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A structural model of capital buffer usability

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Abstract

Under which conditions do usability constraints for regulatory capital buffers emerge? To answer this question, we build a non-linear structural banking sector model with a minimum capital requirement that banks are not allowed to breach, and a capital buffer requirement (CBR) that banks can breach but if they do so potential stigma applies. We prove that even very low stigma costs induce large buffer usability constraints, i.e. when faced with losses banks will deleverage significantly to avoid that their capital ratio falls below the CBR. Our findings imply that non-releasble regulatory capital buffers are unlikely to fully achieve their macro stabilisation goal to support aggregate loan supply when the banking system faces losses.

Keywords: Bank capital requirements, capital buffers, loan supply, macroprudential policy, buffer usability

JEL classification: D21, E44, E51, G21, G28

Non-technical summary

As a response to the global financial crisis (GFC), the Basel III reform package for the banking system introduced a regulatory capital buffer requirement (CBR) on top of the minimum regulatory capital requirement. The main difference of a CBR compared to a minimum capital requirement is that banks are allowed to "use" the CBR, i.e they are allowed to operate with a capital ratio below the CBR, whereas banks are put into resolution if their capital ratio falls below the minimum capital requirement. However, when banks "use" the CBR they face increased supervisory scrutiny, they need to submit a capital conservation plan, and certain payout restrictions for dividends and AT1 coupon payments apply.

The main macroprudential policy motivation for introducing a CBR into banking regulation is to increase banking system resilience to systemic shocks and to reduce cyclicality of the banking system by supporting aggregate loan supply during crises via allowing banks to operate with capital ratios below the CBR. However, some recent empirical banking papers have found indications of potential buffer usability constraints, i.e. indications that banks would rather reduce loan supply and deleverage when faced with adverse shocks rather than let their capital ratio fall below the CBR (Aakriti et al., 2023; Berrospide et al., 2024; Couaillier et al., 2022). Others question whether impediments to buffer usability exist and that this could have a significant effect on bank lending (Schmitz et al., 2021).

We take the inconclusive empirical evidence regarding the existence of buffer usability constraints as a motivation to study in a structural model under which conditions buffer usability constraints can emerge. For this purpose we build on the non-linear banking sector model developed in Lang and Menno (2025) which features monopolistic competition, an occasionally binding equity issuance constraint, and an occasionally binding minimum capital requirement. To this set-up we add two ingredients. First, we add costly bank liquidation in case the capital ratio falls below the minimum capital requirement, which is in line with the Basel III regulatory framework. This gives rise to voluntary capital buffers, i.e. banks maintain a higher capital ratio than the regulatory minimum requirement. Second, we add a structural non-releasable CBR to the model that banks are allowed to "use", but if they do so potential stigma costs apply. These stigma costs are a convenient way to model that under the Basel III framework breaching the CBR entails various consequences that banks may not like. We calibrate our model to euro area data.

The first key finding of our analysis is that in "normal" times, when banks make profits and are not equity constrained, very small stigma costs of around 0.5-3 basis points (bps) are sufficient to induce banks to fulfill the CBR, even under the assumption that bank equity is considerably more expensive than bank debt. This result is reassuring, as it shows that the imposition of a CBR by the supervisor can be effective in increasing bank capital ratios and therefore bank resilience. Compared to a model with only a minimum capital requirement, the introduction of a CBR leads to bank capital ratios that are 0.5-1.3 percentage points (pp) higher, bank liquidation probabilities (PDs) that are 1.25-2.0 pp lower, and aggregate loans that are only 1-13 bps lower. Hence, the introduction of a CBR in "normal" times should fulfill the macro stabilisation objective of having more resilient banks without reducing aggregate loan supply much.

The second key finding of our analysis is that in "bad" times, when banks make losses and become equity constrained, these very small stigma costs of 0.5-3 bps will also be sufficient to rule out that banks "use" the CBR, i.e. that they allow their capital ratio to fall below the CBR to absorb losses. Instead, they prefer to deleverage to still meet the CBR. The intuition for this key result about buffer usability constraints is simple. Banks that "use" the CBR face stigma costs, whereas banks that deleverage to fulfill the CBR face foregone "excess profits" from supplying fewer loans. Banks will only "use" capital buffers if stigma costs are lower than the foregone "excess profits". However, we show that these foregone "excess profits" are extremely low under commonly used assumptions, implying that banks will not "use" buffers when they face losses as long as some form of stigma is present when breaching the CBR, even if this stigma is minimal.

There are two important policy implications of our findings. First, introducing a CBR in "normal" times when banks make profits seems desirable to increase bank resilience and to reduce bank failure probabilities, while this should not constrain bank credit supply much. Second, a structural non-releasable CBR is unlikely to fully achieve its macro stabilisation objective to support aggregate loan supply when the banking sector faces losses due to buffer usability constraints. The latter finding could potentially suggest that the composition of the CBR within the regulatory framework should be rethought with a view to increasing the share of releasable capital buffers.

1 Introduction

As a response to the global financial crisis (GFC), the Basel III reform package for the banking system introduced a regulatory capital buffer requirement (CBR) on top of the minimum regulatory capital requirement. The main difference of a CBR compared to a minimum capital requirement is that banks are allowed to "use" the CBR, i.e they are allowed to operate with a capital ratio below the CBR, whereas banks are put into resolution if their capital ratio falls below the minimum capital requirement. However, when banks "use" the CBR they face increased supervisory scrutiny, they need to submit a capital conservation plan, and certain payout restrictions for dividends and AT1 coupon payments apply.

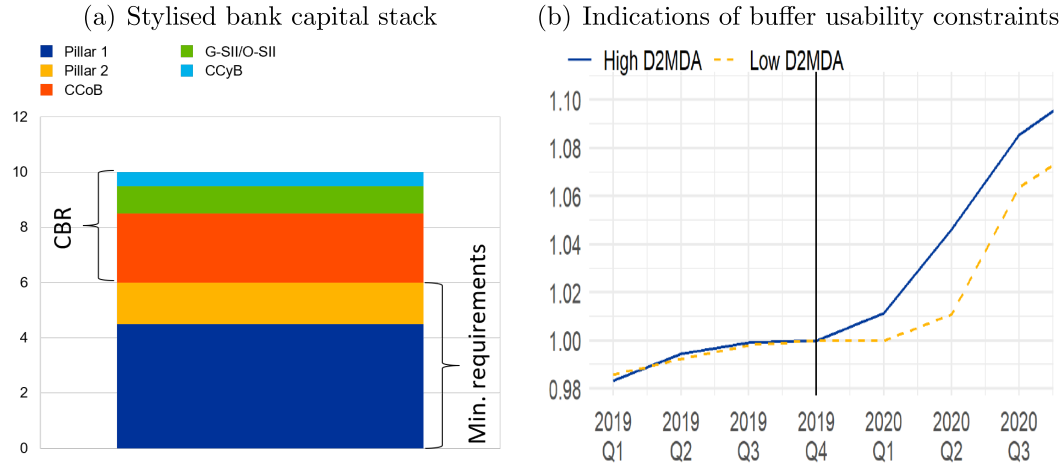
The main macroprudential policy motivation for introducing a CBR into banking regulation is to increase banking system resilience to systemic shocks and to reduce cyclicality of the banking system by supporting aggregate loan supply during crises. Different capital buffers exist within the regulatory framework: some are structural, i.e. they always remain in place, and some are cyclical or releasable, i.e. they are increased during booms and reduced during busts. Prominent structural buffers are the capital conservation buffer (CCoB) of 2.5% and buffers for systemically important institutions (G-SII/O-SII buffers) of up to 3.5%. The most prominent releasable buffer is the countercyclical capital buffer (CCyB), which is varied between 0% and 2.5%. Given the limited build-up of releasable buffers after the GFC, the CBR in most European countries is currently mainly composed of structural macroprudential capital buffers (Figure 1 panel a).

Since the Covid-19 pandemic a debate has started about the need for more releasable rather than structural capital buffers. The reason for this is that some empirical banking papers have found indications of potential buffer usability constraints, i.e. that banks would rather reduce loan supply and deleverage when faced with adverse shocks rather than let their capital ratio fall below the CBR (Aakriti et al., 2023; Berrospide et al., 2024; Couaillier et al., 2022). For example, euro area banks with a low distance between their capital ratio and the CBR reduced lending during the Covid-19 pandemic compared to banks with a high distance between their capital ratio and the CBR (Figure 1 panel b).[1] While this empirical evidence suggests that banks may face buffer usability constraints, others question whether impediments to buffer usability exist and that this could have a significant effect on

[1]Complementing evidence for the U.S. during the GFC is provided by Berger and Bouwman (2013). They show that during the GFC, U.S. banks with higher capital ratios performed better and increased loan supply relative to their peers.

bank lending (Schmitz et al., 2021). If buffer usability constraints indeed exist, it would imply that structural capital buffers might not be able to fully achieve their macro stabilisation objective to support aggregate loan supply when the banking sector faces large losses.

Figure 1: The CBR is mainly structural and banks appear reluctant to "use" it



Notes: Panel (a) - The stylised capital stack applies approximately to European banks. Panel (b) - The figure shows the evolution of lending during the Covid-19 pandemic for different groups of banks and it is taken from Couaillier et al. (2022). D2MDA = distance of capital ratio to the CBR.

We take the inconclusive empirical evidence regarding the existence of buffer usability constraints as a motivation to study in a structural model under which conditions buffer usability constraints can indeed emerge. For this purpose we build on the non-linear banking sector model developed in Lang and Menno (2025) which features monopolistic competition, an occasionally binding equity issuance constraint, and an occasionally binding minimum capital requirement. To this set-up we add two ingredients. First, we add costly bank liquidation in case the capital ratio falls below the minimum capital requirement, which is in line with how banking regulation is implemented in reality.[2] This gives rise to voluntary capital buffers, i.e. banks maintain a higher capital ratio than the regulatory minimum requirement. Second, we add a structural non-releasable CBR to the model that banks are allowed to "use", but if they do so potential stigma costs apply. We restrict the model to two periods, similar to an overlapping generations banking sector model, as this facilitates the derivation of analytical results and clean insights for this complex and non-convex model. The main focus of our analysis is on how high stigma costs need to be for buffer usability constraints to emerge.

[2]For the remainder of the paper we use the terms bank default or bank failure synonymously for bank liquidation.

Our reduced-form stigma costs are a convenient way to model that under the Basel III framework breaching the CBR entails various consequences that banks (or the market) may not like, such as increased supervisory scrutiny, the need to submit a capital conservation plan, restrictions on dividends and AT1 coupon payments, and potential stigma in the true sense of the word. For example, the literature has shown that banks cutting or not paying dividends face a lower stock market value (Acharya et al., 2022; Bessler and Nohel, 1996) and higher CDS spreads (Acharya et al., 2022). These findings are in line with the literature on the signalling channel of dividend distributions (Acharya and Viswanathan, 2011; Bhattacharya, 1979; Forti and Schiozer, 2015; Miller and Rock, 1985). Moreover, a growing empirical literature suggests that one of the most important costs in relation to lower bank capital buffers are *market stigma costs*: lower bank capital ratios are associated with higher bank funding costs (Andreeva et al., 2020; Arnould et al., 2022; Aymanns et al., 2016; Gambacorta and Shin, 2018), higher credit default swaps (e.g. Hasan et al., 2016), lower credit ratings (Andreeva et al., 2020), and lower stock market returns, especially during crisis times (Bouwman et al., 2023).

The first key finding of our analysis is that in "normal" times, when banks make profits and are not equity constrained, very small stigma costs of around 0.5-3 basis points (bps) are sufficient to induce banks to fulfill the CBR, even under the assumption that bank equity is considerably more expensive than bank debt. This result is reassuring, as it shows that the imposition of a CBR by the supervisor can be effective in increasing bank capital ratios and therefore bank resilience. Compared to a model with only a minimum capital requirement, the introduction of a CBR leads to bank capital ratios that are 0.5-1.3 percentage points (pp) higher, bank failure probabilities (PDs) that are 1.25-2.0 pp lower, and aggregate loans that are only 1-13 bps lower. Hence, the introduction of a CBR in "normal" times should fulfill the macro stabilisation objective of having more resilient banks without reducing aggregate loan supply much.

