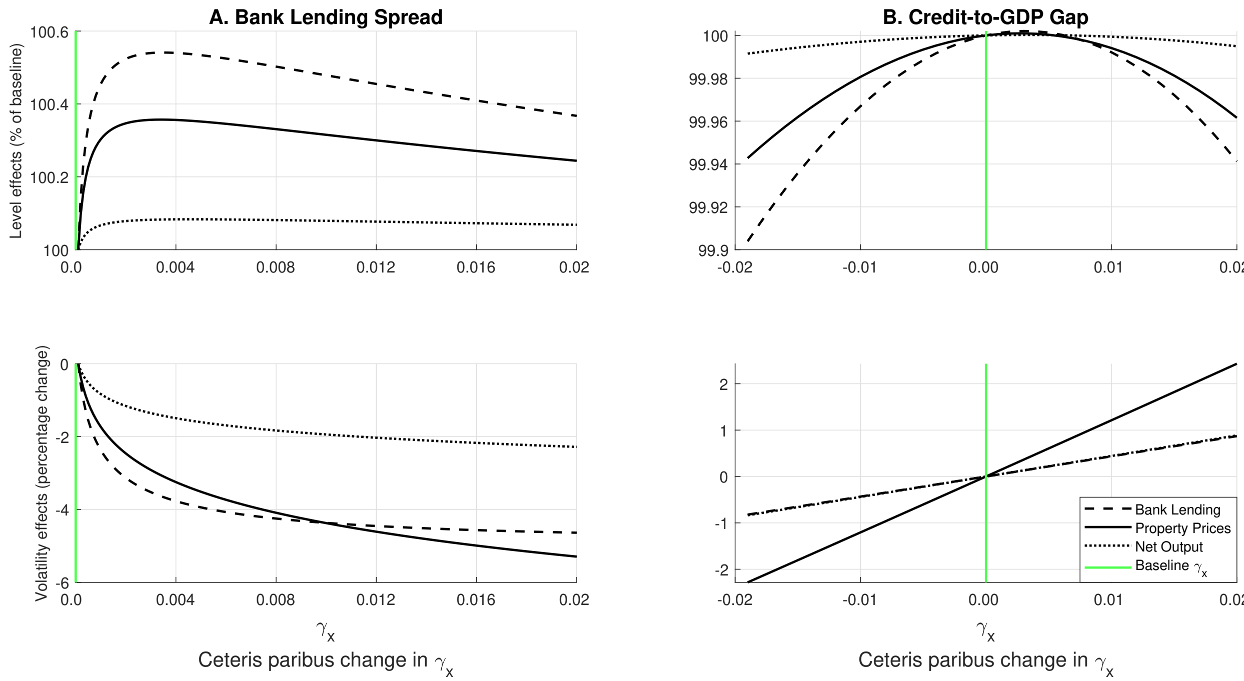
that enter the two expressions (i.e., the collateral constraint and the production function) that revolve around the "collateral channel" and are fundamental to ensure that capital buffer-induced shifts in banks' resilience have effects on the real economy.

5.4 Level and Volatility Effects

What is behind the welfare gains induced by dynamic capital buffers? Figure 7 depicts the level (first row) and volatility effects (second row) on bank lending, property prices and net output of changing the value of parameter γ_x under each of the same two indicators. The shape of the welfare trade-offs presented in Figure 6 is mainly determined by level effects. In contrast to the case of a capital buffer guided by the bank lending spread, at the optimum the positive level effects exerted via a capital buffer guided by the credit-to-GDP gap are negligible.

The magnitude of these welfare gains is notably affected by volatility effects. As opposed to the case of a capital buffer that is guided by the credit-to-GDP gap, one conducted by the expected bank lending spread lowers the volatility of aggregate bank lending, property prices and real economic activity. The explanation of why this sharp difference is in Figure 5. In response to a negative

Figure 7: Level and volatility effects of a dynamic capital buffer



Notes: Level (first row) and volatility effects (second row) on bank lending, property prices and net output of changes in parameter γ_x under the case in which indicator $\widetilde{X}_t$ is the the forward-looking growth rate of the bank lending spread (panel A) and the contemporaneous credit-to-GDP gap (panel B). Level effects are captured by the changes in the second-order approximation to the stochastic mean (expressed as a percent of the baseline level) of the relevant variables. Volatility effects are measured by the percentage change in the second-order approximation to the standard deviation of the same variables. The vertical solid line indicates the value for γ_x under the baseline calibration.

collateral shock, a dynamic capital buffer that builds in response to jumps in the credit-to-GDP gap would have been released, which ultimately would have amplified the negative real effects of the shock by weakening banks' resilience.

5.5 Optimal Dynamic Capital Buffer

By applying the same welfare criterion presented in Section 4, Table 5 reports the individual and social welfare gains and the optimized parameter value for the case in which Problem (23) is solved for γ_x, under each of the two indicators. The results confirm the findings presented in previous subsections and their relevance across agent types. As opposed to the case of a welfare-maximizing capital buffer guided by the credit-to-GDP gap, one conducted by the expected bank lending spread yields significant individual welfare gains. Importantly, such gains are mainly attributed to borrowers. This result further confirms that the main direct real effects of a dynamic capital buffer are transmitted through the problem of the borrower and, more specifically, through the collateral constraint that connects the financial intermediation activity with the production process (equation 17) via a collateral asset that serves as a productive factor (equation 16). This result is also consistent with the one presented in Subsection 5.3 that the shocks in response to which a dynamic capital buffer yields the largest welfare gains are those that more directly affect borrowers through the "collateral channel" (i.e., collateral and TFP shocks).

Table 4: Optimal dynamic capital buffer and welfare gains

	DCB (γ_x)	SCR ($\gamma x100$)	WG Saver ($\lambda_h x100$)	WG Borrower ($\lambda_e x100$)	Social WG ($\lambda x100$)
A. $\{\gamma_x^*\}$					
I. Bank lending spread	0.0050^*	8.00%	0.0628%	0.7480%	0.5656%
II. Credit-to-GDP gap	-0.0037^*	8.00%	-0.0005%	0.0030%	0.0021%

Notes: Second-order approximation to the welfare gains (expressed in percentage permanent consumption) and the corresponding optimized policy parameter value resulting from solving Problem (23) for γ_x under the cases in which $\widetilde{X}_t$ is the forward-looking growth rate of the bank lending spread (Section I) and the contemporaneous credit-to-GDP gap (Section II). Abbreviations DCB, SCR and WG refer to dynamic capital buffer, static capital requirements and welfare gains, respectively. λ_h, λ_e and λ denote households', entrepreneurs' and social consumption equivalent gains, respectively. The policy parameter marked with an asterisk is the one for which social welfare is maximized.

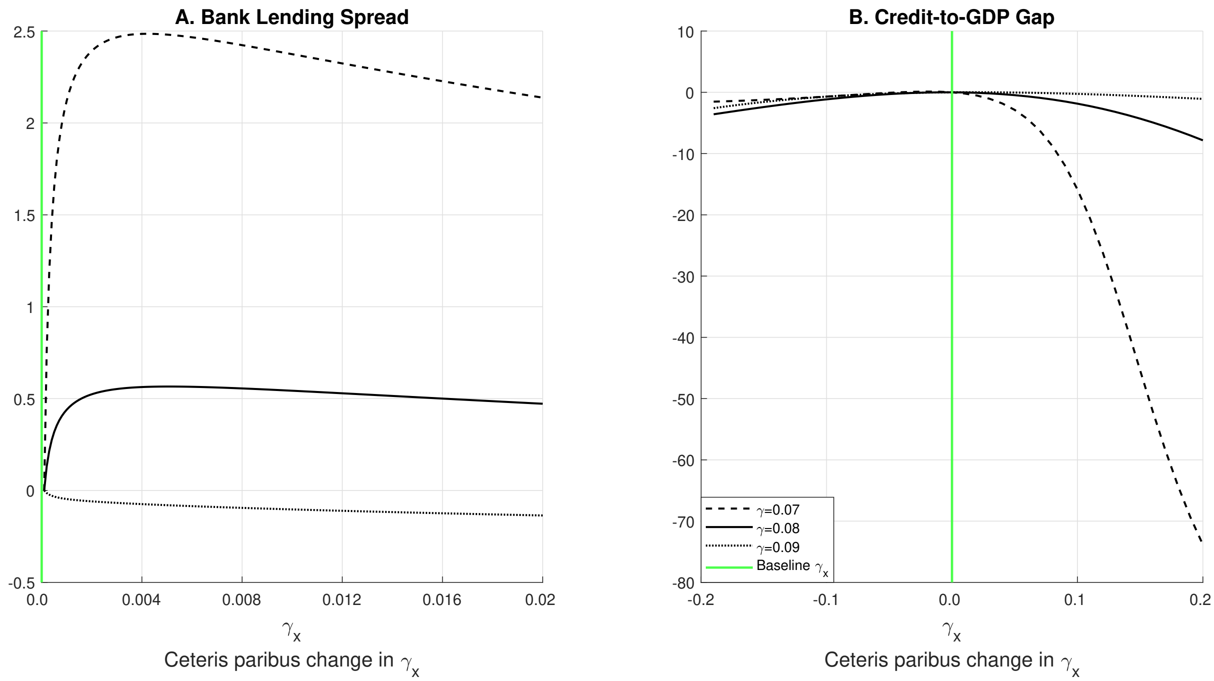
5.6 Interactions Between Static Capital Requirements and a Dynamic Capital Buffer

How do the welfare gains of the optimal dynamic capital buffer depend on γ? To answer this question, Figure 8 plots the welfare gains of changing γ_x for different values of γ under each of the two indicators. Regardless of the level of bank capitalization (γ), a capital buffer guided by the credit-to-GDP gap maximizes social welfare for a value of γ_x of around 0 and the associated welfare gains are not significant. In contrast, the welfare gains generated by the optimal (net interest margin-led) dynamic capital buffer are significant and decrease with static capital requirements. If the level of bank capitalization is sufficiently high (i.e., the bank default probability is sufficiently low) a capital buffer that builds in response to upward shifts in the net interest margin yields welfare losses. This reveals the presence of a trade-off between static capital requirements and dynamic capital buffers.

To shed light on what is the underlying reason behind this result, Figure 9 plots the volatility effects on bank lending, property prices and net output of changing γ_x for different values of γ under the bank lending spread indicator. The stabilization gains of γ_x decrease with γ. This follows from the fact that the volatility of these and other relevant aggregates decreases with γ (increase with bank risk failure), which leaves less room for gains from a dynamic capital buffer when static capital requirements are high.[20] In particular, Panel C reveals that if γ is sufficiently high, there

[20]The result by which higher static capital requirements stabilize the economy is standard in this strand of the literature (e.g., Clerc et al. 2015).