The second key finding is that in "bad" times, when banks make losses and become equity constrained, these very small stigma costs of 0.5-3 bps will also be sufficient to rule out that an equilibrium exists where banks "use" the CBR, i.e. where they allow their capital ratio to fall below the structural CBR to absorb losses. The intuition for this key result about buffer usability constraints is simple. Banks that "use" the CBR face stigma costs, whereas banks that deleverage to fulfill the CBR face foregone "excess profits" from supplying fewer loans.[3] A symmetric

[3]"Excess profits" are measured as the interest rate spread over the marginal cost of loans. The

pure strategy equilibrium with capital buffer use will only exist if stigma costs are lower than the foregone "excess profits" of a deviating bank that deleverages to meet the CBR. However, we show that "excess profits" are low when banks use the CBR, because they can absorb losses with the CBR and do not need to deleverage much. Hence, foregone "excess profits" of a bank that deleverages to fulfill the CBR will also be low and deviating strategies will pay off, ruling out the existence of an equilibrium with capital buffer use. In the same spirit, we show that stigma costs of 10-30 bps are sufficient to support an equilibrium with buffer usability constraints, i.e. an equilibrium where banks prefer to deleverage significantly (e.g. up to 10%) to meet the CBR when they make losses and become equity constrained, rather than let their capital ratio fall below the CBR.

The magnitudes of the required stigma costs to rule out a buffer use equilibrium and to ensure an equilibrium with buffer usability constraints are within empirically plausible ranges: a meta analysis by Andreeva et al. (2020) reports that a 100 bps lower capital ratio is on average associated with an increase of 2-4 bps in the overall bank funding cost, an increase of 15-30 bps in bank bond yields, and a 5-30 bps increase in CDS spreads. Hence, our structural model indicates that buffer usability constraints are likely to exist at empirically plausible stigma costs for banks. This is a very powerful result. It indicates that structural macroprudential capital buffers might not work as intended, as banks will not use such buffers when faced with shocks to their capital ratios as long as banks and investors perceive some form of stigma to be associated with breaching the CBR, even if this stigma is minimal.

There are two important policy implications of our findings. First, introducing a CBR in "normal" times when banks make profits seems desirable to increase bank resilience and to reduce bank failure probabilities, while this should not constrain bank credit supply much. Second, a structural non-releasable CBR is unlikely to fully achieve its macro stabilisation objective to support aggregate loan supply when the banking sector faces losses due to buffer usability constraints. The latter finding could potentially suggest that the composition of the CBR within the regulatory framework should be rethought with a view to increasing the share of releasable capital buffers, although further analysis regarding this question would be needed.

Compared to the existing literature, we are the first to explicitly model capital buffer requirements that banks are allowed to breach and to study the implications for bank resilience and loan supply. So far the literature has only studied implications of minimum capital requirements that banks are not allowed to breach or that

marginal cost also includes the cost of equity.

lead to bank failure when breached. Our banking set-up with occasionally equity constrained banks is related to the modelling of financial intermediaries in He and Krishnamurthy (2013), Brunnermeier and Sannikov (2014), He and Krishnamurthy (2019), Holden et al. (2020), Schroth (2021), Corbae and D'Erasmo (2021), and Van der Ghote (2021). The modelling of costly bank liquidation is similar to Benes and Kumhof (2015). We also add to the literature on the potential pro-cyclical effects of regulatory capital constraints, e.g. Repullo and Suarez (2013). We are not aware of any theory paper that has looked at the introduction of a CBR and potential CBR usability constraints.

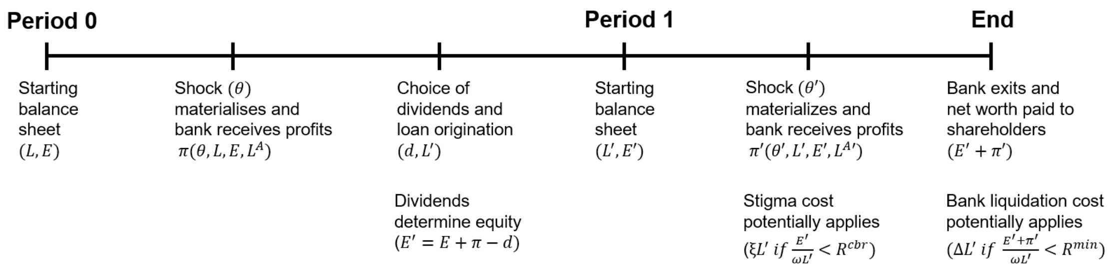
The remainder of the paper is structured as follows. Section 2 presents the structural model set-up that we use for our analysis. Section 3 derives benchmark results for a model with minimum capital requirements but no other frictions. Section 4 shows how costly bank failure induces voluntary bank capital buffers. Section 5 then studies how the imposition of a CBR affects bank capital ratios, bank failure probabilities and loan supply. In Section 6 we derive conditions under which capital buffer usability constraints emerge. Section 7 discusses potential policy implications of our results. Finally, Section 8 concludes.

2 Model set-up and calibration

We build on the dynamic non-linear banking sector model developed in Lang and Menno (2025). For tractability, we restrict the model to 2 periods. We use recursive notation so that variables with a $'$ indicate period 1 variables. In period 0 banks start with given equity E, loans L, and credit risk θ. They receive profits π and decide how many loans L' to originate, and how much dividends d to pay. Starting equity, profits and dividends together determine how much equity funding E' the bank uses. In period 1 the credit risk shock θ' materialises, banks receive profits π', they exit the market, and all net worth $(E' + \pi')$ is paid to shareholders (See Figure 2). This set-up is equivalent to an overlapping generations banking sector model, where remaining networth is passed on to the next generation of bankers. The model also features monopolistic competition with elasticity of substitution μ for loans of different banks, a minimum requirement for the risk-weighted bank capital ratio $CR = \frac{E}{\omega L} \geq R^{min}$, and an equity issuance constraint $d \geq 0$.[4] To this set-up, we add the following two elements.

[4] ω denotes the risk-weight of loans. An equity issuance constraint is equivalent to a non-negativity constraint on bank dividends d.

Figure 2: Overview of the timing of events



First, we add costly bank resolution / liquidation in period 1, which occurs whenever equity plus profits is less than the minimum capital requirement, i.e. whenever $\frac{E'+\pi'}{\omega L'} < R^{min}$. In such states the bank is resolved, i.e. the loan book is liquidated by the supervisor, and a proportional liquidation cost $\Delta L'$ is borne by bank shareholders. This feature resembles the Basel III minimum capital requirement framework, where a bank is put into resolution when it fails to meet the minimum capital requirement and bank resolution tends to be costly. Moreover, the assumption of costly bank liquidation allows us to generate voluntary capital buffers[5] above the minimum capital requirement in a 2-period model. Voluntary capital buffers are a crucial model feature when studying the interaction of a minimum capital requirement and a capital buffer requirement (CBR).

Second, we add a CBR to the model, which is greater or equal to the minimum capital requirement: $R^{cbr} \geq R^{min}$. Banks are allowed to breach (or "use") the CBR, i.e. the capital ratio of a bank is allowed to be below the CBR, so that $CR' = \frac{E'}{\omega L'} < R^{cbr}$ is feasible. However, when banks choose this action, proportional stigma costs of $\xi L'$ apply. These reduced form stigma costs are a convenient way to model that under the Basel III regulatory framework breaching the CBR entails consequences that banks (or the market) might not like, such as increased supervisory scrutiny, the need to submit a capital conservation plan, restrictions on dividends and AT1 coupon payments, and potential stigma in the true sense of the word. The CBR is assumed to be constant over time, i.e. to be of a structural nature and similar in spirit to the CCoB or buffers for systemically important institutions. We only focus on the structural part of the CBR as our main goal is to study under which conditions (stigma costs) banks will not allow their capital ratio to fall below a non-releasable CBR even when they face losses and become capital constrained.

For the analysis of buffer usability constraints in Section 6, it is useful to allow

[5] We refer to voluntary capital buffers whenever equity funding of the bank is greater than what is mandated by the minimum capital requirement (or the capital buffer requirement).

stigma costs to differ depending on whether other banks also breach the CBR or not. Let $\xi^{U|U}$ denote aggregate stigma costs when all banks "use" the CBR and let $\xi^{U|N}$ denote individual stigma costs when all other banks do not "use" the CBR. We assume that individual stigma costs are higher than aggregate stigma costs, i.e. that $\xi^{U|N} > \xi^{U|U}$. This assumption seems reasonable, as the signal that a bank sends when breaching the CBR would be worse if it was the only bank breaching buffer requirements. To save on notation we simply refer to ξ in the remainder of this section and keep in mind that stigma costs can differ depending on what other banks do.[6]

Bank profits are given by subtracting impairment costs θL, operating costs κL, stigma costs ξL, and deposit funding costs $i^D(L-E)$ from interest income $i(L, L^A)L$, where the interest rate charged on loans is a function of individual bank loans L and aggregate bank loans L^A due to monopolistic competition and a downward sloping aggregate loan demand curve (see Lang and Menno (2025) for details):[7]

$$\pi(\theta, L, E, L^A) = \left[i(L, L^A) - i^D - \kappa - \theta - \xi \mathbb{1}_{E<R^{cbr}\omega L}\right] L + i^D E \qquad (1)$$

$$i(L, L^A) = \left(\frac{L}{L^A}\right)^{-\frac{1}{\mu}} \underbrace{\frac{\lambda - log(L^A)}{\epsilon}}_{i^A} \qquad (2)$$

Banks are assumed to be risk neutral and to maximise the present discounted value of expected dividend payments. Dividends are given by starting period equity plus profits minus the equity choice for next period: $d(\theta, L, E, L^A, E') = E + \pi(\theta, L, E, L^A) - E'$. Period 1 dividend payments $d(\theta', L', E', L^{A'}, 0)$ are discounted with the required return on equity $\beta = 1/(1+\rho)$, where we impose the assumption that the required return on equity is strictly greater than the deposit funding cost ($\rho > i^D$). The decision problem of the bank can be represented by a combined discrete-continuous optimisation problem, where aggregate loans are taken as given:

$$V(\theta, L, E, L^A) = \max[V^U(\theta, L, E, L^A), V^N(\theta, L, E, L^A)] \qquad (3)$$

[6] As banks take the actions of all other banks as given, this simplification of notation does not affect results.

[7] μ is the elasticity of substitution between loans from different banks due to monopolistic competition, λ is an aggregate loan demand shifter and ϵ is the interest rate semi-elasticity of aggregate loan demand. Note that we made use of the balance sheet identity $L = D + E$ to substitute out deposits D in the expression for deposit funding costs.

Here V^U represents the maximum expected payoff when using regulatory capital buffers, i.e. when choosing a capital ratio below the CBR ($CR' < R^{cbr}$) but greater or equal to the minimum capital requirement ($CR' \geq R^{min}$).[8] V^N represents the maximum expected payoff when not using regulatory capital buffers, i.e. when choosing a capital ratio greater or equal to the CBR ($CR' \geq R^{cbr}$). The key difference between the two discrete actions is that the bank can avoid stigma costs by choosing V^N instead of V^U, but this comes at the expense of needing to maintain a higher capital ratio which is costly due to the assumption that equity funding is more expensive than debt funding, i.e. $\rho > i^D$. The two maximum expected payoffs are in turn defined as follows:

$$\begin{aligned} V^U(\theta, L, E, L^A) \;=\;& \max_{L',E'} \left(1+\psi^U\right) d(\theta, L, E, L^A, E') + \chi^U \left(E' - R^{min}\omega L'\right) \\ &+\beta \mathbb{E}\left(d(\theta', L', E', L^{A'}, 0)\right) - \beta \int_{\theta^*(L',E',L^{A'})}^{\infty} \Delta L' f(\theta'|\theta) d\theta' \end{aligned} \tag{4}$$

$$\begin{aligned} V^N(\theta, L, E, L^A) \;=\;& \max_{L',E'} \left(1+\psi^N\right) d(\theta, L, E, L^A, E') + \chi^N \left(E' - R^{cbr}\omega L'\right) \\ &+\beta \mathbb{E}\left(d(\theta', L', E', L^{A'}, 0)\right) - \beta \int_{\theta^*(L',E',L^{A'})}^{\infty} \Delta L' f(\theta'|\theta) d\theta' \end{aligned} \tag{5}$$

Where ψ is the lagrange multiplier on the equity issuance constraint, χ^U is the lagrange multiplier on the minimum capital requirement, and χ^N is the lagrange multiplier on the CBR. θ^* is the bank failure threshold, i.e. for credit risk realisations greater than this threshold the bank is liquidated because it breaches the minimum capital requirement. This threshold is defined by rearranging $\frac{E'+\pi'}{\omega L'} = R^{min}$:

$$\theta^*(L', E', L^{A'}) \;=\; i(L', L^{A'}) - i^D - \kappa - \xi \mathbb{1}_{E' < R^{cbr}\omega L'} + (1+i^D)\frac{E'}{L'} - \omega R^{min} \tag{6}$$

The optimal choices for E' and L' under buffer use and no buffer use need to satisfy the respective first-order conditions, and the complementary slackness conditions. Given these two alternative optimal choices, banks compare the expected

[8] Throughout our exposition we assume that the optimal capital ratio choice under buffer use satisfies $CR' < R^{cbr}$. This assumption boils down to imposing that optimal voluntary capital buffers under the minimum capital requirement are smaller than the difference between the CBR and the minimum capital requirement. If this were not the case, imposing a CBR in the model without the equity issuance constraint would not have any effect on bank choices at all, and the analysis of the problem would be trivial.

pay-offs and choose the discrete action (use or no use) with the higher payoff. The derivation of first-order conditions and expected payoffs can be found in Appendix A1.

There is just a single stochastic process for loan impairments that drives the dynamics of the model, i.e. there are no idiosyncratic bank shocks. The dynamic evolution of credit risk is specified as a log AR(1) process in order to get a fat right tail of credit impairments, in line with the empirical distribution of provisioning across euro area banks:

$$ln(\theta') = \alpha_0 + \alpha_1 ln(\theta) + \alpha_2 \varepsilon' \tag{7}$$

As we abstract from bank heterogeneity, an industry equilibrium for this banking sector model is given whenever the optimal individual bank choice is the same as the assumed aggregate choice that the individual bank takes as given, i.e. whenever $L' = L^{A'}$. For the remainder of this paper we focus on the analysis of such symmetric pure strategy equilibria of our model in a representative bank setting. In principle bank heterogeneity or mixed strategy equilibria could also be studied, but we leave this for future research.

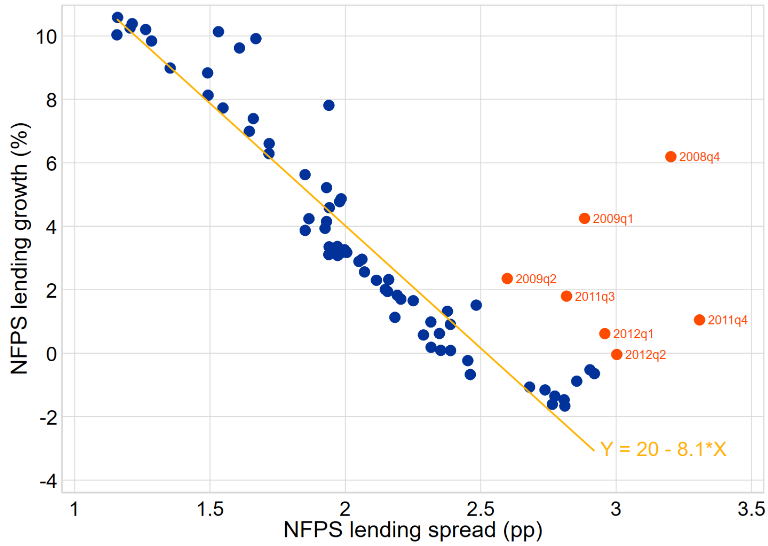
To illustrate the analytical insights that we derive with concrete examples, we calibrate our model to match key features of euro area bank data. The calibrated model parameters are summarised in Table 1 and are taken from Lang and Menno (2025), with the exception of the interest rate semi-elasticity of loan demand which we set at $\epsilon = 8$. We get to this calibrated value by estimating the sensitivity of bank loan growth for the non-financial private sector (NFPS) with respect to the lending rate spread (Figure 3).[9]

Compared to Lang and Menno (2025), our model has four additional parameters that need to be calibrated (R^{cbr}, Δ, $\xi^{U|U}$, $\xi^{U|N}$). We set the capital buffer requirement at $R^{cbr} = 0.125$ so that it equals the minimum capital requirement plus the capital conservation buffer (CCoB). The bank liquidation cost Δ is set at 1%, which seems like a reasonable ad-hoc parameter choice. Finally, we set aggregate and individual stigma costs at 3 bps and 25 bps respectively, which ensures that banks fulfil the CBR and deleverage when hit with negative shocks, i.e. buffer usability

[9] The lending rate spread is measured as the difference between the composite cost of short-term bank borrowing minus the 3-month OIS rate. The sample covers the period 2003 Q1 to 2022 Q3. Outliers during the global financial crisis and the euro area sovereign debt crisis are excluded from the regression.

constraints exist, as shown in Section 6.[10] However, it should be noted that the specific calibration of stigma costs has no impact on the results that are derived in the remainder of the paper.

Figure 3: Empirical relationship between lending spreads and lending growth



Notes: The lending spread is measured as the difference between the composite cost of short-term bank borrowing minus the 3-month OIS rate. The sample covers the period 2003 Q1 to 2022 Q3. Outliers (marked in red) during the global financial crisis and the euro area sovereign debt crisis are excluded from the regression.

Table 1: Overview of calibrated model parameters

Parameter	**Value**	**Source**
ρ	0.08	Based on bank cost of equity estimates in Altavilla et al. (2021)
i^D	0.02	Empirical: Average cost of liabilities for euro area banks 2005-2019
κ	0.014	Empirical: Average cost-to-asset ratio for euro area banks 2005-2019
ω	0.48	Empirical: Average risk-weight for euro area banks 2005-2019
λ	0.344	Scaling parameter set to target steady state loans of 1
ϵ	8	Empirical: Semi-elasticity of bank loan growth to lending spread
μ	100	Set to target the empirical mean of the price-to-book ratio of 1.2
α_0	-2.40	Empirical: Estimated intercept of a log AR(1) process for cost of risk
α_1	0.56	Empirical: Estimated persistence of a log AR(1) process for cost of risk
α_2	0.67	Empirical: Estimated shock SD of a log AR(1) process for cost of risk
R^{min}	0.10	Empirical: Aggregate ECB minimum capital requirement 2019 - 2021
R^{cbr}	0.125	Empirical: Minimum requirement + capital conservation buffer (CCoB)
Δ	0.01	Reasonable ad-hoc parameter choice
$\xi^{U\|U}$	0.0003	Ad-hoc: low but sufficient to induce banks to fulfill the CBR
$\xi^{U\|N}$	0.0025	Ad-hoc: low but sufficient to induce banks to fulfill the CBR

Notes: Model calibration is done to match euro area bank data and is based on the parameter values used in Lang and Menno (2025).

[10] Our model calibration ensures that next period bank net worth never turns negative. Hence, we can disregard the explicit modelling of limited liability by banks, which is implied by the equity issuance constraint.

3 Benchmark results with minimum capital requirements

In order to establish how a CBR affects loan supply, it is useful to first derive benchmark results for a model with only a minimum capital requirement, but no CBR, no stigma, no equity issuance constraint, and no costly bank failure.

Proposition 1 (Equilibrium with only a minimum capital requirement). *In an economy with a minimum capital requirement and no other frictions:*

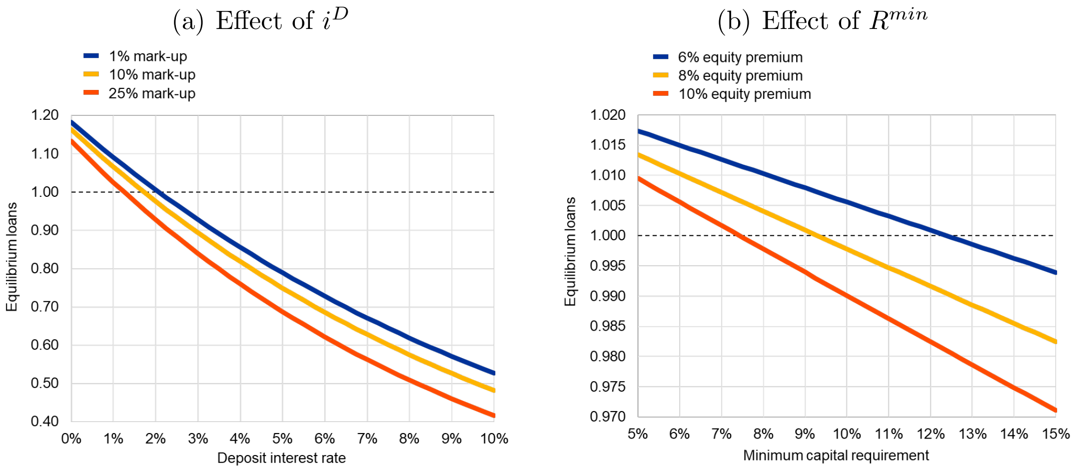
- *Banks will never maintain voluntary capital buffers:* $CR' = R^{min}$
- *Equilibrium loans are:* $log(L') = \lambda - \epsilon \underbrace{\frac{\mu}{\mu - 1}\left[i^D + \kappa + \mathbb{E}(\theta') + (\rho - i^D)\omega R^{min}\right]}_{i\,=\,\text{mark-up}\,\cdot\,\text{marginal cost}}$

Proof. See Appendix A2. ■

As shown in Proposition 1, banks will never maintain voluntary capital buffers in the absence of costly bank liquidation, i.e. banks will always choose just enough equity funding to exactly meet the minimum capital requirement. This result is intuitive. Without an equity issuance constraint and costly bank liquidation, there are no reasons for banks to maintain voluntary capital buffers. Banks can always go to the market and raise new equity from shareholders in case of need, e.g. when losses are incurred. As bank equity is assumed to be more costly than deposit funding, banks will minimise the equity funding they use. Hence, banks will always use just enough equity funding to meet the minimum capital requirement.

The marginal cost of providing a loan is given by the deposit funding cost i^D, the operating cost κ, expected credit risk $E(\theta')$, and the additional cost of equity funding, which is given by the equity premium $(\rho - i^D)$ times the share of a loan that needs to be funded with equity ωR^{min}. Due to monopolistic competition banks charge a mark-up $\mu/(\mu - 1)$ over the marginal cost of loans. The interest rate semi-elasticity of aggregate loan demand ϵ then determines how the charged interest rate translates into equilibrium loan quantities. Note, as banks can always obtain as much equity as needed, equilibrium loans do not depend on current bank equity.

Figure 4: Effect of deposit interest rates and capital requirements on lending



Notes: For the calibration of model parameters see Table 1. The exposition is done for $\mathbb{E}(\theta') = 0.0054$. In panel (a) the elasticity of substitution μ is set at 100, 11, and 5 implying loan interest rate mark-ups over marginal costs of 1%, 10%, and 25% respectively. In panel (b) the required return on equity ρ is set at 0.08, 0.10, and 0.12 implying bank equity premia of 6%, 8%, and 10% respectively.

The expression for equilibrium loans in Proposition 1 can also be used to gauge the impact of monetary policy and capital requirements on lending rates and equilibrium loans (See Figure 4). Under the assumption of full pass-through to the deposit funding cost i^D, monetary policy rate hikes will increase the marginal cost of loans one-for-one. In contrast, the impact of higher capital requirements on the marginal cost is given by the equity premium times the risk-weight, which is just 0.03 for our model calibration to euro area data.[11] This represents the low impact "pricing channel" of changing bank capital requirements pointed out in Lang and Menno (2025). Hence, in the absence of other frictions, the impact of higher capital requirements on lending rates and loans should be an order of magnitude lower than the impact of tighter monetary policy. This is also in line with the empirical findings for euro area NFCs presented in Lang et al. (2025). Figure 4 illustrates this order of magnitude difference for our calibrated model.

4 The impact of costly bank liquidation

Compared to Section 3 we now add costly bank failure and study how the bank choices are affected in equilibrium.

[11]Even under more conservative assumptions of a 10% equity premium and a 100% risk-weight the coefficient will be just 0.1.