Figure 8: Welfare gains of a dynamic capital buffer: γ_x - γ interactions



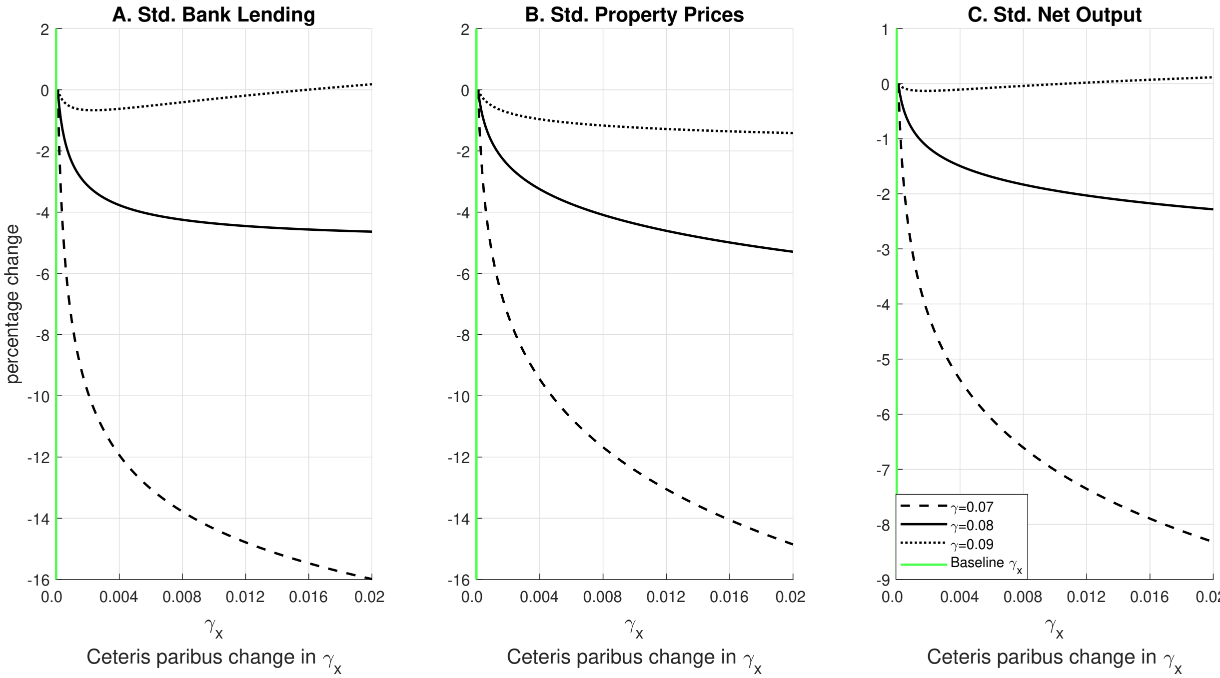
Notes: Second-order approximation to the unconditional social welfare gains (expressed in percentage permanent consumption) as a function of parameter γ_x for different values of γ under the cases in which indicator $\widetilde{X}_t$ is the forward-looking growth rate of the bank lending spread (Panel A) and the contemporaneous credit-to-GDP gap (Panel B). The vertical solid line indicates the value for γ_x under the baseline calibration.

is not much room for generating welfare gains through the transmission described in Subsection 5.2. This is the case because there is not much room for reducing the bank default probability further (see Appendix C). This result shows that there is an "effective lower bound" for the bank default probability (effective upper bound for the static capital requirement) below (above) which a dynamic capital buffer is ineffective (or even counterproductive) as the transmission mechanism previously explained does no longer operate.

The presence of this trade-off between static capital requirements and dynamic capital buffers makes us wonder what is the pair of values for γ_x and γ that solve Problem (23) under the baseline calibration. Table 5 provides such information by reporting the corresponding optimized policy parameter values and welfare gains. Interestingly (and coincidentally), we find that under the baseline calibration (which implies that the value for γ in the baseline scenario is equal to 0.08), the optimized values for the two policy parameters and the resulting welfare gains are very similar to those reported in Subsection 5.5 for the case in which Problem (23) is only solved for γ_x. Put it differently, when the baseline value for γ is 0.08 welfare gains displayed in Panel A of Figure 8 for the case in which the baseline value for γ is 0.07 are simply not attainable because of the large cost from lowering the static capital requirement from 8% to 7% (see Figure 2).[21]

[21] For the shake of completeness, Table 5 also reports the same information for the case in which the indicator is

Figure 9: Volatility effects of a dynamic capital buffer: γ_x - γ interactions



Notes: Volatility effects on bank lending (Panel A), property prices (Panel B) and net output (Panel C) of changes in parameter γ_x for different γ values under the case in which indicator $\widetilde{X}_t$ is the forward-looking growth rate of the bank lending spread. Volatility effects are measured by the percentage change in the second-order approximation to the standard deviation of the same variables. The vertical solid line indicates the value for γ_x under the baseline calibration.

Table 5: Optimal dynamic capital requirements and welfare gains

	DCB (γ_x)	SCR ($\gamma x100$)	WG Saver ($\lambda_h x100$)	WG Borrower ($\lambda_e x100$)	Social WG ($\lambda x100$)
A. $\{\gamma_x^*; \gamma^*\}$					
I. Bank lending spread	0.0049*	8.07%*	0.0655%	0.7484%	0.5667%
II. Credit-to-GDP gap	0.0220*	9.17%*	0.0750%	0.6551%	0.5007%

Notes: Second-order approximation to the welfare gains (expressed in percentage permanent consumption) and the corresponding optimized policy parameter values resulting from solving Problem (23) for γ_x and γ under the cases in which $\widetilde{X}_t$ is the forward-looking growth rate of the bank lending spread (Section I) and the contemporaneous credit-to-GDP gap (Section II). Abbreviations DCB, SCR and WG refer to dynamic capital buffer, static capital requirements and welfare gains, respectively. λ_h, λ_e and λ denote households', entrepreneurs' and social consumption equivalent gains, respectively. Policy parameters marked with an asterisk are those for which social welfare is maximized.

the credit-to-GDP gap. It just confirms our conclusions that there are no significant gains from guiding a dynamic capital buffer with such indicator over the business cycle, also regardless of the level of bank capitalization.

5.7 The Role of Capital Buffer Smoothing

In practice, competent authorities typically build dynamic capital buffers very gradually over time to mitigate any potential unintended consequences a capital requirement hike could have on bank lending (see Section 4 and Appendix C). To assess the welfare effects of smoothing the build-up (and adjustment, more generally speaking) of a dynamic capital buffer in this model economy, we re-formulate equation (18) as

$$\gamma_t = \rho_\gamma \gamma_{t-1} + (1 - \rho_\gamma)\left(\gamma + \gamma_x \widetilde{X}_t\right), \tag{27}$$

where ρ_γ is the capital buffer smoothing parameter. Table 6 provides the individual and social welfare gains (and the associated optimized policy parameter values) for the case in which Problem (23) is solved for ρ_γ, γ_x and γ and for the one in which it is solved only for ρ_γ, γ_x.[22] Smoothing the capital buffer is optimal. It amplifies the welfare gains generated via optimal dynamic capital buffers guided by the expected net interest margin (Table 6A) and it materially improves the trade-off between such buffers and static capital requirements studied in the previous section. This implies that, under high capital buffer smoothing, it is optimal to tolerate a higher level of bank risk failure since the comparatively larger benefits of dynamic capital buffers under higher bank default probability (lower γ) scenarios more than compensate for the cost of lowering γ, in this case from 0.08 to 0.07 (Table 6B).

Table 6: Optimal dynamic capital requirements, buffer smoothing and welfare gains

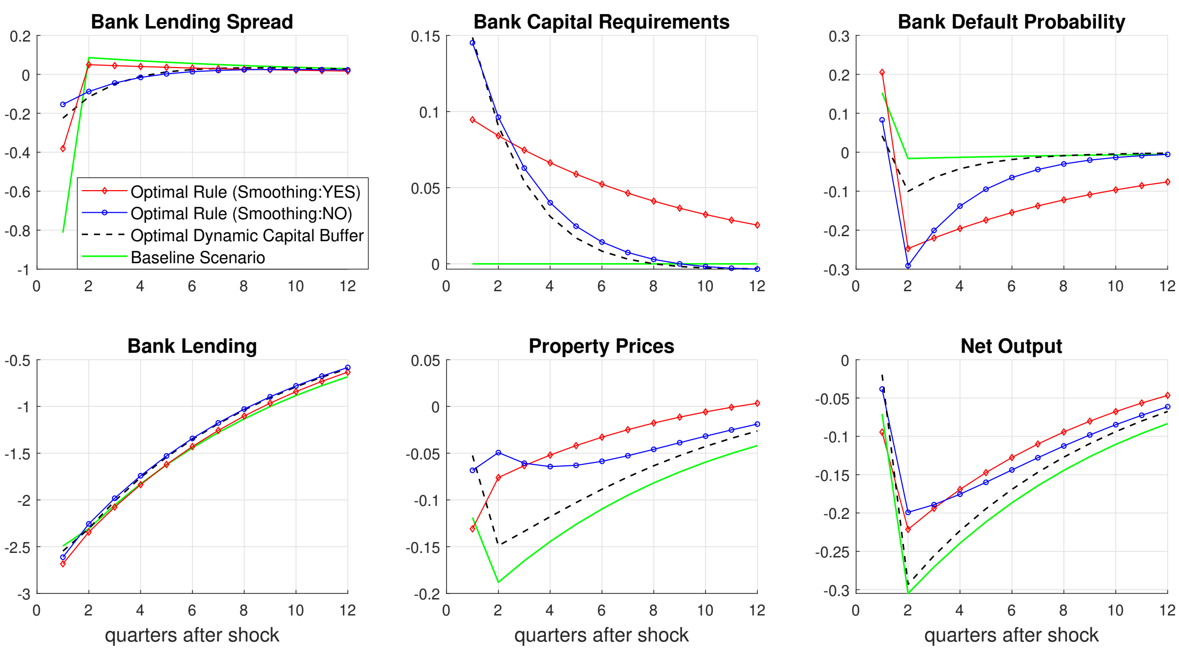
	DCB (γ_x)	Smoothing (ρ_γ)	SCR ($\gamma x100$)	WG Saver ($\lambda_h x100$)	WG Borrower ($\lambda_e x100$)	Social WG ($\lambda x100$)
A. $\left\{\gamma_x^*; \rho_\gamma^*\right\}$						
I. Bank lending spread	0.0089*	0.90*	8.00%	0.4166%	3.8665%	2.9485%
II. Credit-to-GDP gap	−0.0037*	0.00*	8.00%	−0.0005%	0.0030%	0.0021%
B. $\left\{\gamma_x^*; \rho_\gamma^*; \gamma^*\right\}$						
I. Bank lending spread	0.0064*	0.90*	7.00%*	1.0696%	19.1822%	14.3625%
II. Credit-to-GDP gap	0.0363*	0.87*	9.18%*	0.0757%	0.6816%	0.5204%

Notes: Second-order approximation to the welfare gains (expressed in percentage permanent consumption) and the corresponding optimized policy parameter values resulting from solving Problem (23) for γ_x and ρ_γ (Part A) as well as for γ_x, ρ_γ and γ (Part B) under the cases in which $\widetilde{X}_t$ is the forward-looking growth rate of the bank lending spread (Section I) and the contemporaneous credit-to-GDP gap (Section II). Abbreviations DCB, SCR and WG refer to dynamic capital buffer, static capital requirements and welfare gains, respectively. λ_h, λ_e and λ denote households', entrepreneurs' and social consumption equivalent gains, respectively. Policy parameters marked with an asterisk are those for which social welfare is maximized.

[22] The grids of parameter values over which we search to numerically solve Problem (23) in each case are: γ_x $\{(-1.00) - 1.00\}$, ρ_γ $\{0.00 - 0.90\}$, and γ $\{0.07 - 0.15\}$.