Proposition 2 (**Equilibrium with costly bank failure**). *In an economy with a minimum capital requirement and costly bank failure, the following equilibrium properties will hold whenever $f(\theta^{*m}|\theta) > \frac{\rho - i^D}{\Delta(1+i^D)}$, where θ^{*m} is the failure threshold if banks choose a capital ratio equal to the minimum capital requirement:*

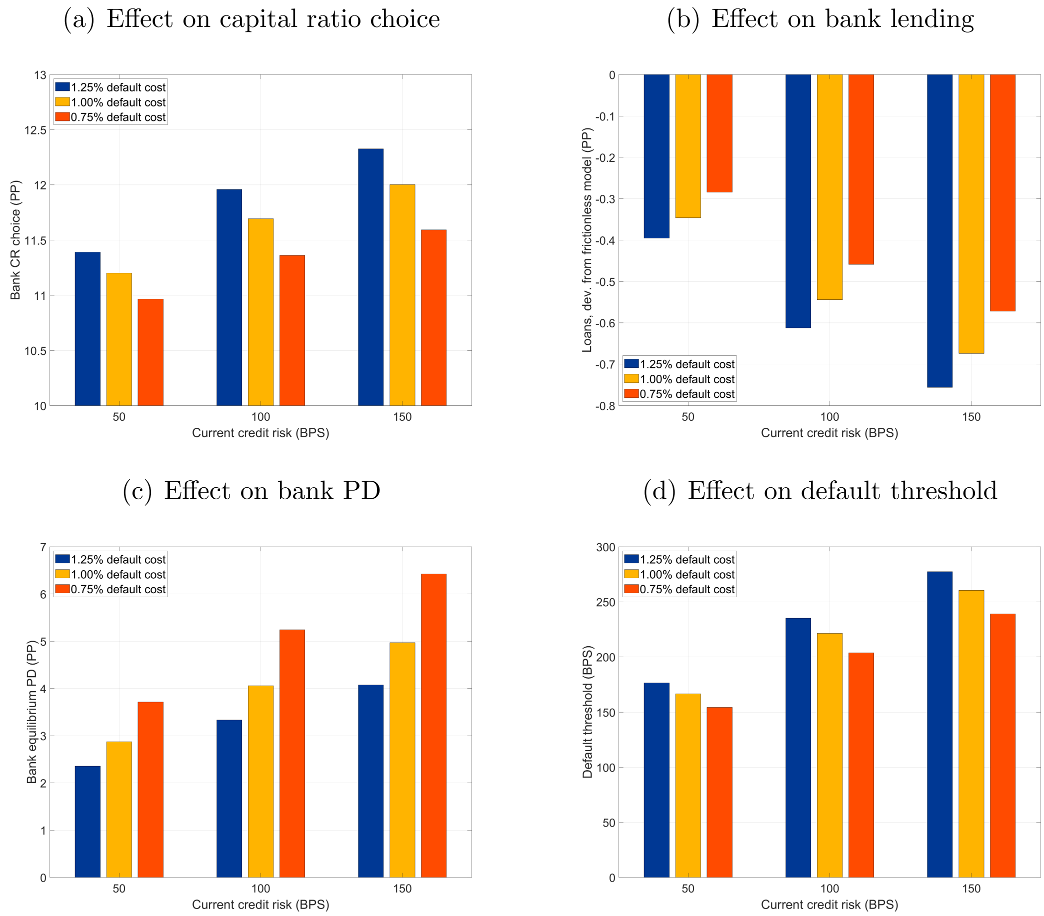
- *Banks maintain voluntary capital buffers:* $CR' > R^{min}$
- *The bank failure probability will be positive:* $PD(\theta^*) = 1 - F(\theta^*|\theta) > 0$
- *The failure threshold satisfies:* $f(\theta^*|\theta) = \frac{\rho - i^D}{\Delta(1+i^D)}$
- *The capital ratio satisfies:* $CR' = \frac{R^{min}}{(1+i^D)} + \frac{i^D + \kappa + \theta^* - i}{(1+i^D)\omega}$
- *The interest rate charged by banks satisfies:*
$$i = \underbrace{\frac{\mu}{\mu - 1 - \frac{\rho - i^D}{1+i^D}}}_{\textit{mark-up (MU)}} \cdot \underbrace{\left[i^D + \kappa + \mathbb{E}\left(\theta'\right) + (\rho - i^D)\omega CR' + \Delta PD(\theta^*)\right]}_{\textit{marginal cost (MC)}}$$

Proof. See Appendix A3. ∎

The first insight from Proposition 2 is that in the presence of costly bank liquidation banks maintain voluntary capital buffers above the minimum capital requirement. The intuition for this is simple. More equity funding raises the failure threshold and therefore decreases the expected default cost. This marginal benefit is given by $(1+i^D)\Delta f(\theta^\star|\theta)$, whereas the marginal cost of equity is given by the equity premium $\rho - i^D$. Whenever the marginal benefit of equity exceeds the marginal cost at a capital ratio equal to the minimum capital requirement, it pays off for banks to maintain voluntary capital buffers up to the point where the marginal benefit equals the marginal cost. However, Proposition 2 shows that banks will not perfectly self insure against breaching the minimum capital requirement, as the bank failure probability is always positive.

The second insight from Proposition 2 is that voluntary capital buffers and expected default costs are both priced into bank lending rates. As equity is more costly than debt, and banks maintain a higher capital ratio than the minimum requirement, the weighted average funding cost of loans increases by $(\rho - i^D)\omega(CR' - R^{min})$ which is passed on to borrowers. Moreover, the per unit expected default cost of $\Delta PD(\theta^*)$ needs to be recouped via the charged interest rate. Therefore, the loan interest rate is slightly higher than in the model without costly bank failure.

Figure 5: Effect of credit risk and default costs on voluntary capital buffers and PDs



(a) Effect on capital ratio choice (b) Effect on bank lending (c) Effect on bank PD (d) Effect on default threshold

Notes: For the calibration of model parameters see Table 1. The benchmark model calibration is represented by the yellow bars.

For our benchmark model calibration (1% default cost) banks maintain voluntary capital buffers of 1pp to 2pp, and these voluntary capital buffers are pro-cyclical, i.e. they go up in "bad" states where credit risk is high and profits are low (Figure 5 panel a). Moreover, while voluntary capital buffers go up in "bad" states, bank PDs also increase in such states, as shown in Figure 5 panel c. These two observations are driven by the log AR(1) process for credit risk: higher current credit risk implies a fatter right tail and more probability mass on high future credit risk. Hence, the marginal benefit of using more equity funding increases and voluntary capital buffers go up, but not enough to completely counteract the fatter right tail of the credit risk distribution. Although banks maintain voluntary capital buffers and face positive PDs, lending is only reduced marginally by 30 to 75 bps compared to the model without bank failure due to the low impact "pricing channel" referred to above.[12] Finally, higher default costs Δ increase the marginal benefit of using more equity funding, which explains why voluntary capital buffers and the failure threshold are increasing and the bank default probability is decreasing with the default cost parameter (Figure 5 panels a, d and c).

5 The impact of capital buffer requirements

We now move on and add a CBR to the model from Section 4. While banks are allowed to operate with a capital ratio below the CBR, they face stigma costs whenever they choose to do so. In the following we study under which conditions banks are willing to fulfill the CBR and the properties of the associated equilibrium. For that purpose, denote by $CR^{U\prime}$ and θ^{*U} the capital ratio and the bank failure threshold in case banks "use" the CBR, i.e. they choose a capital ratio below the CBR, and let θ^{*N} denote the bank failure threshold in case banks do not use the CBR.

Proposition 3 (Equilibrium with a capital buffer requirement). *In an economy with a minimum capital requirement, costly bank failure, stigma costs and a CBR, banks will fulfill the buffer requirement whenever the following condition holds:*

$$\xi^{U|U} > (\rho - i^D)\omega \left[R^{cbr} - CR^{U'}\right] + \Delta \left[PD(\theta^{*N}) - PD(\theta^{*U})\right] \tag{8}$$

The equilibrium where banks fulfill the CBR has the following properties:

- *Banks do not maintain voluntary capital buffers above the CBR:* $CR' = R^{cbr}$
- *The failure probability is lower than when using buffers:* $PD(\theta^{*N}) < PD(\theta^{*U})$
- *The failure threshold satisfies:* $\theta^{*N} = i^N - i^D - \kappa + (1 + i^D)\omega R^{cbr} - \omega R^{min}$
- *The interest rate charged by banks satisfies:*
$$i^N = \underbrace{\frac{\mu}{\mu - 1 - \Delta f(\theta^{*N}|\theta)}}_{MU^N} \cdot \underbrace{\left[i^D + \kappa + \mathbb{E}\left(\theta'\right) + (\rho - i^D)\omega R^{cbr} + \Delta PD(\theta^{*N})\right]}_{MC^N}$$

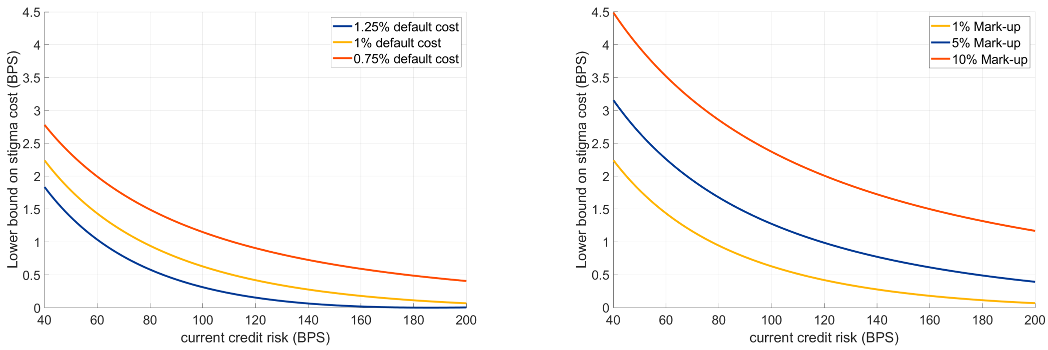
Proof. See Appendix A4. ■

[12] To better understand this magnitude note that a capital ratio of 1pp above the minimum requirement and a bank PD of 3%, imply higher marginal costs of 6 bps that are priced into bank interest rates. This leads to around 45 bps lower equilibrium loans given an aggregate interest rate semi-elasticity of 8 and low market power.

As shown in Proposition 3, banks will fulfill the CBR whenever aggregate stigma costs are higher than the net cost of fulfilling the CBR. The latter consists of two parts. First, the additional equity funding cost, which is given by the equity premium times the additional fraction of loans that has to be funded by equity when fulfilling the CBR: $(\rho - i^D)\omega\left[R^{cbr} - CR^{U'}\right]$.[13] Second, the higher loan funding cost is partially offset by the benefit of a lower expected default cost $\Delta\left[PD(\theta^{*N}) - PD(\theta^{*U})\right]$: as banks maintain a higher capital ratio when fulfilling the CBR, the bank failure threshold is higher and therefore the bank failure probability is lower than when using the CBR.

Figure 6: For the benchmark model calibration, stigma costs of 0.5-3 bps are sufficient to induce banks to fulfill the CBR

(a) Varying bank default costs (b) Varying bank market power



Notes: Implied lower bound on aggregate stigma costs for the model with a capital buffer requirement characterized in Proposition 3. For the calibration of model parameters see Table 1. The benchmark model calibration is represented by the yellow lines.

For our benchmark model calibration, aggregate stigma costs of 0.5-3 bps are sufficient to induce banks to fulfill the CBR (Figure 6 yellow line). These magnitudes can be easily explained with the help of Figure 7. For a default cost of 1% and current credit risk of 50 bps, the CBR is 1.3 pp above the capital ratio of banks that "use" the CBR. Given an equity premium of 6% and a risk weight of around 50%, the loan funding cost increases by merely 3.9 bps. At the same time the bank PD decreases by 2 pp, leading to a lower expected bank default cost of 2 bps. The net cost of fulfilling the CBR is therefore just 1.9 bps. If stigma costs exceed this value, it pays off for banks to fulfill the CBR, as shown in Figure 6. The result that very low aggregate stigma costs are sufficient to induce banks to fulfill the CBR in the absence of equity constraints is reassuring, as it shows that the imposition of a CBR

[13] By assumption, we restrict the analysis to cases where absent stigma costs the capital ratio choice is below the CBR, i.e. the CBR induces banks to maintain higher capital ratios.

by the supervisor can be effective in increasing bank capital ratios and therefore bank resilience.

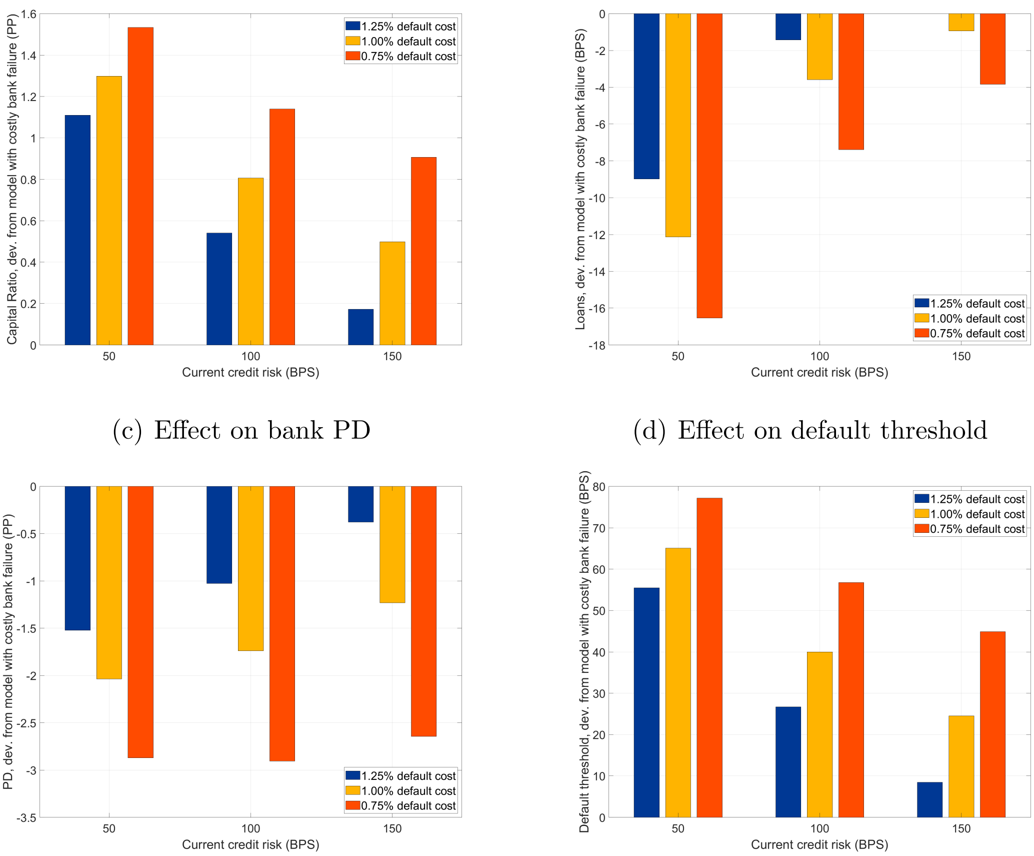
Figure 7: Effect of a CBR on capital ratios, lending, PDs, and default thresholds

(a) Effect on capital ratio choice

(b) Effect on bank lending

(c) Effect on bank PD

(d) Effect on default threshold



Notes: For the calibration of model parameters see Table 1. The benchmark model calibration is represented by the yellow bars.