Admittedly, these welfare gains are unrealistically high. This is the case as the model assumes that all bank lending that flows to the real economy is obtained by pledging as collateral an asset that is traded in a market with very particular market features (see Subsection 5.2). In practice, bank lending is obtained against various different collateral assets, each of which is traded in markets with very specific characteristics. Some of these market features crucially determine the welfare-improving capacity of dynamic capital requirements (see Section 6).

Figure 10: IRFs to a financial (collateral) shock and capital buffer smoothing



Notes: Variables are expressed in percentage deviations from the steady state with the exceptions of bank capital requirements, the lending spread and the bank default probability, which are shown as absolute deviations from the steady state and are expressed in percentage points, with all of them except for the first one being annualized. The solid line refers to the baseline (calibration) scenario. The diamond, dotted and dashed lines make reference to alternative scenarios that differ from the baseline one in that $\{\gamma_x^* = 0.0064; \rho_\gamma^* = 0.9; \gamma^* = 0.07\}$, $\{\gamma_x = 0.0064; \gamma = 0.07\}$ and $\{\gamma_x^* = 0.005\}$, respectively. Indicator $\widetilde{X}_t$ is the forward-looking growth rate of the bank lending spread. The size of the shock, σ_ϕ, is set to 0.01.

To distill the channels through which lower static capital requirements and higher capital buffer smoothing amplify the stabilization gains attained by dynamic capital buffers, Figure 10 displays the impulse responses of selected aggregates to an exogenous negative collateral shock under three alternative scenarios that we compare against the baseline (calibration) scenario (solid line): (i) a scenario under which social welfare is maximized with respect to ρ_γ, γ_x and γ as in Table 6A.I (diamond line); (ii) one that only differs from the previous one in that ρ_γ is set to a value of 0, to capture the effect of a lower value for γ (dotted line); and (iii) a scenario under which Problem (23) is solved only for γ_x as in Table 5A.I (dashed line).

For a detailed description of the responses and transmission under the baseline scenario (solid line) and the optimal dynamic buffer scenario (dashed line), we refer the reader to Subsection 5.2. Under the optimal rule without smoothing (dotted line), γ is comparatively lower (the bank default probability is higher), which means that: (i) the economy is more unstable, and (ii) there is more room for adjusting the bank default probability downwards. For a given increase in the capital buffer in response to the same shock, the bank default probability falls under this scenario three times more than under the one in which the optimal dynamic capital buffer is in place with γ being one percentage point higher (dashed line). That yields substantially larger economic stabilization gains. Under the optimal rule with smoothing (diamond line), the capital buffer builds more gradually over time. The bank default probability recedes by a little bit less on impact, but then remains below its steady state level for a significantly longer horizon, which enables a more prominent and swift economy recovery.

6 The Role of Collateral Market Features: Distilling the Mechanisms of the "Collateral Channel"

As explained in Subsection 5.2, the model captures several key distinctive features of property markets that strengthen the nexus between financial intermediation and the real economy - enabled by collateral constraints - through which adjustments in capital buffers have real effects. This section further investigates the relevance of the "collateral channel" by assessing the impact of shutting down each of these market features on the welfare and stabilization gains of dynamic capital buffers.

6.1 Collateral Market Features

To shut down each of these collateral market features, we consider four specifications of the model that differ from one another in at least one of the key features of the collateral market (including the baseline model presented in Section 3).

Model A (property-based collateral constraint, exogenous housing supply and housing in utility function): This is the model described in Section 3, which features an economy in which borrowers obtain lending against property collateral. The supply in the property market is exogenous and fixed, entrepreneurs use property as an input in the production process and houdeholds derive utility from housing services.

Model B (earnings-based collateral constraint): The only difference when compared to Model A is that, under this specification of the model, the borrowings of the representative entrepreneur are constrained not by her stock of commercial real estate but by her earnings (EBITDA), defined as the difference between total sales, $A_t h_{e,t-1}^{\nu} n_{e,t}^{(1-\nu)}$, and input costs, $w_t n_{e,t}$ (Drechsel 2023; Drechsel and Kim 2024):

$$l_{e,t} \leq \phi_t^B \left(A_t {h_{e,t-1}}^{\nu} {n_{e,t}}^{(1-\nu)} - w_t n_{e,t} \right), \tag{28}$$

where $\phi_t^B = \phi^B \varepsilon_t^{\phi}$ is a possibly time-varying fraction (or multiple) of the aggregate against which the entrepreneur gets indebted, with $\phi^B \geq 0$ and ε_t^{ϕ} capturing exogenous shocks to the entrepreneurs' borrowing capacity. In this version of the model, property markets remain unchanged and the class of collateral constraint under consideration is also empirically relevant (Lian and Ma 2021).

Model C (endogenous housing supply): It only differs from the baseline model in that the supply of real estate is endogenous:

$$H_t = h_{h,t} + h_{e,t}. \tag{29}$$

H_t evolves according to the standard law for capital accumulation,

$$H_t = (1 - \delta_h) H_{t-1} + IH_t, \tag{30}$$

where δ_h is the depreciation rate of real estate. For simplicity and to consider the opposite extreme case under which adjustments in the market for the collateral asset are fully made via quantities rather than via prices, we assumed that the property price is fixed and normalized to unity.

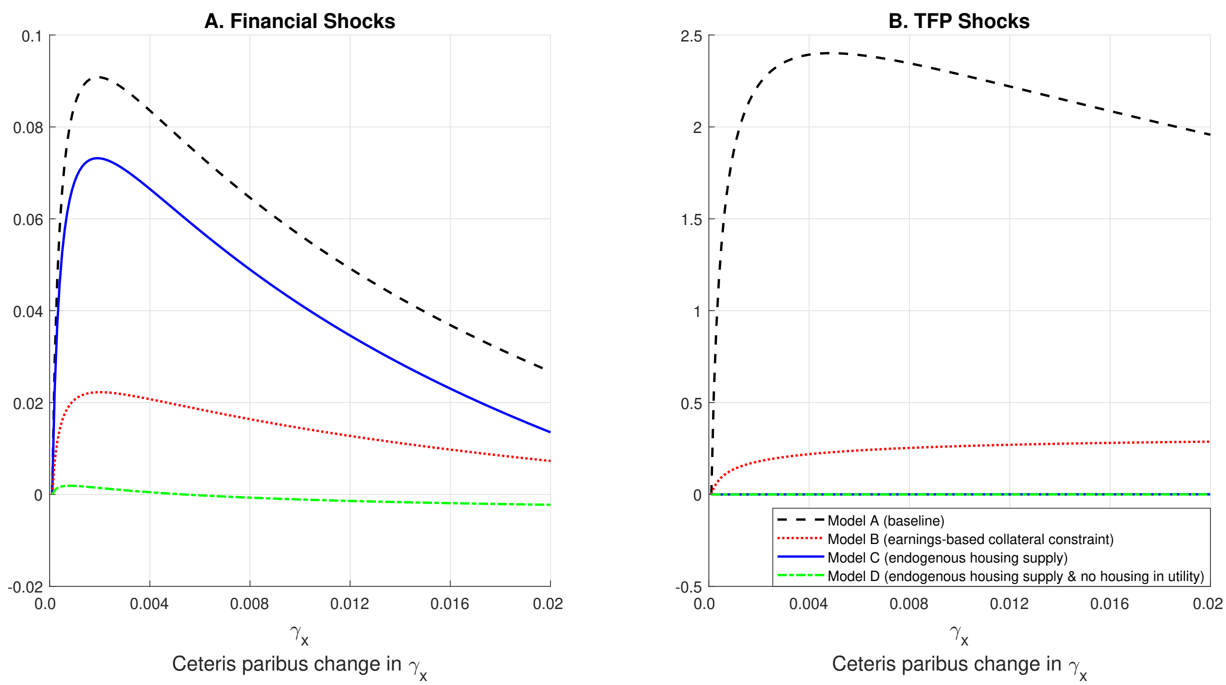
Model D (endogenous housing supply and no housing in utility function): This version of the model differs from Model A in that the supply of real estate is endogenous (as in Model C) and households do not derive utility from housing services. In particular, households do still hold property but accumulate it to be rented by entrepreneurs as an input. In essence, the market features of the collateral asset under this variant of the model are akin to those of a standard physical capital market in a saver-borrower model and very much mimic those of the relevant physical capital (collateral) market in Mendicino et al. (2020).[23] This means that, as opposed to the three other variants of the model, the productive factor that is combined with labor to produce output is a physical capital-like input rather than a property-like one.

[23]For further details on the specification and calibration of each of the four versions of the model, see Appendices D.1 and D.2, respectively.

6.2 Welfare Gains of a Dynamic Capital Buffer

Figure 11 plots the welfare gains of changing the value of parameter γ_x - under each of the four versions of the model - for financial (collateral) shocks (Panel A) and TFP shocks (Panel B). Figure 12 depicts the volatility effects on selected aggregates of varying the same parameter value. Such aggregates are bank lending and the stock of commercial real estate - chosen for the role they play in the nexus between financial intermediation and the real economy - as well as residential real estate (housing services) and private consumption (from which utility is derived).

Figure 11: Welfare gains of a dynamic capital buffer: Collateral market features

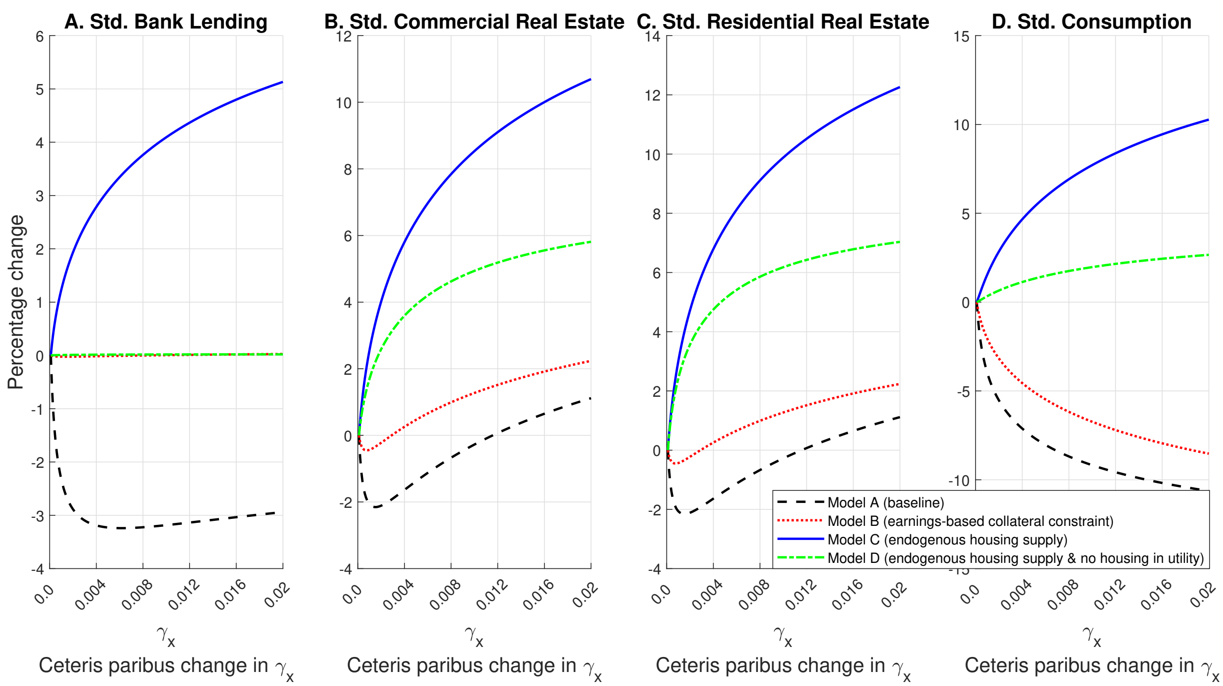


Notes: Second-order approximation to the unconditional social welfare gains (expressed in percentage permanent consumption) as a function of parameter γ_x under the case in which indicator $\widetilde{X}_t$ is the the forward-looking growth rate of the bank lending spread for each of the four versions of the model. Under panels A and B only financial (collateral) and TFP shocks are active with a size equal to 0.01, respectively.

Maximum attainable welfare gains are the largest under Model A. Through the transmission mechanism described in Subsection 5.2, a dynamic capital buffer significantly reduces the volatility of the four variables for the range of welfare-maximizing γ_x parameter values. Welfare gains under Model B are also significant but considerably smaller. In this case, entrepreneurs do not internalize changes in wages, which in turn affect their earnings. As documented in Drechsel and Kim (2024), the externality due to earnings-based collateral constraints differs from the one generated by asset-based collateral constraints (Model A).

Under Models C and D, real estate supply is endogenous and property prices are fixed. This implies that adjustments in the collateral market are fully made via quantities and that these adjustments do not have any consequences on property prices that entrepreneurs may not be internalizing. That is, there are no pecuniary externalities originated by collateral constraints and dynamic capital buffers are counterproductive in the sense that they de-stabilize the economy and do not generate any significant welfare gains. The exception to these welfare consequences of dynamic capital buffers when the supply of the collateral asset is endogenous is in Model C under collateral shocks. Positive level effects through the collateral constraint still operate under this specification of the model (as in Model A; recall Figure 7). In contrast, when all mechanisms around the "collateral channel" are shut-down and the market features of the collateral asset are akin to those of physical capital markets rather than to property ones, dynamic capital buffers do not yield any positive level effects (see Appendix D.3).

Figure 12: Volatility effects of a dynamic capital buffer: Collateral market features



Notes: Volatility effects on bank lending, commercial real estate, residential real estate and aggregate consumption of changes in parameter γ_x under the case in which indicator $\widetilde{X}_t$ is the the forward-looking growth rate of the bank lending spread for each of the of the four versions of the model. Volatility effects are measured by the percentage change in the second-order approximation to the standard deviation of the relevant variables. Only financial (collateral) shocks are active with a size equal to 0.01.

7 Application: Calibration of the Optimal PN-CCyB

To get a sense of how would the optimized parameter values of the optimal rules presented in Section 5 map into the type of capital requirements and buffers typically calibrated by regulators in practice, this section provides an application of our quantitative analysis in the form of a simple framework for computing micro-prudential capital requirements and macro-prudential (releasable) capital buffers, including the so-called "positive neutral countercyclical capital buffer" (henceforth, PN-CCyB).

The PN-CCyB is the rate at which the CCyB is set in the neutral phase of the cycle, a concept akin to the definition of steady state in our model. Setting this rate to a positive value implies that in the steady state there is a capital buffer that could eventually be released, causing overall capital requirements to fall below their steady-state level (which in our model corresponds to γ). The two-sided nature of dynamic capital buffers captured by policy rule (18) allows for this.

The question is how to calibrate the proportion of these steady state (or structural) capital requirements that can be released by means of a dynamic capital buffer and the proportion that is genuinely static and interpretable as microprudential capital requirements, or minimun levels of capital requirements that banks hold over time to mitigate the risk and costs of individual bank failure. We turn to this in the next subsection.

7.1 Overview of the Framework

We define "calibrated optimal capital requirements at the peak of the $\widetilde{X}_t$ cycle" as

$$\gamma_c^* = \underbrace{\gamma^*}_{\substack{\text{Structural} \\ \text{Capital Reqs.}}} + \underbrace{\gamma_x^* \left(n\sigma_{\widetilde{X}}^*\right)}_{\substack{\text{Max Cyclical} \\ \text{Capital Reqs.}}} , \tag{31}$$

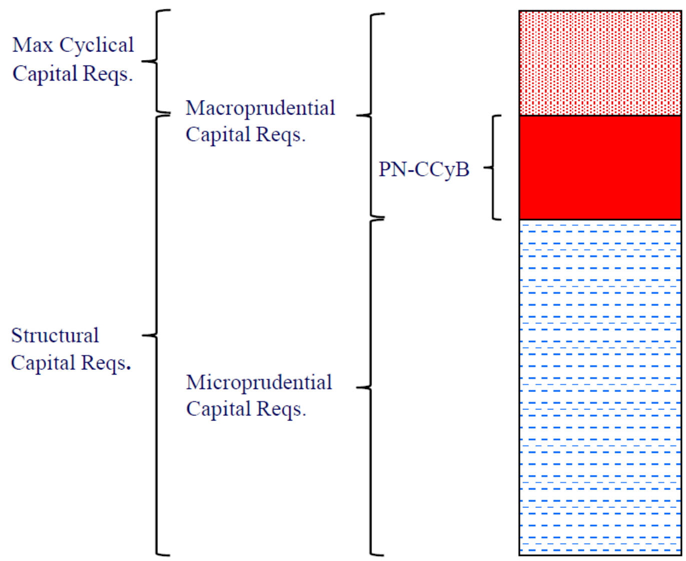
where γ^* and γ_x^* denote the optimized policy parameter values that solve Problem (23); $\sigma_{\widetilde{X}}^*$ is the theoretical standard deviation of $\widetilde{X}_t$ under such optimal capital requirement; and n is a positive number of the choice of the regulator. The first term, γ^*, serves to calibrate optimal steady-state or structural (prudential) capital requirements, whereas $\gamma_x^* \left(n\sigma_{\widetilde{X}}^*\right)$ is computed to calibrate the optimal dynamic capital buffer (or cyclical capital requirements) at the peak of the $\widetilde{X}_t$ cycle (as an add-on to such structural capital requirements).

For simplicity, policy rule (18) is specified to be symmetric in the sense that the degree of responsiveness of γ_t to changes in indicator $\widetilde{X}_t$ (measured by γ_x) is the same one for positive and negative shocks. This means that, the size of the calibrated optimal capital buffer that can be released below the steady-state level of capital requirements (i.e., the calibrated optimal PN-CCyB) should be identical to the size of the calibrated optimal capital buffer at the peak of the cycle as an add-on to such steady-state capital requirements or identical to $\gamma_x^* \left(n\sigma_{\widetilde{X}}^*\right)$. Then, it follows that - according to expression (31) - calibrated optimal microprudential capital requirements are given by the part of optimal static or structural capital requirements that are not the calibrated optimal

PN-CCyB or $[\gamma^* - \gamma_x^*(n\sigma^*_{\widetilde{X}})]$.[24]

Figure 13 provides an illustrative overview of the components of calibrated optimal micro and macro-prudential bank capital requirements under this simple framework.

Figure 13: Illustrative overview of calibrated optimal capital requirements



7.2 The Case of the Euro Area

To illustrate how to apply this simple framework to the case of the quantitative analysis presented in Section 5, Table 7 reports the value that each of the components required to compute calibrated optimal capital requirements (COCR) (as defined in expression 31) take for the cases in which Problem (23) is solved for ρ_γ, γ_x and γ (Part A) and for γ_x and γ only (Part) under the assumption that indicator $\widetilde{X}_t$ is the the expected growth rate of the bank lending spread. Note that the only difference between the two cases is whether capital buffer smoothing is allowed or not.[25] As shown in our quantitative analysis, this is important even if ρ_γ does not directly enter expression (31) since allowing for buffer smoothing affects the volatility of the indicator and the optimized parameter values for γ_x and γ. Based on simulations of the model over large periods of time under the two

[24]Note that, as opposed to the language used in Section 4 here we refer to the components of "calibrated optimal capital requirements" rather than to "optimal capital requirements". They are optimal, as our computations of the different components are based on welfare-maximizing policy rules. However, they are "calibrated optimal" rather than simply "optimal", as such computations rely on the calibration of parameter n and are intended to calibrate the optimal size of a steady state component of optimal capital requirements (i.e., the PN-CCyB) rather than the level optimal capital requirements have in each period over time.

[25]For convenience, the table also reports the associated social welfare gains, computed and presented in Section 5.

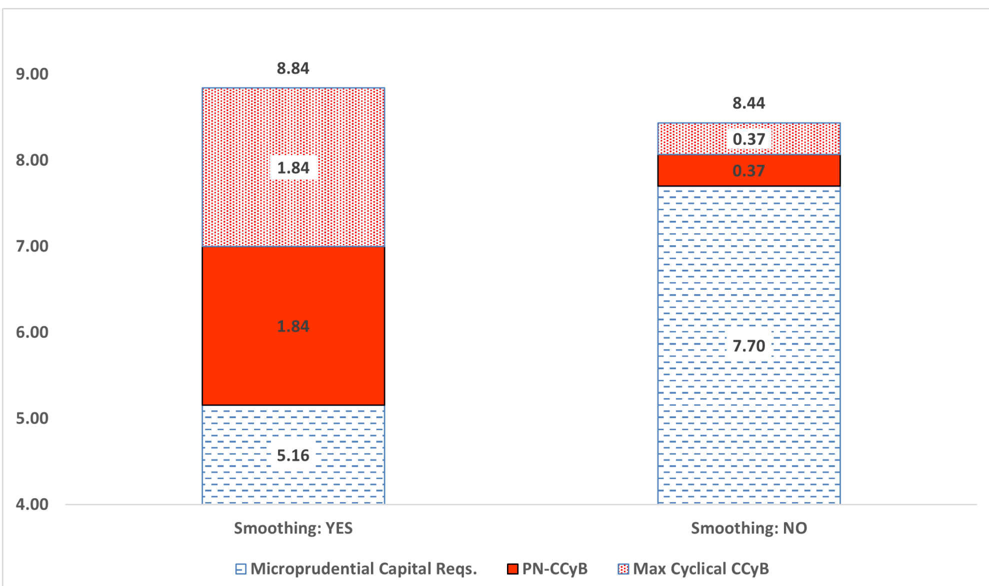
optimal rules, we set parameter n to a value of 1.[26]

Table 7: Calibrated optimal capital requirements

	SCR Param (γ^*)	DCB Param (γ_x^*)	Std(Indicator) $\left(\sigma^*_{\widetilde{X}}\right)$	COCR (γ_c^*)	Social WG ($\lambda x100$)
A. Smoothing					
I. YES	0.0700	0.0064	2.8771	0.0884	14.3625%
II. NO	0.0807	0.0049	0.7491	0.0844	0.5667%

Notes: Calibrated optimal capital requirements and each of its components for the cases in which Problem (23) is solved for γ_x, ρ_γ and γ (Section I) as well as for γ_x and γ (Section II) with indicator $\widetilde{X}_t$ being the expected growth rate of the bank lending spread. For convenience, social welfare gains (expressed in percentage permanent consumption) are reported in each case. Abbreviations SCR, param, DCB, COCR and WG refer to structural capital requirements, parameter, dynamic capital buffer, calibrated optimal capital requirements and welfare gains, respectively.