It is also interesting to note that the required aggregate stigma cost for fulfilling the CBR is decreasing in credit risk (Figure 6). As explained in Section 4, banks voluntarily maintain higher capital ratios for higher credit risk, i.e. there is more self insurance by banks. Therefore, the additional weighted average funding cost induced by fulfilling the CBR decreases with higher credit risk, while the expected default cost is still lower than when using the CBR (Figure 7). In net terms it is therefore ”cheaper” for banks to fulfill the CBR at higher credit risk, leading to lower required aggregate stigma costs. Moreover, Figure 6 shows that the minimum aggregate stigma costs to induce banks to fulfill the CBR remains in the range of 0.5 and 4.5 bps, even with lower bank liquidation costs or significantly higher market power (see panel b). The fact that higher market power leads to somewhat higher required stigma costs is due to the fact that with higher market power banks make larger profits on average, which reduces the failure probability all else equal. This leads to lower voluntary capital buffers in the absence of a CBR (see Figure B1 in the Appendix), which makes it more costly in relative terms to fulfill the CBR.

The benefits of higher capital ratios and lower bank PDs in presence of a CBR come at arguably low economic costs in terms of reduced lending (Figure 7): for the benchmark calibration with a default cost of 1%, the decrease in lending is only 1-13 bps, while the capital ratio increases by 0.5-1.3 pp, and bank PDs go down by 1.25-2 pp. Similar magnitudes also hold when varying the default cost parameter (Figure 7) or when increasing the degree of bank market power significantly (Figure B1 in the Appendix).

6 Conditions for buffer usability constraints

Now that we have established conditions under which unconstrained banks choose to fulfill the CBR, it is instructive to study how the introduction of a potentially binding equity issuance constraint changes the picture. From now on, let variables denoted by ^{N} indicate outcomes for the unconstrained no use case, let variables denoted by $^{\tilde{N}}$ indicate outcomes for the no use case when the equity issuance constraint is binding, and let variables denoted by ^{U} indicate outcomes for the use case (independent of whether the equity issuance constraint is binding or not). Moreover, let $^{\tilde{N}|U}$ indicate deviating strategies when all other banks use the CBR, and let $^{U|\tilde{N}}$ indicate deviating strategies when all other banks do not use the CBR and are equity constrained. Let us first consider sufficient conditions to rule out that buffer use is an equilibrium.

Proposition 4 (Absence of an equilibrium with capital buffer use). *Consider an economy with a minimum capital requirement, costly bank failure, stigma costs, a CBR, and an equity issuance constraint. In states where the equity issuance constraint is binding, an equilibrium where banks use the CBR does not exist if:*

$$\begin{aligned}\xi^{U|U} \quad > \quad & (\rho - i^{D})\omega\left[R^{cbr} - CR^{U'}\right] + \Delta\left[PD(\theta^{*\tilde{N}|U}) - PD(\theta^{*U})\right] + \\ & \underbrace{\frac{\mathbf{1 - s^{\tilde{N}|U}}}{\mathbf{s^{\tilde{N}|U}}}\left[\mathbf{i^{U} - MC^{U}}\right]}_{\substack{\textit{foregone "excess profit"} \\ \textit{from deleveraging}}} - \underbrace{\left[(\mathbf{s^{\tilde{N}|U}})^{-\frac{1}{\mu}} - \mathbf{1}\right]\mathbf{i^{U}}}_{\mathbf{i^{\tilde{N}|U} - i^{U} > 0}} \end{aligned} \tag{9}$$

Where $^{\tilde{N}|U}$ indicates a binding equity issuance constraint for deviating strategies when all other banks use the CBR, and where the following definitions apply:

$$s^{\tilde{N}|U} = \frac{CR^{L^{U'}}}{R^{cbr}} < 1;\ CR^{L^{U'}} = \frac{E+\pi}{\omega L^{U'}} < R^{cbr};\ i^U = MU^U[MC^U + \psi^U(1-\rho)\omega CR^U];$$
$$MU^U = \frac{\mu}{\mu - 1 - \Delta f(\theta^{*U}|\theta)};\ MC^U = i^D + \kappa + \mathbb{E}(\theta') + (\rho - i^D)\omega CR^U + \Delta PD(\theta^{*U}) + \xi^{U|U}$$

Proof. See Appendix A5. ∎

As shown in Proposition 4, if aggregate stigma is greater than the net cost of fulfilling the CBR as a deviating bank, an equilibrium where banks use capital buffers when they become equity constrained does not exist. This is because it would always pay off for a bank to not use buffers and deleverage to avoid stigma, even if all other banks chose to use buffers. Compared to the condition in Proposition 3 for the unconstrained case, there are now two additional terms highlighted in **bold** that determine the net cost of fulfilling the CBR when the equity issuance constraint is binding.[14] These two additional terms reflect that a bank which is equity constrained and fulfills the CBR supplies less loans to the market than a bank that uses buffers, because $CR^U < R^{cbr}$.

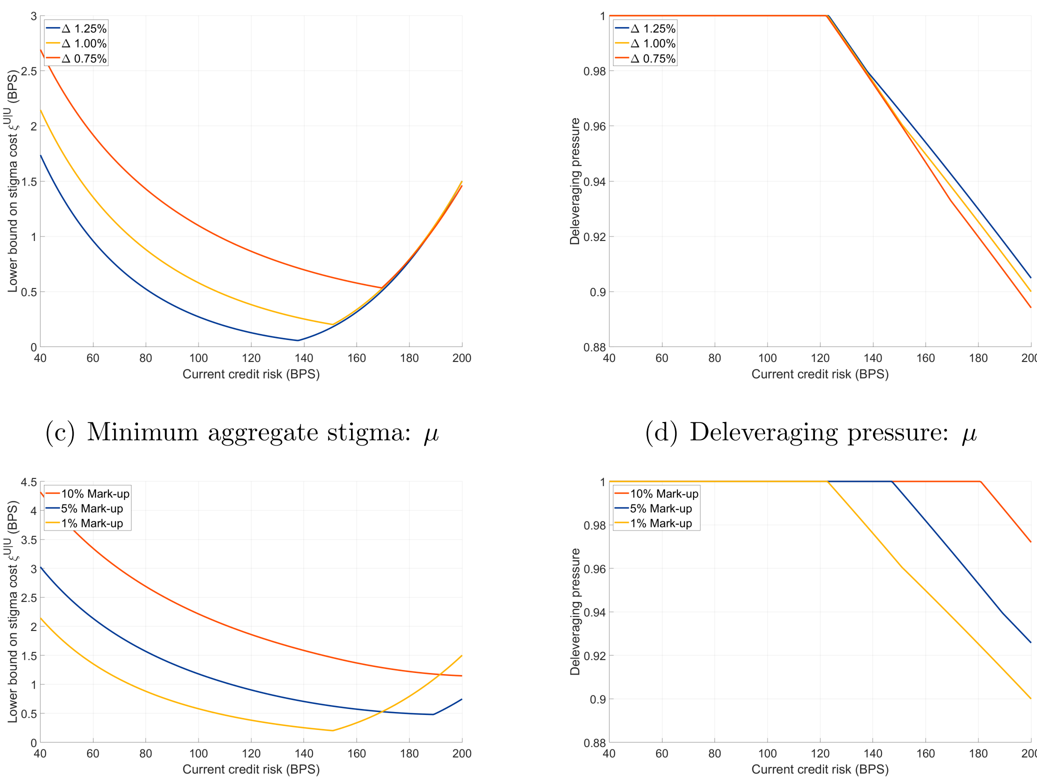
The first term reflects foregone aggregate "excess profit" over marginal cost due to the lower loan quantity that a (deviating) non-using bank supplies to the market (at the equilibrium price i^U in case all banks "use" the CBR). The deleveraging pressure faced by a non-using bank compared to a using bank depends on the hit to its capital ratio, which is represented by $s^{\tilde{N}|U}$ in equation (9). How much "excess profit" is lost by a non-using bank on this lower loan quantity depends to some extent on the market power of banks, but mainly on whether using banks are equity constrained or not. This can be seen from the term $i^U - MC^U$, which reflects the interest rate spread charged by using banks. If market power is low so that $MU^U \approx 1$ and if using banks are not yet equity constrained so that $\psi^U = 0$, the interest rate that using banks charge will be close to the marginal cost, and hence little "excess profit" is lost by non-using banks from deleveraging. The second term reflects that due to monopolistic competition a constrained non-using bank can charge a marginally higher interest rate than all other using banks because of the lower loan quantity it supplies. How much higher the interest rate of a non-using bank is depends again on the market power of banks. If market power is low, the interest rate differential between non-using and using banks will also be low.

[14] These terms come on top of the two terms reflecting the higher weighted-average funding cost associated with fulfilling the CBR and the lower expected default cost due to a higher capital ratio.

Figure 8: For the benchmark model calibration, aggregate stigma costs of 0.5-3 bps are sufficient to rule out the existence of an equilibrium with capital buffer use

(a) Minimum aggregate stigma: Δ (b) Deleveraging pressure: Δ

(c) Minimum aggregate stigma: μ (d) Deleveraging pressure: μ



Notes: Implied lower bound on aggregate stigma costs for the model with a capital buffer requirement and a binding equity issuance constraint characterized in Proposition 4. For the calibration of model parameters see Table 1. The benchmark model calibration is represented by the yellow lines.

Overall, compared to the condition for the unconstrained case in Proposition 3, the condition in Proposition 4 implies a slightly higher aggregate stigma cost to rule out an equilibrium where banks use capital buffers when they become equity constrained. However, for our benchmark model calibration to euro area data, this minimum aggregate stigma cost will still be very low in the range of 0.5-3 bps (Figure 8 yellow lines). For example, with a default cost of 1% and a shock that would require non-using banks to deleverage by around 7.5%, an aggregate stigma cost of below 1 bps would be sufficient to rule out an equilibrium where banks use regulatory capital buffers.[15] Moreover, Figure 8 shows that the minimum aggregate stigma costs to rule out an equilibrium with buffer use remains in the range of 0.5 and 4.5 bps, even with lower bank liquidation costs or significantly higher bank market power (see panel c). This is a very powerful analytical result! It indicates that structural non-releasable regulatory capital buffers might not work fully as

[15]See yellow lines in Figure 8 at a 180 bps credit risk shock.

intended, as banks will not use such buffers when faced with shocks to their capital ratios as long as banks perceive some form of stigma to be associated with breaching the CBR, even if this stigma is minimal.

Another important insight from the examples in Figure 8 is that the minimum aggregate stigma cost to rule out a buffer use equilibrium only starts to increase once the equity issuance constraint becomes binding for using banks, i.e. when they are no longer able to achieve their desired loan choice and their desired voluntary capital buffer at the same time. This can be seen from the fact that the kinks in panels (a) and (c) happen at higher credit risk realisations than the kinks in panels (b) and (d), where the latter kinks indicate the start of deleveraging by non-using banks.[16] These differences in the kinks show that the lost "excess profit" from deleveraging for non-using banks is initially negligible, even with significant bank market power, and only starts to become more important once using banks also become equity constrained and start to charge a higher interest rate spread over marginal cost. However, this increase in the aggregate interest rate will initially be minimal as long as using banks are still able to maintain some voluntary capital buffers over the minimum capital requirement. This explains why the increase in the minimum aggregate stigma cost at the kink is still quantitatively small.

In a final step, it is necessary to establish under which conditions an equilibrium with buffer usability constraints exists, i.e. under which conditions all banks deleverage when they become equity constrained to fulfill the CBR and avoid stigma.