Figure 14: Calibrated optimal capital requirements



Notes: Calibrated optimal capital requirements and each of its components for the cases in which Problem (23) is solved for γ_x, ρ_γ and γ (Smoothing: YES) as well as for γ_x and γ (Smoothing: NO) with indicator $\widetilde{X}_t$ being the expected growth rate of the bank lending spread. In particular, the figure reports the calibrated optimal: (i) microprudential capital requirements (dashed area), (ii) PN-CCyB (solid area), and (iii) maximum cyclical component of the CCyB (dotted area). Capital requirements are expressed in percentage points.

Figure 14 displays calibrated optimal capital requirements by components for the two optimal rules. The results allow us to complement the findings on optimal dynamic capital requirements

[26] As illustrated in Appendix E, given the dynamics of this model economy this is a reasonable value for parameter n.

presented in Section 5. the rate of the calibrated optimal PN-CCyB - and, more generally speaking, that of dynamic (releasable) capital buffers - is larger with smoothing than without it.[27] The reason is twofold. First, due to a lower γ value (a higher steady-state bank default probability) macroeconomic and financial aggregates (from the net interest margin to consumption) are more volatile, which means that society stands ready for gaining more from having dynamic capital buffers in place. This is reflected in a comparatively higher optimized value for γ_x. Second, less aggressive (i.e., more gradual) responses to expected shifts in the bank lending spread via capital buffer smoothing imply that fluctuations in the bank lending spread are wider under the optimal rule with smoothing (see the difference in the standard deviation of the indicator under the optimal rules in Table 7 and the responses of the net interest margin in Figure 10). Given that the bank lending spread is the variable that drives the adjustments in capital requirements, it seems reasonable that more volatile net interest margins map into larger dynamic capital buffers. For a simulation of dynamic capital requirements over a long period of time under the optimal rule with smoothing, see Appendix E.

8 Conclusion

We reconcile recent evidence on the benefits of building releasable capital buffers when there is headroom for doing so with the theoretical literature on macro-banking models featuring bank risk failure, limited liability and deposit insurance. Our model also captures previous findings in the empirical literature on bank capital regulation including those of the negative impact on short-term lending of an exogenous capital requirement tightening and the macroeconomic and welfare gains of setting relatively conservative static bank capital requirements.

To account for these empirical observations, it is sufficient to allow for certain empirically-relevant features of collateral markets. The simplicity of the model is instrumental to clearly identify the transmission of capital buffers that build in response to upward shifts in net interest margins. However, it comes at the cost of omitting additional considerations that may be policy relevant and which constitute promising avenues for future research. Among others, the assessment of dynamic capital buffers in an environment with twin defaults (Mendicino et al. 2024) that also allows for pecuniary externalities due to collateral constraints.

[27] Given that steady-state capital requirements are lower with smoothing, this means that calibrated optimal micro-prudential capital requirements are significantly lower under the optimal rule with smoothing.

References

Abad, J. (2019). Breaking the sovereign-bank nexus. *Manuscript*.

Abad, J., Martinez-Miera, D., and Suarez, J. (2024). A macroeconomic model of bank's systemic risk taking.

Admati, A. and Hellwig, M. (2013). *The Bankers' New Clothes: What's Wrong with Banking and What to Do about It-New and Expanded Edition*. Princeton University Press.

Admati, A. R., DeMarzo, P. M., Hellwig, M. F., and Pfleiderer, P. C. (2013). Fallacies, irrelevant facts, and myths in the discussion of capital regulation: Why bank equity is not socially expensive. *Max Planck Institute for Research on Collective Goods*, 23:13–7.

Aguilar, P., Hurtado, S., Fahr, S., and Gerba, E. (2019). Quest for robust optimal macroprudential policy.

Aiyar, S., Calomiris, C. W., Hooley, J., Korniyenko, Y., and Wieladek, T. (2014). The international transmission of bank capital requirements: Evidence from the uk. *Journal of Financial Economics*, 113(3):368–382.

Alderson, M. J. and Betker, B. L. (1995). Liquidation costs and capital structure. *Journal of Financial Economics*, 39(1):45–69.

Alpanda, S. and Zubairy, S. (2017). Addressing household indebtedness: Monetary, fiscal or macroprudential policy? *European Economic Review*, 92:47–73.

Angeloni, I. and Faia, E. (2013). Capital regulation and monetary policy with fragile banks. *Journal of Monetary Economics*, 60(3):311–324.

Bahaj, S. and Malherbe, F. (2020). The forced safety effect: How higher capital requirements can increase bank lending. *The Journal of Finance*, 75(6):3013–3053.

Banerjee, A. V. and Duflo, E. (2014). Do firms want to borrow more? testing credit constraints using a directed lending program. *Review of Economic Studies*, 81(2):572–607.

Bedayo, M. and Galán, J. (2024). The impact of the countercyclical capital buffer on credit: Evidence from its accumulation and release before and during covid-19.

Begenau, J. (2020). Capital requirements, risk choice, and liquidity provision in a business-cycle model. *Journal of Financial Economics*, 136(2):355–378.

Begenau, J. and Landvoigt, T. (2022). Financial regulation in a quantitative model of the modern banking system. *The Review of Economic Studies*, 89(4):1748–1784.

Bergant, K. and Forbes, K. (2023). Macroprudential policy during covid-19: The role of policy space. In *MACRO-FINANCIAL STABILITY POLICY IN A GLOBALISED WORLD: LESSONS FROM INTERNATIONAL EXPERIENCE: Selected Papers from the Asian Monetary Policy Forum 2021 Special Edition and MAS-BIS Conference*, pages 130–174. World Scientific.

Bernanke, B. S., Gertler, M., and Gilchrist, S. (1999). The financial accelerator in a quantitative business cycle framework. *Handbook of macroeconomics*, 1:1341–1393.

Bianchi, J. and Mendoza, E. G. (2018). Optimal time-consistent macroprudential policy. *Journal of Political Economy*, 126(2):588–634.

Boissay, F., Collard, F., and Smets, F. (2016). Booms and banking crises. *Journal of Political Economy*, 124(2):489–538.

Burlon, L., Muñoz, M. A., and Smets, F. (2024). The optimal quantity of cbdc in a bank-based economy. *American Economic Journal: Macroeconomics*, 16(4):172–217.

Campello, M., Graham, J. R., and Harvey, C. R. (2010). The real effects of financial constraints: Evidence from a financial crisis. *Journal of financial Economics*, 97(3):470–487.

Canzoneri, M., Diba, B., Guerrieri, L., and Mishin, A. (2021). A static capital buffer is hard to beat. Technical report, working paper, November.

Christiano, L. J., Motto, R., and Rostagno, M. (2014). Risk shocks. *American Economic Review*, 104(1):27–65.

Clerc, L., Derviz, A., Mendicino, C., Moyen, S., Nikolov, K., Stracca, L., Suarez, J., and Vardoulakis, A. (2015). Capital regulation in a macroeconomic model with three layers of default. *International Journal of Central Banking*.

Collard, F., Dellas, H., Diba, B., and Loisel, O. (2017). Optimal monetary and prudential policies. *American Economic Journal: Macroeconomics*, 9(1):40–87.

Corbae, D. and D'Erasmo, P. (2021). Capital buffers in a quantitative model of banking industry dynamics. *Econometrica*, 89(6):2975–3023.

Couaillier, C., Reghezza, A., d'Acri, C. R., and Scopelliti, A. (2022). How to release capital requirements during a pandemic? evidence from euro area banks. *European Central Bank. Working Papers (Online)*.

Dávila, E. and Korinek, A. (2018). Pecuniary externalities in economies with financial frictions. *The Review of Economic Studies*, 85(1):352–395.

Davydiuk, T. (2017). Dynamic bank capital requirements. *Available at SSRN 3110800*.

De Nicolò, G., Gamba, A., and Lucchetta, M. (2014). Microprudential regulation in a dynamic model of banking. *The Review of Financial Studies*, 27(7):2097–2138.

Dewatripont, M., Tirole, J., et al. (1994). *The prudential regulation of banks*, volume 6. MIT press Cambridge, MA.

Drechsel, T. (2023). Earnings-based borrowing constraints and macroeconomic fluctuations. *American Economic Journal: Macroeconomics*, 15(2):1–34.

Drechsel, T. and Kim, S. (2024). Macroprudential policy with earnings-based borrowing constraints. *Journal of Monetary Economics*, page 103595.

Dursun-de Neef, H. Ö., Schandlbauer, A., and Wittig, C. (2023). Countercyclical capital buffers and credit supply: evidence from the covid-19 crisis. *Journal of Banking & Finance*, 154:106930.

Edge, R. M. and Liang, N. (2020). Stronger financial stability governance leads to greater use of the countercyclical capital buffer. *The Brookings Institute*.

Elenev, V., Landvoigt, T., and Van Nieuwerburgh, S. (2021). A macroeconomic model with financially constrained producers and intermediaries. *Econometrica*, 89(3):1361–1418.

Faria-e Castro, M. (2021). A quantitative analysis of the countercyclical capital buffer.

Ferreira, M. H., Haber, T., and Rorig, C. (2023). Financial constraints and firm size: Micro-evidence and aggregate implications.

Gersbach, H. and Rochet, J.-C. (2017). Capital regulation and credit fluctuations. *Journal of Monetary Economics*, 90:113–124.

Gertler, M. and Karadi, P. (2011). A model of unconventional monetary policy. *Journal of monetary Economics*, 58(1):17–34.

Granja, J., Matvos, G., and Seru, A. (2017). Selling failed banks. *The Journal of Finance*, 72(4):1723–1784.

Greenwood, J., Hercowitz, Z., and Huffman, G. W. (1988). Investment, capacity utilization, and the real business cycle. *The American Economic Review*, pages 402–417.

Gropp, R., Mosk, T., Ongena, S., and Wix, C. (2019). Banks response to higher capital requirements: Evidence from a quasi-natural experiment. *The Review of Financial Studies*, 32(1):266–299.

He, Z. and Krishnamurthy, A. (2012). A model of capital and crises. *The Review of Economic Studies*, 79(2):735–777.

Iacoviello, M. (2005). House prices, borrowing constraints, and monetary policy in the business cycle. *American economic review*, 95(3):739–764.

Jermann, U. and Quadrini, V. (2012). Macroeconomic effects of financial shocks. *American Economic Review*, 102(1):238–271.

Jiménez, G., Ongena, S., Peydró, J.-L., and Saurina, J. (2017). Macroprudential policy, countercyclical bank capital buffers, and credit supply: Evidence from the spanish dynamic provisioning experiments. *Journal of Political Economy*, 125(6):2126–2177.

Jordà, Ò., Schularick, M., and Taylor, A. M. (2017). Macrofinancial history and the new business cycle facts. *NBER macroeconomics annual*, 31(1):213–263.

Kiyotaki, N. and Moore, J. (1997). Credit cycles. *Journal of political economy*, 105(2):211–248.

Lambertini, L., Mendicino, C., and Punzi, M. T. (2013). Leaning against boom-bust cycles in credit and housing prices. *Journal of Economic dynamics and Control*, 37(8):1500–1522.

Lang, J. H. and Menno, D. (2023). The state-dependent impact of changes in bank capital requirements.

Lian, C. and Ma, Y. (2021). Anatomy of corporate borrowing constraints. *The Quarterly Journal of Economics*, 136(1):229–291.