Proposition 5 (Existence of an equilibrium with usability constraints). *Consider an economy with a minimum capital requirement, costly bank failure, stigma costs, a CBR, and an equity issuance constraint. In states where the equity issuance constraint is binding, an equilibrium where banks deleverage to fulfill the CBR exists if:*

$$\begin{aligned}\xi^{U|\tilde{N}} \quad > \quad & (\rho - i^D)\omega\left[R^{cbr} - CR^{U|\tilde{N}'}\right] + \Delta\left[PD(\theta^{*\tilde{N}}) - PD(\theta^{*U|\tilde{N}})\right] + \\ & \frac{\mathbf{n-1}}{\mathbf{n}}\Big[\underbrace{\mathbf{i^N} - \frac{\mathbf{log(s^{\tilde{N}})}}{\epsilon}}_{\mathbf{i^{\tilde{N}}}} - \underbrace{\mathbf{MC^N} + \mathbf{\Delta[PD(\theta^{*N}) - PD(\theta^{*\tilde{N}})]}}_{\mathbf{MC^{\tilde{N}}}}\Big] \qquad (10)\end{aligned}$$

Where $^{U|\tilde{N}}$ indicates deviating strategies when all other banks do not use the CBR and are equity constrained. The following definitions apply:

[16] The fact that the deleveraging kinks move to the right for higher market power in Figure 8 (d) is due to the fact that higher market power increases profits of banks and therefore the credit risk realisations needed to make non-using banks equity constrained.

$n = \frac{R^{cbr}}{CR^{U|\tilde{N}'}} > 1$; $s^{\tilde{N}} = \frac{CR^{L^{N'}}}{R^{cbr}} < 1$; $CR^{L^{N'}} = \frac{E+\pi}{\omega L^{N'}}$; $i^N = MU^N \cdot MC^N$; $MU^N = \frac{\mu}{\mu - 1 - \Delta f(\theta^{*N}|\theta)}$; $MC^N = i^D + \kappa + \mathbb{E}(\theta') + (\rho - i^D)\omega R^{cbr} + \Delta PD(\theta^{*N})$

Proof. See Appendix A6. ■

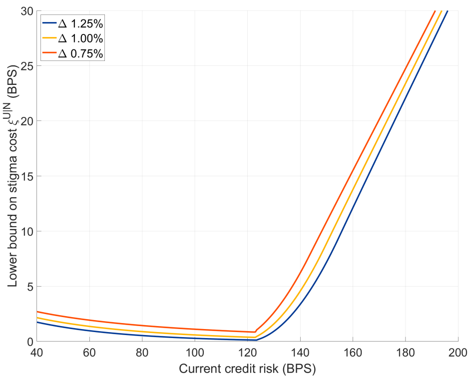
The intuition behind the condition in Proposition 5 for the existence of an equilibrium with buffer usability constraints is similar to the intuition for the condition in Proposition 4: if individual stigma for a deviating bank is greater than the net cost of fulfilling the CBR when all other banks fulfill the CBR, an equilibrium with buffer usability constraints exists. This is because in such cases it would not pay off for a bank to use buffers and be the only bank to face stigma, if all other banks chose not to use regulatory capital buffers. Compared to the condition in Proposition 4, the additional term of the net cost of fulfilling the CBR, which is highlighted in **bold**, takes a slightly different form. The expression has a fairly intuitive interpretation, as it reflects two key mechanisms.

First, a deviating bank which uses buffers can supply significantly more loans to the market than a bank which fulfills the CBR even though it is equity constrained. This is reflected by the term $(n-1)/n$ in equation (10), which reaches its maximum whenever a deviating bank chooses to exactly fulfil the minimum capital requirement, so that $n = R^{cbr}/R^{min}$. Second, this higher loan quantity will be of value to a deviating bank that uses buffers if it can earn significant "excess profit" over marginal cost on it. The magnitude of "excess profit" a using bank can earn on the higher loan quantity is captured by the expression in square brackets. The most important aspect to note is that in the constrained no-use case the aggregate interest rate will be significantly above the marginal cost of loans because banks need to deleverage to fulfill the CBR. This effect is captured by the term $-log(s^{\tilde{N}})/\epsilon$, which reflects the difference between the aggregate interest rate in the constrained and unconstrained no use case, where the shock size $s^{\tilde{N}}$ reflects the deleveraging pressure compared to the unconstrained no use case. Due to the higher aggregate interest rate when all non-using banks deleverage to fulfill the CBR, a deviating bank which uses buffers can earn substantial additional "excess profit" over marginal cost on the higher loan quantity that it supplies to the market.[17]

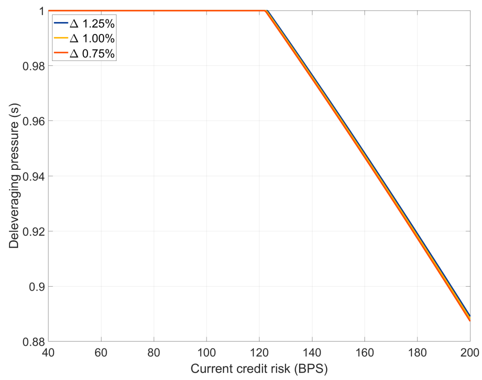
[17] The term $i^N - MC^N$ is analogous to the term in Proposition 4 and reflects the "excess profit" over marginal cost in the unconstrained no use case. This term will be close to zero whenever bank market power is not too high. The term $\Delta[PD(\theta^{*N}) - PD(\theta^{*\tilde{N}})]$ reflects that the marginal cost in the constrained no use case will be slightly below the marginal cost in the unconstrained no use case, because the PD is lower due to the higher aggregate interest rate. This difference in marginal cost also slightly increases the "excess profit" compared to the unconstrained no use case.

Figure 9: Individual stigma costs of 10-30 bps are sufficient to ensure existence of a ”no use” equilibrium with deleveraging of up to 10%

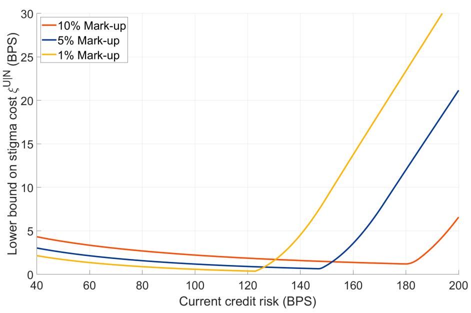
(a) Minimum individual stigma: Δ



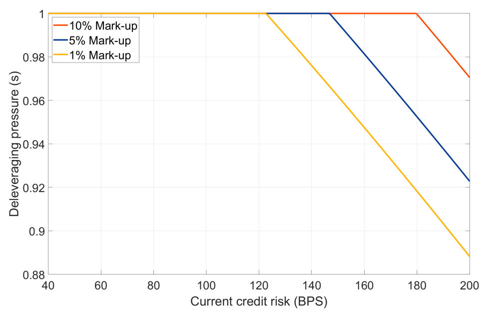
(b) Deleveraging pressure: Δ



(c) Minimum individual stigma: μ



(d) Deleveraging pressure: μ



Notes: Implied lower bound on individual stigma costs for the model with a capital buffer requirement and a binding equity issuance constraint characterized in Proposition 5. For the calibration of model parameters see Table 1. The benchmark model calibration is represented by the yellow lines.

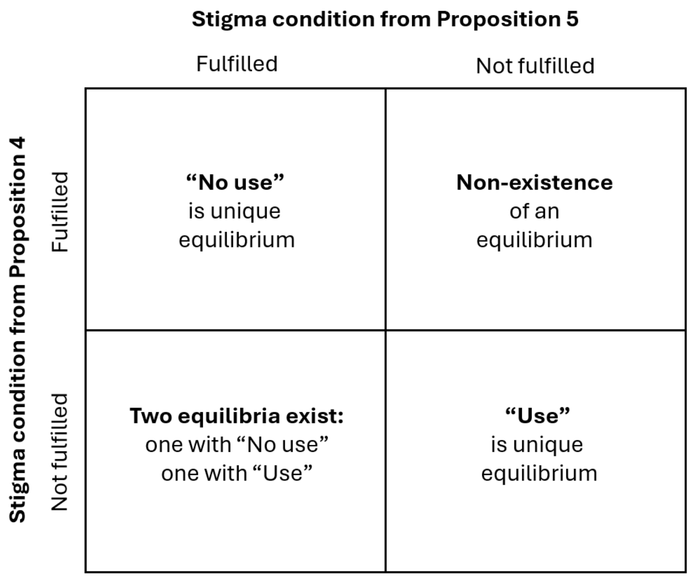
Overall, condition (10) of Proposition 5 implies that individual stigma needs to be significantly higher compared to the unconstrained no use case in Proposition 3, to ensure that an equilibrium exists where banks deleverage to fulfill the CBR when they become equity constrained. Our benchmark model calibration to euro area data can again be used to provide further quantitative insights into this. For a default cost of 1% and deleveraging pressure of 4%, individual stigma costs of around 10 bps would be enough to ensure an equilibrium with buffer usability constraints (Figure 9 yellow lines).[18] For the same default cost and deleveraging pressure of around 10%, individual stigma costs of around 30 bps would be enough. More generally, the results in Figure 9 show that the higher the deleveraging pressure for non-using banks is, the higher the individual stigma cost needs to be to ensure an equilibrium with buffer usability constraints. This reflects the fact that the aggregate interest rate is increasing quickly with deleveraging pressure of non-using

[18]See yellow lines in Figure 9 at credit risk of 150 bps.

banks and therefore higher individual stigma costs are needed to prevent deviating strategies to dominate. Compared to this, the degree of market power is negligible in determining the minimum individual stigma to ensure an equilibrium with buffer usability constraints (Figure 9 c).

Based on the stigma cost conditions in Propositions 4 and 5 the following four constellations are possible regarding the existence and uniqueness of different equilibria (See Figure 10): "No use" is the unique equilibrium if both conditions are fulfilled. "Use" is the unique equilibrium if neither condition is fulfilled. Two equilibria, one with "Use" and the other with "No use", exist if the condition in Proposition 4 is not fulfilled and the condition in Proposition 5 is fulfilled. No equilibrium exists at all if the condition in Proposition 4 is fulfilled and the condition in Proposition 5 is not fulfilled.

Figure 10: Overview of the existence and uniqueness of different equilibria



The results from Propositions 4 and 5 together show that the minimum aggregate stigma to rule out a buffer use equilibrium is an order of magnitude lower than the minimum individual stigma to ensure an equilibrium with buffer usability constraints, i.e. an equilibrium where banks deleverage to meet the CBR when they become equity constrained. Hence, an equilibrium with buffer use is unlikely to exist as long as some form of stigma cost applies when breaching the CBR, even if this stigma cost is minimal! Moreover, in the real world it is likely that if stigma for breaching the CBR exists, that such stigma will be larger if only a single bank breaches the CBR compared to a situation where all banks breach the CBR, i.e. $\xi^{U|N} > \xi^{U|U}$ seems plausible. Hence, at least for medium-sized deleveraging shocks that require modest minimum individual stigma of 10-30 bps, it seems plausible that an equilibrium with buffer usability constraints exists! The properties of such an equilibrium with buffer usability constraints are summarised in Proposition 6.

Proposition 6 (**Equilibrium properties with buffer usability constraints**). *Consider an economy with a minimum capital requirement, costly bank failure, stigma costs, a CBR, and an equity issuance constraint. If aggregate and individual stigma costs fulfil the conditions in Propositions 4 and 5, the unique equilibrium where banks deleverage to fulfill the CBR when they are equity constrained has the following properties:*

- *Banks do not maintain voluntary capital buffers above the CBR:* $CR^{\tilde{N}'} = R^{cbr}$
- *Banks deleverage compared to the unconstrained case:* $L^{\tilde{N}'} = s^{\tilde{N}} L^{N'} < L^{N'}$
- *Deleveraging is proportional to the capital ratio shock size:* $s^{\tilde{N}} = \frac{CR^{L^{N'}}}{R^{cbr}} < 1$
- *The interest rate charged by banks satisfies:* $i^{\tilde{N}} = i^N - \frac{log(s^{\tilde{N}})}{\epsilon} > i^N$
- *The failure threshold satisfies:* $\theta^{*\tilde{N}} = i^{\tilde{N}} - i^D - \kappa + (1 + i^D)\omega R^{cbr} - \omega R^{min}$
- *The failure probability is lower than when using buffers:* $PD(\theta^{*\tilde{N}}) < PD(\theta^{*U})$

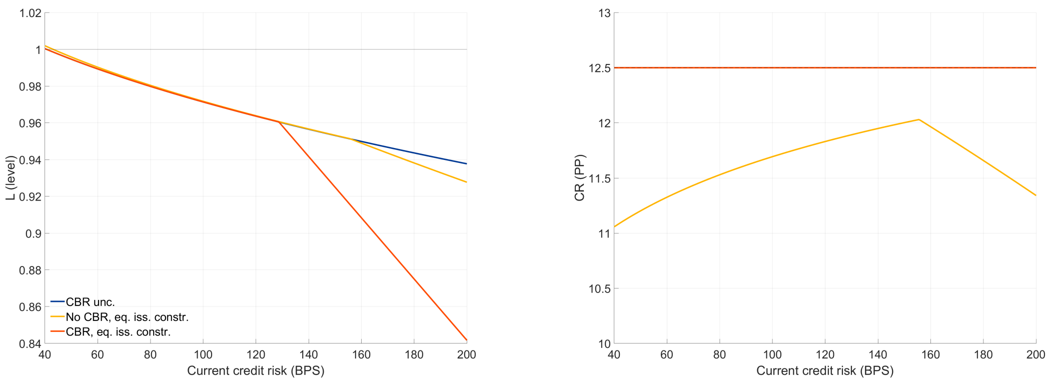
Where $^{\tilde{N}}$ *denotes that the equity issuance constraint is binding and* $CR^{L^{N'}} = \frac{E+\pi}{\omega L^{N'}} < R^{cbr}$ *is the implied capital ratio if the unconstrained loan volume was chosen.*

Proof. See Appendix A7. ■

We can now put together the results from all Propositions to show how aggregate loan supply is affected by a capital buffer requirement during normal times, and during crisis times when banks make losses and become equity constrained. For our benchmark calibration to euro area data, small aggregate stigma costs of 3 bps are sufficient to induce banks during normal times to maintain a 0.5-1.5pp higher capital ratio to fulfil the CBR, while aggregate loan supply is only reduced marginally by 1-13 bps compared to an economy with only a minimum capital requirement (Figure 11). This is a reassuring result, as the higher capital ratios reduce bank failure probabilities and this comes at arguably very low economic costs. However, in states where high credit risk materialises and banks make losses (at ca. 130 bps credit risk in Figure 11), the picture changes abruptly. The same small aggregate stigma costs of 3 bps prevent that banks are willing to let their capital ratio fall below the structural non-releasable CBR, even though banks are equity constrained. Instead, banks start to deleverage significantly to still meet the CBR. Individual stigma costs of 25 bps are sufficient to ensure that such an equilibrium with buffer usability constraints exists for deleveraging pressure of up to 8%.