Lorenzoni, G. (2008). Inefficient credit booms. *The Review of Economic Studies*, 75(3):809–833.

Malherbe, F. (2020). Optimal capital requirements over the business and financial cycles. *American Economic Journal: Macroeconomics*, 12(3):139–174.

Mathur, A., Naylor, M., and Rajan, A. (2023). Creditable capital: macroprudential regulation and bank lending in stress.

Mendicino, C., Nikolov, K., Rubio-Ramírez, J. F., Suarez, J., and Supera, D. (2024). Twin default crises. *Journal of Finance, forthcoming*.

Mendicino, C., Nikolov, K., Suarez, J., and Supera, D. (2018). Optimal dynamic capital requirements. *Journal of Money, Credit and Banking*, 50(6):1271–1297.

Mendicino, C., Nikolov, K., Suarez, J., and Supera, D. (2020). Bank capital in the short and in the long run. *Journal of Monetary Economics*, 115:64–79.

Mian, A., Sufi, A., and Verner, E. (2017). Household debt and business cycles worldwide. *The Quarterly Journal of Economics*, 132(4):1755–1817.

Muñoz, M. (2021). Rethinking capital regulation: The case for a dividend prudential target. *International Journal of Central Banking*, 17(3):271–336.

Repullo, R. (2004). Capital requirements, market power, and risk-taking in banking. *Journal of financial Intermediation*, 13(2):156–182.

Repullo, R. (2013). Cyclical adjustment of capital requirements: A simple framework. *Journal of Financial Intermediation*, 22(4):608–626.

Repullo, R. and Suarez, J. (2013). The procyclical effects of bank capital regulation. *The Review of financial studies*, 26(2):452–490.

Schmitt-Grohé, S. and Uribe, M. (2007). Optimal simple and implementable monetary and fiscal rules. *Journal of monetary Economics*, 54(6):1702–1725.

Schularick, M. and Taylor, A. M. (2012). Credit booms gone bust: monetary policy, leverage cycles, and financial crises, 1870–2008. *American Economic Review*, 102(2):1029–1061.

Van den Heuvel, S. J. (2008). The welfare cost of bank capital requirements. *Journal of Monetary Economics*, 55(2):298–320.

Van der Ghote, A. (2021). Interactions and coordination between monetary and macroprudential policies. *American Economic Journal: Macroeconomics*, 13(1):1–34.

A Equations of the Model

This section presents the full set of equilibrium equations of the model described in Section 3.

A.1 Households

Households seek to maximize their objective function subject to the following budget constraint:

$$c_{h,t} + q_t(h_{h,t} - h_{h,t-1}) + d_{h,t} + b_{h,t} + T_t = \widetilde{R}_t^d d_{h,t-1} + R_{t-1}^b b_{h,t-1} + w_t n_{h,t} + \Omega_t, \tag{A.1}$$

where the realized gross return on bank deposits is given by $\widetilde{R}_t^d = R_{t-1}^d - (1-\kappa)\Psi_t$.

Their choice variables are $c_{h,t}$, $h_{h,t}$, $d_{h,t}$, $b_{h,t}$ and $n_{h,t}$. The first order conditions of the problem read

$$\lambda_{h,t} = \left[c_{h,t} - \frac{n_{h,t}^{1+\phi}}{(1+\phi)} \right]^{-\sigma_u}, \tag{A.2}$$

$$q_t \lambda_{h,t} = \frac{j_{h,t}}{h_{h,t}} + \beta_h E_t \left(q_{t+1} \lambda_{h,t+1} \right), \tag{A.3}$$

$$\lambda_{h,t} = \beta_h E_t \left(\lambda_{h,t+1} \widetilde{R}_{t+1}^d \right), \tag{A.4}$$

$$\lambda_{h,t} = \beta_h E_t \left(\lambda_{h,t+1} R_t^b \right), \tag{A.5}$$

$$w_t = n_{h,t}^{\phi}, \tag{A.6}$$

where $\lambda_{h,t}$ is the Lagrange multiplier on the budget constraint of the representative household.

A.2 Banking Groups

A.2.1 Bankers

The law of motion of bankers' net worth is

$$N_{b,t} = \theta_b \rho_{b,t} e_{b,t-1} + (1-\theta_b)\, \chi_b \rho_{b,t} N_{b,t-1}. \tag{A.7}$$

The gross return on equity can be defined as

$$\rho_{b,t+1} = \frac{[1 - G_{t+1}(\overline{\omega}_{b,t+1})] R^l_{t+1} l_{b,t} - [1 - F_{t+1}(\overline{\omega}_{b,t+1})] R^d_t d_{b,t}}{e_{b,t}}. \tag{A.8}$$

The stochastic discount factor of the banker is

$$\Lambda_{b,t+1} = \Lambda_{h,t+1} \left(1 - \theta_b + \theta_b \upsilon_{b,t+1}\right). \tag{A.9}$$

The transfer from retiring bankers to the household net of the initial endowment received by new bankers is given by

$$\Omega_t = (1-\theta_b)\, \rho_{b,t} \left(e_{b,t-1} - \chi_b N_{b,t-1}\right). \tag{A.10}$$

A.2.2 Banks

Banks maximize their objective function subject to a balance sheet identity and a capital requirement constraint,

$$l_{b,t} = e_{b,t} + d_{b,t}, \tag{A.11}$$

$$e_{b,t} \geq \gamma_t l_{b,t}. \tag{A.12}$$

The resulting optimality condition reads

$$E_t \left\{ \Lambda_{b,t+1} \left[\left(1 - G_{t+1}(\overline{\omega}_{b,t+1})\right) R^l_{t+1} - \left(1 - F_{t+1}(\overline{\omega}_{b,t+1})\right) (1-\gamma_t)\, R^d_t \right] \right\} = \gamma_t \upsilon_{b,t}. \tag{A.13}$$

The threshold for the value of $\omega_{b,t}$ below which the bank defaults is

$$\overline{\omega}_{b,t+1} = (1-\gamma_t)\, \frac{R^d_t}{R^l_{t+1}}. \tag{A.14}$$

A.3 Entrepreneurs

Entrepreneurs seek to maximize their objective function subject to a budget constraint

$$c_{e,t} + q_t(h_{e,t} - h_{e,t-1}) + R_t^l l_{e,t-1} + w_t n_{e,t} = Y_{e,t} + l_{e,t}, \tag{A.15}$$

where the homogeneous final good is produced by using a Cobb-Douglas technology that combines labor and CRE as follows

$$Y_{e,t} = A_t h_{e,t-1}^{\nu} n_{e,t}^{(1-\nu)}, \tag{A.16}$$

The maximization of entrepreneurs' objective function is also constrained by a collateral constraint:

$$l_{e,t} \leq \phi_t^A q_t h_{e,t}, \tag{A.17}$$

Their choice variables are $c_{e,t}$, $l_{e,t}$, $n_{e,t}$ and $h_{e,t}$. The first order conditions are given by

$$\lambda_{e,t} = {c_{e,t}}^{-\sigma_u}, \tag{A.18}$$

$$\lambda_{e,t} = \beta_e E_t \left(\lambda_{e,t+1} R_{t+1}^l \right) + \mu_{e,t}. \tag{A.19}$$

$$q_t \lambda_{e,t} = \beta_e E_t \left[\lambda_{e,t+1} \left(q_{t+1} + \frac{\nu Y_{e,t+1}}{h_{e,t}} \right) \right] + \mu_{e,t} \phi_t^A E_t(q_t), \tag{A.20}$$

$$w_t = \frac{(1-\nu) Y_{e,t}}{n_{e,t}}, \tag{A.21}$$

where $\lambda_{e,t}$ and $\mu_{e,t}$ are the Lagrange multipliers on the budget constraint and the collateral constraint of the representative entrepreneur, respectively.

A.4 Public Authorities

A.4.1 Prudential Authority

The prudential authority sets the regulatory capital requirement according to a simple rule

$$\gamma_t = \gamma + \gamma_x \widetilde{X}_t \tag{A.22}$$

A.4.2 Deposit Insurance Scheme

The DIS collects lump-sump taxes to cover the gap between the losses on insured deposits incurred by households due to bank failure and the repossessed bank assets

$$T_t = \kappa \Psi_t d_{h,t-1}, \tag{A.23}$$

where total losses incurred by households on deposits that are not covered with repossessed bank assets are given by

$$\Psi_t d_{h,t-1} = \left[\left(R^d_{t-1} d_{b,t-1} \right) F(\overline{\omega}_{b,t}) - (1-\mu_b) R^l_t l_{b,t-1} G_t(\overline{\omega}_{b,t}) \right], \tag{A.24}$$

$F(\overline{\omega}_{b,t})$ is the probability of bank default

$$F(\overline{\omega}_{b,t}) = \int_0^{\overline{\omega}_{b,t}} f\left(\omega_b; \sigma_{\omega,t}\right) d\omega_b = \digamma \left[\frac{\log(\overline{\omega}_{b,t}) + \sigma^2_{\omega,t}/2}{\sigma_{\omega,t}} \right], \tag{A.25}$$

and $G(\overline{\omega}_{b,t})$ is the share of total assets owned by bankers which end up in default

$$G(\overline{\omega}_{b,t}) = \int_0^{\overline{\omega}_{b,t}} \omega_b f\left(\omega_b; \sigma_{\omega,t}\right) d\omega_b = \digamma \left[\frac{\log(\overline{\omega}_{b,t}) - \sigma^2_{\omega,t}/2}{\sigma_{\omega,t}} \right], \tag{A.26}$$

with $f\left(\omega_b; \sigma_{\omega,t}\right)$ and $\digamma\,[.]$ denoting the probability density function and the cumulative distribution function of the bank-idiosyncratic asset return shock $\omega_{b,t}$, respectively. This shock is i.i.d. across banks and follows a log-normal distribution with a mean of one and a standard deviation, $\sigma_{\omega,t} = \sigma_\omega \varepsilon^\omega_t$, that evolves stochastically over time, driven by some aggregate risk shocks ε^ω_t.

A.5 Aggregation and Market Clearing

Market clearing is implied by the Walras' law, by aggregating all the budget constraints. The aggregate resource constraint of the economy represents the equilibrium condition for the final goods market:

$$Y_{e,t} = C_t + \mu_b R^l_t l_{b,t-1} G_t(\overline{\omega}_{b,t}). \tag{A.27}$$

Similarly, in equilibrium labor demand equals total labor supply,

$$n_{e,t} = n_{h,t}. \tag{A.28}$$

The stock of real estate must equal the demand coming from households and entrepreneurs

$$\overline{H} = h_{h,t} + h_{e,t}. \tag{A.29}$$

Aggregate net worth of bankers equals equity issued by banks

$$N_{b,t} = e_{b,t}. \tag{A.30}$$

Similarly, in equilibrium demand for loans of entrepreneurs equals bank credit supply

$$l_{e,t} = l_{b,t}. \tag{A.31}$$

The stock of bank deposits held by households must be equal to banks' deposit funding

$$d_{h,t} = d_{b,t}. \tag{A.32}$$

In equilibrium, the risk-free asset is in zero net supply

$$b_t = 0. \tag{A.33}$$

A.6 Shocks

The following zero-mean, AR(1) shocks are present in the baseline calibration model: A_t, ε_t^h, ε_t^ϕ, ε_t^ω. These shocks follow the processes given by:

$$\log A_t = \rho_A \log A_{t-1} + e_t^A,\ e_t^A \sim N(0, \sigma_A). \tag{A.34}$$

$$\log \varepsilon_t^h = \rho_h \log \varepsilon_{t-1}^h + e_t^h,\ e_t^h \sim N(0, \sigma_h), \tag{A.35}$$

$$\log \varepsilon_t^\phi = \rho_\phi \log \varepsilon_{t-1}^\phi + e_t^\phi,\ e_t^\phi \sim N(0, \sigma_\phi), \tag{A.36}$$

$$\log \varepsilon_t^{\omega} = \rho_{\omega} \log \varepsilon_{t-1}^{\omega} + e_t^{\omega},\ \ e_t^{\omega} \sim N(0, \sigma_{\omega}). \tag{A.37}$$

B Data and Sources

This section presents the dataset employed for the construction of Figure 1 and the calibration of the model in Section 3 of the paper.