Figure 11: A CBR can induce deleveraging when banks are constrained

(a) Aggregate loan supply (b) Aggregate capital ratio



Notes: For the calibration of model parameters see Table 1.

7 Discussion of potential policy implications

There are two important policy implications of our findings. First, introducing a CBR in "normal" times when banks make profits seems desirable to increase bank resilience and to reduce bank failure probabilities, while this should not constrain bank credit supply much. Second, a structural non-releasable CBR is unlikely to fully achieve its macro stabilisation objective to support aggregate loan supply when the banking sector faces losses due to potential buffer usability constraints. The latter finding could potentially suggest that the composition of the CBR within the regulatory framework should be rethought with a view to increasing the share of releasable capital buffers, although further analysis of this would be needed to draw firm conclusions.

Based on our model we are only able provide conjectures about how releasable capital buffers may alleviate buffer usability constraints. For example, if the supervisory authority is able to release or remove the CBR during crisis episodes when banks make losses, and such a CBR release is effective in eliminating stigma, then such supervisory action could provide a significant boost to credit supply in crisis times and potentially mitigate bank deleveraging: the support to aggregate credit supply would be given by the difference between the yellow and red lines in Figure 11. Of course this assumes that a CBR release eliminates or significantly reduces stigma costs and that the market-imposed minimum capital requirement in crisis times is lower than the CBR.

8 Conclusion

Building on Lang and Menno (2025), this paper developed the first structural banking sector model that features both a minimum capital requirement that banks are not allowed to breach and a capital buffer requirement that banks are allowed to breach, but if they do so potential stigma costs apply. The reduced-form stigma costs are a convenient way to model that under the Basel III regulatory framework breaching capital buffer requirements entails consequences that banks might not like, such as increased supervisory scrutiny, the need to submit a capital conservation plan, restrictions on dividends and AT1 coupon payments, and potential stigma in the true sense of the word. The model was then used to study the impact of introducing a structural non-releasable capital buffer requirement and under which conditions (stigma costs) buffer usability constraints can emerge.

We showed that very low aggregate stigma costs of 0.5-3 bps are sufficient to induce banks to fulfill the capital buffer requirement in normal times. This is a reassuring result, as the higher bank capital ratios induced by the buffer requirement lead to significantly lower bank failure probabilities with almost no change in aggregate bank loan supply. However, we also showed that the same small aggregate stigma costs will prevent that banks are willing to let their capital ratio fall below the buffer requirement when they make losses and become equity constrained. Instead, banks will start to deleverage significantly (e.g. up to 10%) to still meet the buffer requirement, as long as individual stigma costs are in the range of 10-30 bps. I.e. buffer usability constraints in crisis times are likely to exist even with small aggregate stigma costs and moderate individual stigma costs.

Overall, our results show that if the goal of macroprudential capital buffer requirements is to make banks more resilient and to support bank intermediation during stress episodes, then a structural non-releasable buffer requirement is likely to achieve the first goal but not necessarily the second one. This has potentially important policy implications for the design of the regulatory capital buffer framework and the balance between releasable and non-releasable macroprudential capital buffers. Analysing the optimal composition of the bank capital stack between minimum requirements, structural capital buffers and releasable capital buffers could be a promising avenue for future research.

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Appendix A: Derivation of analytical results

A1 First-order conditions and expected payoffs

The first-order conditions for **buffer use** are:

$$\left(1+\psi^U\right) d_{E'} + \chi^U + \beta \mathbb{E}\left(d'_{E'}\right) - \beta\Delta\left(-L' f(\theta^*|\theta)\theta^*_{E'}\right) = 0 \quad (11)$$

$$-\chi^U \omega R^{min} + \beta \mathbb{E}\left(d'_{L'}\right) - \beta\Delta\left(-L' f(\theta^*|\theta)\theta^*_{L'} + \int_{\theta^*}^{\infty} f(\theta'|\theta)d\theta'\right) = 0 \quad (12)$$

where the expressions are defined as follows:

$$d_{E'} = -1 \quad (13)$$

$$d'_{E'} = 1 + \pi'_{E'} = 1 + i^D \quad (14)$$

$$d'_{L'} = \pi'_{L'} = \frac{\mu - 1}{\mu} i(L', L^{A'}) - i^D - \kappa - \theta' - \xi \quad (15)$$

$$\theta^*_{E'} = \frac{1 + i^D}{L'} \quad (16)$$

$$\theta^*_{L'} = -\frac{i(L', L^{A'})}{\mu L'} - (1 + i^D)\frac{E'}{(L')^2} \quad (17)$$

Using these expressions in the first-order conditions for **buffer use** yields:

$$\chi^U = 1 + \psi^U - \frac{1 + i^D}{1 + \rho}\left[1 + \Delta f(\theta^{*U}|\theta)\right] \quad (18)$$

$$i(L', L^{A'}) = \underbrace{\frac{\mu}{\mu - 1 - \Delta f(\theta^{*U}|\theta)}}_{\text{Mark-up} = MU^U} \cdot \underbrace{\left[i^D + \kappa + \mathbb{E}\left(\theta'\right) + \xi + \chi^U(1+\rho)\omega R^{min} + \Delta\left(f(\theta^{*U}|\theta)(1 + i^D)\frac{E'}{L'} + PD(\theta^{*U})\right)\right]}_{\text{Marginal cost} = MC^U} \quad (19)$$

The probability of default is defined as $PD(\theta^*) = 1 - F(\theta^*|\theta)$.

The first-order conditions for **no buffer use** are:

$$\left(1+\psi^N\right)d_{E'}+\chi^N+\beta\mathbb{E}\left(d'_{E'}\right)-\beta\Delta\left(-L'f(\theta^*|\theta)\theta^*_{E'}\right) = 0 \quad (20)$$

$$-\chi^N\omega R^{cbr}+\beta\mathbb{E}\left(d'_{L'}\right)-\beta\Delta\left(-L'f(\theta^*|\theta)\theta^*_{L'}+\int_{\theta^*}^{\infty}f(\theta'|\theta)d\theta'\right) = 0 \quad (21)$$

where the expressions have the same definitions as above, except that now:

$$d'_{L'} = \pi'_{L'}=\frac{\mu-1}{\mu}i(L',L^{A'})-i^D-\kappa-\theta' \quad (22)$$

Using these expressions in the first-order conditions for **no buffer use** yields:

$$\chi^N=1+\psi^N-\frac{1+i^D}{1+\rho}\left[1+\Delta f(\theta^{*N}|\theta)\right] \quad (23)$$

$$i(L',L^{A'})=\underbrace{\frac{\mu}{\mu-1-\Delta f(\theta^{*N}|\theta)}}_{\text{Mark-up }=\,MU^N}\cdot\Bigg[i^D+\kappa+\mathbb{E}\left(\theta'\right)+\chi^N(1+\rho)\omega R^{cbr} \quad (24)$$

$$\underbrace{+\Delta\left(f(\theta^{*N}|\theta)(1+i^D)\frac{E'}{L'}+PD(\theta^{*N})\right)\Bigg]}_{\text{Marginal cost }=\,MC^N}$$

The **expected payoff** for the bank is defined as:

$$V = E+\pi-E'+\frac{1}{1+\rho}\mathbb{E}\left[E'+\pi'-\int_{\theta^*}^{\infty}\Delta L'f(\theta'|\theta)d\theta'\right]$$

or

$$V = E+\pi+\frac{1}{1+\rho}\left[\mathbb{E}\left(\pi'\right)-\rho E'-\Delta L'PD(\theta^*)\right] \quad (25)$$

Now, notice that we can make use of the following definitions:

$$\mathbb{E}(\pi') = \left(i(L', L^{A'}) - i^D - \kappa - \mathbb{E}(\theta') - \xi \mathbb{1}_{CR'<R^{cbr}} + i^D CR'\omega\right) L' \quad (26)$$

$$E' = CR'\omega L' \quad (27)$$

$$i(L', L^{A'}) = MU \cdot MC \quad (28)$$

$$L' = i(L', L^{A'})^{-\mu} \cdot \underbrace{L^{A'} \left(\frac{\epsilon}{\lambda - log(L^{A'})}\right)^{-\mu}}_{g(L^{A'})} \quad (29)$$

Using these definitions in the **expected payoff** function, we get:

$$V = E + \pi + \frac{1}{1+\rho} \left[i(L', L^{A'}) - i^D - \kappa - \mathbb{E}(\theta') - \xi \mathbb{1}_{CR'<R^{cbr}} - (\rho - i^D)CR'\omega - \Delta PD(\theta^*)\right] L' \quad (30)$$

or

$$V = E + \pi + \frac{1}{1+\rho} \left[MU \cdot MC - i^D - \kappa - \mathbb{E}(\theta') - \xi \mathbb{1}_{CR'<R^{cbr}} - (\rho - i^D)CR'\omega - \Delta PD(\theta^*)\right] (MU \cdot MC)^{-\mu} \cdot g(L^{A'}) \quad (31)$$

A2 Proof of proposition 1

In the absence of a CBR, stigma, an equity issuance constraint, and costly bank failure, the first-order conditions in equations (18) and (19) reduce to:

$$\chi = 1 - \frac{1 + i^D}{1+\rho} = \frac{\rho - i^D}{1+\rho} \quad (32)$$

$$i(L', L^{A'}) = \frac{\mu}{\mu - 1} \cdot \left[i^D + \kappa + \mathbb{E}(\theta') + \chi(1+\rho)\omega R^{min}\right] \quad (33)$$

As $\rho > i^D$ we know that $\chi > 0$. Hence, the minimum capital requirement is always binding and $CR' = R^{min}$. Using the expression for χ in the first-order condition for L' yields:

$$i(L', L^{A'}) = \frac{\mu}{\mu - 1} \cdot \left[i^D + \kappa + \mathbb{E}\left(\theta'\right) + (\rho - i^D)\omega R^{min} \right] \tag{34}$$

Using the definition of the interest rate in equation (2), setting $L' = L^{A'}$, and rearranging yields:

$$log(L') = \lambda - \epsilon \frac{\mu}{\mu - 1} \cdot \left[i^D + \kappa + \mathbb{E}\left(\theta'\right) + (\rho - i^D)\omega R^{min} \right] \tag{35}$$

A3 Proof of proposition 2

In the absence of a CBR, stigma, and an equity issuance constraint, but in the presence of a minimum capital requirement and costly bank failure, the first-order conditions in equations (18) and (19) reduce to:

$$\chi = 1 - \frac{1 + i^D}{1 + \rho} \left[1 + \Delta f(\theta^* | \theta) \right] \tag{36}$$

$$\begin{aligned} i(L', L^{A'}) = \frac{\mu}{\mu - 1 - \Delta f(\theta^* | \theta)} \cdot & \left[i^D + \kappa + \mathbb{E}\left(\theta'\right) + \chi(1 + \rho)\omega R^{min} \right. \\ & \left. + \Delta \left(f(\theta^* | \theta)(1 + i^D)\frac{E'}{L'} + PD(\theta^*) \right) \right] \end{aligned} \tag{37}$$