Credit-to-GDP Gap: Euro area - Credit-to-GDP gaps (actual-trend), Credit from All sectors to Private non-financial sector, percentage of GDP. Source: BIS statistics.

Gross Domestic Product: Gross domestic product at market prices, Euro area (fixed composition), Domestic (home or reference area), Total economy, Euro, Current prices, Non transformed data, Calendar and seasonally adjusted data. Source: ESA2010 National accounts, Main aggregates, Eurostat.

GDP Deflator: Gross domestic product at market prices, Euro area (fixed composition), Domestic (home or reference area), Total economy, Index, Deflator (index), Non transformed data, Calendar and seasonally adjusted data. Source: ESA2010 National accounts, Main aggregates, Eurostat.

Bank Loans to NFCs: Loans vis-a-vis euro area NFC reported by MFI excluding ESCB in the euro area (stock), Euro area (changing composition), Outstanding amounts at the end of the period (stocks), MFIs excluding ESCB reporting sector - Loans, Total maturity, All currencies combined - Euro area (changing composition) counterpart, Non-Financial corporations (S.11) sector, denominated in Euro, data Neither seasonally nor working day adjusted. Source: MFI Balance Sheet Items (BSI Statistics), European Central Bank.

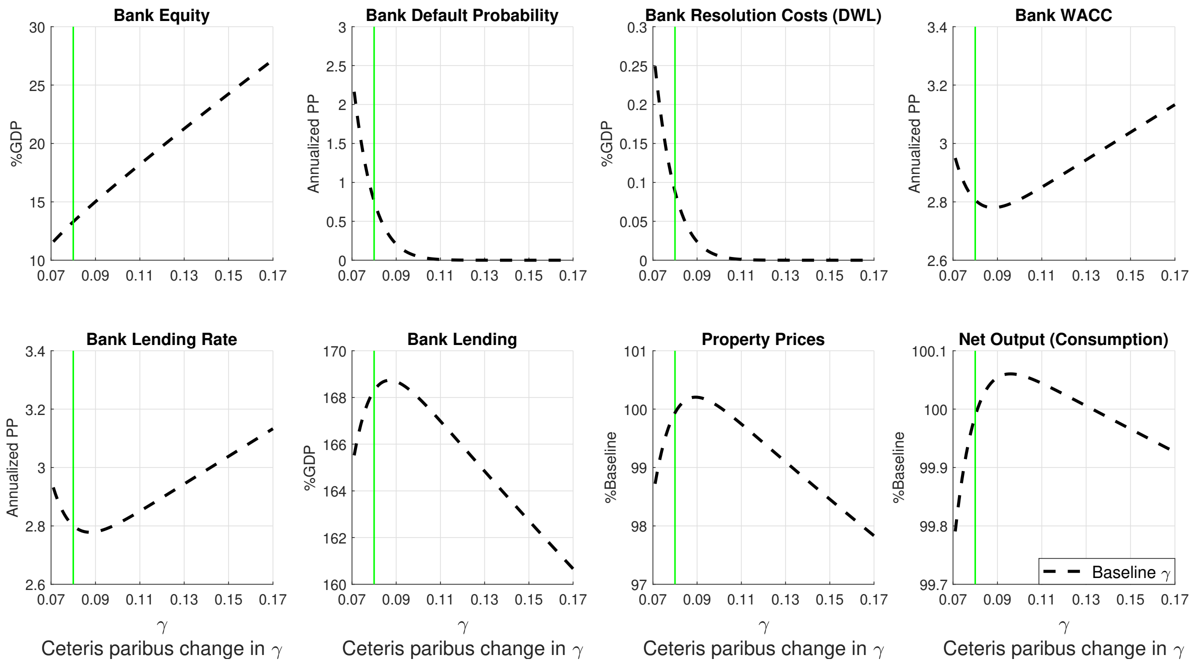
Deposit Interest Rate: Bank interest rates, overnight deposits from households - euro area, Euro area (changing composition), Annualised agreed rate (AAR) / Narrowly defined effective rate (NDER), Credit and other institutions (MFI except MMFs and central banks) reporting sector, Overnight deposits, Total original maturity, New business coverage, Households and non-profit institutions serving households (S.14 and S.15) sector, denominated in Euro. Source: MFI Interest Rate Statistics (MIR Statistics), European Central Bank.

NFC Loans Interest Rate: Bank interest rates, loans to corporations with an original maturity of up to one year (outstanding amounts) - euro area, Euro area (changing composition), Annualised agreed rate (AAR) / Narrowly defined effective rate (NDER), Credit and other institutions (MFI except MMFs and central banks) reporting sector, Loans, Up to 1 year original maturity, Outstanding amount business coverage, Non-Financial corporations (S.11) sector, denominated in Euro. Source: MFI Interest Rate Statistics (MIR Statistics), European Central Bank.

C Static Capital Requirements: Transmission

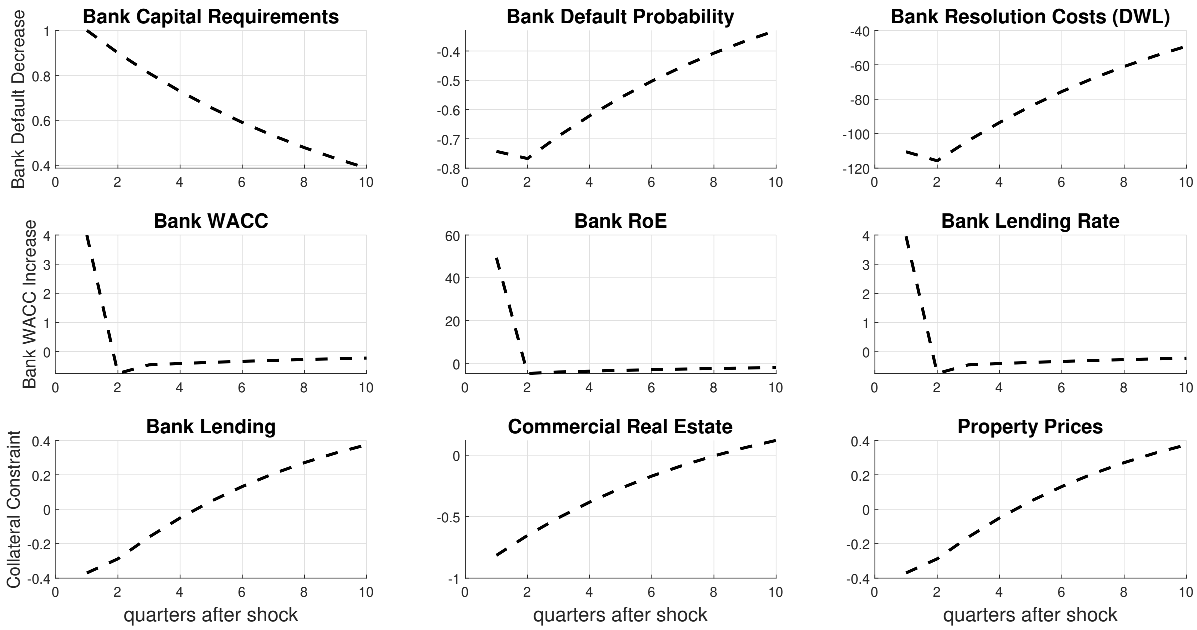
This section outlines the transmission of permanent and transitory increases in static capital requirements, γ.

Figure C.1: Permanent increase in static capital requirements



Notes: The figure reports the steady state level of key selected aggregates as a function of γ. Bank equity, lending and resolution costs are expressed as a percent of quarterly GDP. Banks' default probability, WACC and lending rate are expressed in annualized percentage points. Property prices and net output are expressed as a percentage of their baseline levels. The solid line indicates the baseline static capital requirements level. Abbreviations DWL refers to deadweight loss.

Figure C.2: Transitory increase in static capital requirements



Notes: Impulse responses of selected aggregates to a capital requirement shock. The shock size, σ_γ, is set to 0.125 such that, on impact, the capital requirement goes up by 1 percentage point. Variables are expressed in percentage deviations from the steady state. The exceptions are bank capital requirements, the bank default probability, the bank WACC, the bank RoE and the lending rate, which are shown as absolute deviations from the steady state and are expressed in percentage points, with all of them being annualized except for the case of capital requirements.

D The Role of Collateral Market Features

D.1 Equations of the Models

This section presents the equations of models B and C that differ from those of Model A as well as the equations of Model D that differ from those of Model C. For the remainder of the section, it is useful to define $\phi_t^s = \phi^s \varepsilon_t^\phi$ as a possibly time-varying fraction (or multiple) of the aggregate against which the entrepreneur gets indebted, with $s = \{A, B, C, D\}$, $\phi^s \geq 0$, and ε_t^ϕ capturing exogenous shocks to the entrepreneurs' borrowing capacity.

D.1.1 Model B

Under Model B, the borrowing limit faced by entrepreneurs takes the form of an earnings-based collateral constraint

$$l_{e,t} \leq \phi_t^B \left(A_t {h_{e,t-1}}^{\nu} {n_{e,t}}^{(1-\nu)} - w_t n_{e,t} \right). \tag{D.1}$$

The first order conditions with respect to $l_{e,t}$ and $h_{e,t}$ are given by

$$q_t \lambda_{e,t} = \beta_e E_t \left[\lambda_{e,t+1} \left(q_{t+1} + \frac{\nu Y_{e,t+1}}{h_{e,t}} \right) \right] + \mu_{e,t} \phi_{t+1}^B E_t \left(\frac{\nu Y_{e,t+1}}{h_{e,t}} \right), \tag{D.2}$$

$$w_t \lambda_{e,t} = \lambda_{e,t} \frac{(1-\nu) Y_{e,t}}{n_{e,t}} + \mu_{e,t} \phi_t^B \left[\left(\frac{(1-\nu) Y_{e,t}}{n_{e,t}} \right) - w_t \right]. \tag{D.3}$$

D.1.2 Model C

Households' budget constraint is given by:

$$c_{h,t} + q_t[h_{h,t} - (1-\delta) h_{h,t-1}] + d_{h,t} + b_{h,t} + T_t = \widetilde{R}_t^d d_{h,t-1} + R_{t-1}^b b_{h,t-1} + w_t n_{h,t} + \Omega_t. \tag{D.4}$$

The first order condition with respect to $h_{h,t}$ reads

$$q_t \lambda_{h,t} = \frac{j_{h,t}}{h_{h,t}} + \beta_h E_t \left[\lambda_{h,t+1} q_{t+1} (1-\delta) \right]. \tag{D.5}$$

Entrepreneurs' budget constraint is given by:

$$c_{e,t} + q_t[h_{e,t} - (1-\delta) h_{e,t-1}] + R_t^l l_{e,t-1} + w_t n_{e,t} = Y_{e,t} + l_{e,t}. \tag{D.6}$$

The first order condition with respect to $h_{e,t}$ reads

$$q_t \lambda_{e,t} = \beta_e E_t \left[\lambda_{e,t+1} \left(q_{t+1}(1-\delta) + \frac{\nu Y_{e,t+1}}{h_{e,t}} \right) \right] + \mu_{e,t} \phi_t^C E_t(q_t). \tag{D.7}$$

The aggregate stock of produced real estate must be equal to the stock of housing held by savers and borrowers:

$$H_t = h_{h,t} + h_{e,t}, \tag{D.8}$$

where H_t evolves according to the standard law for capital accumulation,

$$H_t = (1-\delta_h) H_{t-1} + IH_t. \tag{D.9}$$

The equilibrium condition for the final goods market reads

$$Y_{e,t} = C_t + IH_t + \mu_b R_t^l l_{b,t-1} G_t(\overline{\omega}_{b,t}). \tag{D.10}$$

D.1.3 Model D

Households' budget constraint is given by:

$$c_{h,t} + q_t[h_{h,t} - (1-\delta) h_{h,t-1}] + s_t h_{h,t} + d_{h,t} + b_{h,t} + T_t = \widetilde{R}_t^d d_{h,t-1} + R_{t-1}^b b_{h,t-1} + w_t n_{h,t} + r_t^h h_{h,t-1} + \Omega_t + \Xi_t, \tag{D.11}$$

where s_t is the per unit management cost subject to which households can hold real estate (interpretable as physical capital), r_t^h is the rental rate and Ξ_t denotes profits from capital management firms.

The first order condition with respect to $h_{h,t}$ reads

$$(q_t + s_t) \lambda_{h,t} = \beta_h E_t \left[\lambda_{h,t+1} (r_{t+1}^h + (1-\delta) q_{t+1}) \right]. \tag{D.12}$$

Entrepreneurs' budget constraint is given by:

$$c_{e,t} + q_t[h_{e,t} - (1-\delta) h_{e,t-1}] + R_t^l l_{e,t-1} + w_t n_{e,t} + r_t^h (H_{t-1} - h_{e,t-1}) = Y_{e,t} + l_{e,t}, \tag{D.13}$$

where the homogeneous final good is produced by using a Cobb-Douglas technology that combines labor and the total stock of real estate as follows

$$Y_{e,t} = A_t H_{t-1}^{\nu} n_{e,t}^{(1-\nu)}. \tag{D.14}$$

The first order conditions with respect to $h_{e,t}$ and H_t read

$$q_t \lambda_{e,t} = \beta_e E_t \left[\lambda_{e,t+1} \left(r_{t+1}^h + q_{t+1}(1-\delta) + \frac{\nu Y_{e,t+1}}{h_{e,t}} \right) \right] + \mu_{e,t} \phi_t^D E_t(q_t), \tag{D.15}$$

$$r_t^h = \frac{\nu Y_{e,t}}{H_t}. \tag{D.16}$$

The equilibrium condition for the final goods market reads

$$Y_{e,t} = C_t + IH_t + \mu_b R_t^l l_{b,t-1} G_t(\overline{\omega}_{b,t}) + z(h_{h,t}). \tag{D.17}$$

Capital Management Firms They maximize profits:

$$\Xi_t = s_t h_{h,t} - z(h_{h,t}), \tag{D.18}$$

where $z(h_{h,t}) = \frac{\xi}{2} h_{h,t}^2$ is a cost function that we assume to be quadratic, with $\xi > 0$. Then, the first order condition is given by $s_t = \xi h_{h,t}$.

D.2 Calibration

Under the baseline calibration for Model A, all steady state rates and ratios with which we match the list of data targets reported in Tables 1B and 2A remain unchanged across the four different versions of the model with two exceptions; the bank lending-to-GDP ratio and the households' property wealth-to-GDP ratio. For comparability purposes, we (re-)calibrate only the parameters that are strictly needed to match these two data targets across the different versions of the model while all other parameters remain at their baseline calibration values (Table D.1).

Under Model B, the bank lending-to-GDP ratio is the only data target that is no longer matched under the baseline calibration. To match it, we set the value of the borrowing limit parameter, ϕ^B, to a value of 56.[28] Under Model C, we simultaneously match the two data targets by fixing the depreciation rate of real estate to a value of 0.0005. Under Model D and given that in this case real

[28]Note that the value of borrowers' property holdings is significantly larger than that of quarterly NFC earnings.

estate is interpretable as physical capital in all respects, the physical capital share in production and the capital management cost parameter, ξ, are set to conventional values of 0.3 and 0.006, respectively (Mendicino et al. 2020). For comparability purposes, we fix the depreciation rate to the same value as in Model C. Then, the borrowing limit parameter, ϕ^D is set to 0.046 such that the data target for the bank lending-to-GDP ratio is matched.[29]

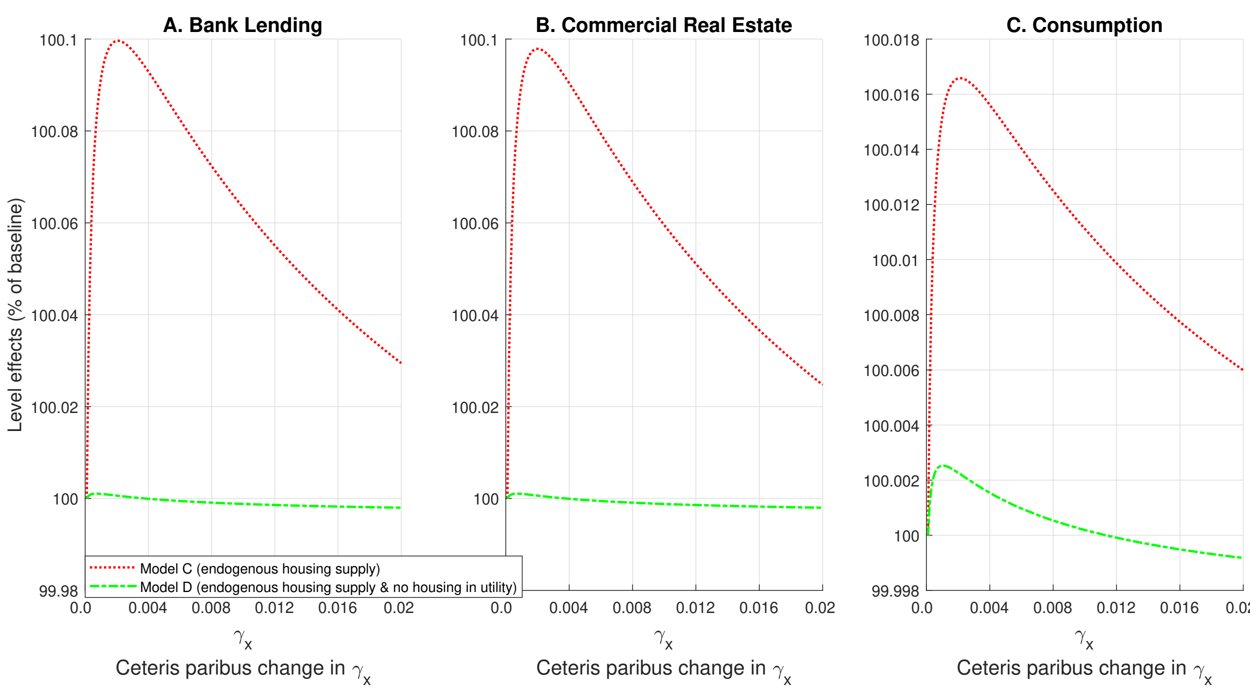
Table D.1: Model fit

Variable	Description	Data	Model A	Model B	Model C	Model D
$\overline{l_b}/\overline{Y}$	Bank lending-to-GDP ratio	1.682	1.683	1.680	1.608	1.689
$\overline{q}\overline{h}_h/\overline{Y}$	HH property wealth-to-GDP ratio	2.802	2.803	2.802	2.830	–

Notes: All series in Euros are seasonally adjusted and deflated. Abbreviation HH refers to households.

D.3 Level Effects

Figure D.1: Level effects of a dynamic capital buffer: Collateral market features

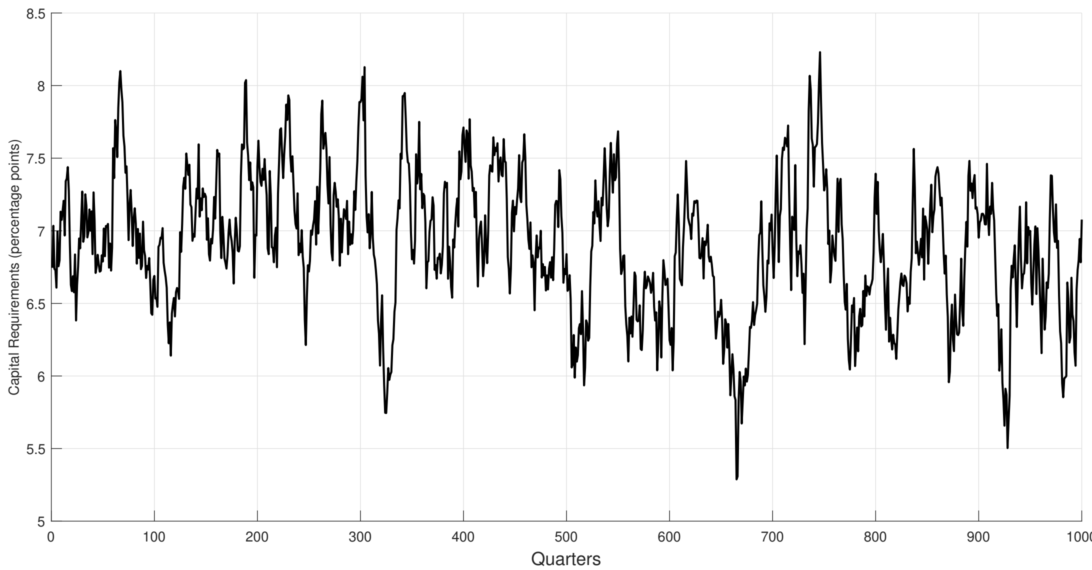


Notes: Level effects on bank lending, commercial real estate and aggregate consumption of changes in parameter γ_x under the case in which indicator $\widetilde{X}_t$ is the the forward-looking growth rate of the bank lending spread for models C and D. Level effects are captured by the changes in the second-order approximation to the stochastic mean (expressed as a percent of the baseline level) of the relevant variables. Only financial (collateral) shocks are active with a size equal to 0.01.

[29]Given that households do not derive utility from housing services under Model D, matching the households' property wealth-to-GDP ratio is not possible. Under the calibration of Model D, the equivalent to this ratio (i.e., households' physical capital-to-GDP ratio is equal to 0.020%).

E Application: Calibration of the Optimal PN-CCyB

Figure E.2: Simulated optimal dynamic capital requirements



Notes: Simulation of dynamic capital requirements, γ_t, over a period of 1,000 quarters for the case in which Problem (23) is solved for γ_x, ρ_γ and γ. Indicator $\widetilde{X}_t$ is the expected growth rate of the bank lending spread. Capital requirements are expressed in percentage points.