Now assume that banks do not want to maintain voluntary capital buffers so that $\chi > 0$ and $CR' = R^{min}$. Plugging equation (36) into equation (37) and using $E'/L' = \omega CR'$ as well as $CR' = R^{min}$ yields:

$$i^m = \frac{\mu}{\mu - 1 - \Delta f(\theta^{*m} | \theta)} \cdot \left[i^D + \kappa + \mathbb{E}\left(\theta'\right) + (\rho - i^D)\omega R^{min} + PD(\theta^{*m}) \right] \tag{38}$$

Where θ^{*m} is the failure threshold if banks choose a capital ratio equal to the minimum capital requirement:

$$\theta^{*m} \quad = \quad i^m - i^D - \kappa + i^D \omega R^{min} \tag{39}$$

From equation (36) it is easy to see that in case $f(\theta^{*m}|\theta) > \frac{\rho - i^D}{\Delta(1+i^D)}$ the lagrange multiplier χ will be negative, which cannot be the case. Hence, choosing a capital ratio equal to the minimum capital requirement cannot be the optimal action. If we impose the weak assumption that $f_{\theta'}(\theta'|\theta) < 0 \; \forall \theta' \geq \theta^{*m}$, it is easy to see that at some point $\theta^* > \theta^{*m}$ equation (36) will be satisfied for $\chi = 0$, i.e. banks will maintain voluntary capital buffers. Using $\chi = 0$ in equation (36) implies that:

$$f(\theta^*|\theta) = \frac{\rho - i^D}{\Delta(1+i^D)} \tag{40}$$

This equation implicitly also defines the value for the failure threshold θ^*. Because $f(\theta^*|\theta) > 0$, we also know that $F(\theta^*|\theta) < 1$ and hence the failure probability will be positive, i.e. $PD(\theta^*) > 0$. Moreover, using the expression for $f(\theta^*|\theta)$ and $\chi = 0$ in equation (37) yields:

$$i = \frac{\mu}{\mu - 1 - \frac{\rho - i^D}{1+i^D}} \cdot \left[i^D + \kappa + \mathbb{E}(\theta') + (\rho - i^D)\omega CR' + \Delta PD(\theta^*)\right] \tag{41}$$

We can now make use of the definition of the failure threshold in equation (6) and rearrange for the capital ratio:

$$CR' = \frac{R^{min}}{(1+i^D)} + \frac{i^D + \kappa + \theta^* - i}{(1+i^D)\omega} \tag{42}$$

Using the definition of the interest rate in equation (2), setting $L' = L^{A'}$, and rearranging yields:

$$log(L') = \lambda - \epsilon \cdot i \tag{43}$$

A4 Proof of proposition 3

In the absence of an equity issuance constraint, but in the presence of a minimum capital requirement, costly bank failure, stigma costs, and a CBR, the first-order conditions for the use case in equations (18) and (19) reduce to:

$$\chi^U = 1 - \frac{1+i^D}{1+\rho}\left[1 + \Delta f(\theta^{*U}|\theta)\right] \tag{44}$$

$$i(L', L^{A'}) = \frac{\mu}{\mu - 1 - \Delta f(\theta^{*U}|\theta)} \cdot \Bigg[i^D + \kappa + \mathbb{E}(\theta') + \xi + \chi^U (1+\rho)\omega R^{min} \quad (45)$$
$$+ \Delta \left(f(\theta^{*U}|\theta)(1+i^D)\frac{E'}{L'} + PD(\theta^{*U}) \right) \Bigg]$$

From section A3 we know that for the use case if $f(\theta^{*m}|\theta) > \frac{\rho - i^D}{\Delta(1+i^D)}$ and $f_{\theta'}(\theta'|\theta) < 0 \ \forall \theta' \geq \theta^{*m}$ banks will maintain voluntary capital buffers. As indicated in footnote 8, we also impose the assumption that the optimal capital ratio choice is lower than the CBR. Using $E'/L' = \omega CR'$, $\chi^U = 0$, and $f(\theta^{*U}|\theta) = \frac{\rho - i^D}{\Delta(1+i^D)}$ in equation (45) yields:

$$i^U = \underbrace{\frac{\mu}{\mu - 1 - \frac{\rho - i^D}{1+i^D}}}_{\text{Mark-up } = MU^U} \cdot \underbrace{\left[i^D + \kappa + \mathbb{E}(\theta') + \xi + (\rho - i^D)\omega CR' + \Delta PD(\theta^{*U}) \right]}_{\text{Marginal cost } = MC^U} \quad (46)$$

Now let us look at the case of not using buffers. The first-order conditions in equations (23) and (24) reduce to:

$$\chi^N = 1 - \frac{1+i^D}{1+\rho} \left[1 + \Delta f(\theta^{*N}|\theta) \right] \quad (47)$$

$$i(L', L^{A'}) = \frac{\mu}{\mu - 1 - \Delta f(\theta^{*N}|\theta)} \cdot \Bigg[i^D + \kappa + \mathbb{E}(\theta') + \chi^N (1+\rho)\omega R^{cbr} \quad (48)$$
$$+ \Delta \left(f(\theta^{*N}|\theta)(1+i^D)\frac{E'}{L'} + PD(\theta^{*N}) \right) \Bigg]$$

As the capital ratio under buffer use is lower than the CBR and the failure threshold in equation (6) is increasing in the capital ratio of the bank, it must be that $\theta^{*N} > \theta^{*U}$. Because of the assumption that $f_{\theta'}(\theta'|\theta) < 0 \ \forall \theta' \geq \theta^{*m}$ it must be that $f(\theta^{*N}|\theta) < \frac{\rho - i^D}{\Delta(1+i^D)} = f(\theta^{*U}|\theta)$. Therefore, $\chi^N > 0$ and the CBR will be binding such that $CR' = R^{cbr}$. Moreover, because $\theta^{*N} > \theta^{*U}$ it must be that $F(\theta^{*N}|\theta) > F(\theta^{*U}|\theta)$ and hence $PD(\theta^{*N}) < PD(\theta^{*U})$.

Plugging equation (47) into equation (48) and using $E'/L' = \omega CR'$ as well as

$CR' = R^{cbr}$ yields:

$$i^N = \underbrace{\frac{\mu}{\mu - 1 - \Delta f(\theta^{*N}|\theta)}}_{\text{Mark-up } = MU^N} \cdot \underbrace{\left[i^D + \kappa + \mathbb{E}\left(\theta'\right) + (\rho - i^D)\omega R^{cbr} + \Delta PD(\theta^{*N})\right]}_{\text{Marginal cost } = MC^N} \tag{49}$$

Plugging the interest rate conditions for the use case and the no use case from equations (46) and (49) into the definition of the expected payoff in equation (31) shows that we can rewrite the expected payoffs as:

$$V = E + \pi + \frac{1}{1+\rho}\left[(MU - 1) \cdot MC\right](MU \cdot MC)^{-\mu} \cdot g(L^{A'}) \tag{50}$$

or

$$V = E + \pi + \frac{1}{1+\rho}\left[(MU - 1)MU^{-\mu} \cdot MC^{1-\mu}\right] \cdot g(L^{A'}) \tag{51}$$

Banks will choose to fufill the CBR and not use buffers whenever $V^N > V^U$, which implies that:

$$(MU^N - 1)(MU^N)^{-\mu} \cdot (MC^N)^{1-\mu} > (MU^U - 1)(MU^U)^{-\mu} \cdot (MC^U)^{1-\mu} \tag{52}$$

Now define the function $g(MU) = (MU - 1)(MU)^{-\mu}$ and take the derivative:

$$g_{MU}(MU) = (1 - \mu)MU^{-\mu} + \mu MU^{-\mu-1} \tag{53}$$

Plugging $MU = \frac{\mu}{\mu-1-x}$ into the derivative function and rearranging, yields:

$$g_{MU}\left(\frac{\mu}{\mu - 1 - x}\right) = -x\left(\frac{\mu}{\mu - 1 - x}\right)^{-\mu} \tag{54}$$

It is easy to see that for $\mu - 1 > x > 0$ the derivative will be negative, i.e. the function g will be decreasing in the mark-up MU. As we know that $f(\theta^{*N}|\theta) < \frac{\rho - i^D}{\Delta(1+i^D)} = f(\theta^{*U}|\theta)$, we also know that $MU^U > MU^N$ and therefore $g(MU^N) > g(MU^U)$.

Hence, it is possible to derive an upper bound condition based on the marginal costs of the two cases, that ensures that banks will fulfill the CBR and not use buffers whenever it is satisfied:

$$(MC^N)^{1-\mu} > (MC^U)^{1-\mu} \tag{55}$$

$$MC^N < MC^U \tag{56}$$

$$(\rho - i^D)\omega R^{cbr} + \Delta PD(\theta^{*N}) < \xi + (\rho - i^D)\omega CR^{U'} + \Delta PD(\theta^{*U}) \tag{57}$$

Hence, when the following condition is met, banks will definitely fulfill the CBR:

$$(\rho - i^D)\omega[R^{cbr} - CR^{U'}] + \Delta[PD(\theta^{*N}) - PD(\theta^{*U})] < \xi \tag{58}$$

A5 Proof of proposition 4

For the full model with a minimum capital requirement, costly bank failure, stigma costs, a CBR, and an equity issuance constraint, the first-order conditions for the no use case are the ones from equations (23) and (24):

$$\chi^N = 1 + \psi^N - \frac{1+i^D}{1+\rho}\left[1 + \Delta f(\theta^{*N}|\theta)\right] \tag{59}$$

$$i(L', L^{A'}) = \frac{\mu}{\mu - 1 - \Delta f(\theta^{*N}|\theta)} \cdot \Bigg[i^D + \kappa + \mathbb{E}(\theta') + \chi^N(1+\rho)\omega R^{cbr} + \Delta\left(f(\theta^{*N}|\theta)(1+i^D)\frac{E'}{L'} + PD(\theta^{*N})\right)\Bigg] \tag{60}$$

From now on, let variables denoted by ^{N} indicate the unconstrained no use case, and let variables denoted by $^{\tilde{N}}$ indicate the no use case when the equity issuance constraint is binding. From Appendix A4 for the model without the issuance constraint we know that $\chi^N > 0$. Hence, when the issuance constraint is binding, i.e. when $\psi^{\tilde{N}} > 0$, it must also be that $\chi^{\tilde{N}} > 0$ and therefore $CR^{\tilde{N}'} = R^{cbr}$. Moreover, because the issuance constraint is binding, we also know that $d = 0$ and hence $E' = E + \pi$.

Now let us look at the use case and derive a sufficient condition that ensures that buffer use is not an equilibrium. Assume all banks use buffers, so that aggregates are given by $i^A = i^U$ and $L^A = L^U$. For the remaining exposition it is irrelevant whether the equity issuance constraint is binding for the use case or not, as this will only affect the values of the mark-up and the marginal cost, but not the expressions derived below.

Now let us look at deviating strategies, i.e. what would the payoff be for a bank that chose to not use buffers when all other banks use buffers. Denote all variables from deviating strategies by $^{\tilde{N}|U}$. Without loss of generality, we restrict our exposition to cases where $i^N < i^U$, i.e. where the aggregate interest rate in the unconstrained no use case is smaller than the interest rate in the unconstrained use case.[19] If this were not the case, then using buffers would be the equilibrium if banks are not equity constrained. For these cases we know that an unconstrained deviating bank would want to supply more loans than if all other banks did not use buffers, because the aggregate interest rate is higher and aggregate loans are lower. So we must have $L^{N|U} > L^N$. As we are looking at cases with possible buffer usability constraints, i.e. cases where L^N is not attainable, it must also be that $L^{N|U}$ is not attainable and the equity issuance constraint must be binding.

As the no use deviating strategy is equity constrained, we know that $d = 0$ and $E' = E + \pi$. Moreover, we know from above that for the no use case the bank will not maintain voluntary capital buffers. Using this in the definition of the capital ratio and rearranging, yields:

$$L^{\tilde{N}|U'} = \frac{E + \pi}{\omega R^{cbr}} \tag{61}$$

Now define the implied capital ratio for the deviating bank under the available equity but a loan choice equal to the use case as:

$$CR^{L^{U'}} = \frac{E + \pi}{\omega L^{U'}} < R^{cbr} \tag{62}$$

The assumption that $CR^{L^{U'}} < R^{cbr}$ simply ensures that we are looking at situations where shocks are big enough to require some form of deleveraging to fulfill the CBR.

Rearranging the previous two equations for $E + \pi$, setting them equal and rearranging again, yields:

$$L^{\tilde{N}|U'} = \underbrace{\frac{CR^{L^{U'}}}{R^{cbr}}}_{\equiv s^{\tilde{N}|U} < 1} L^{U'} \tag{63}$$

[19]Note that the aggregate interest rate in the constrained use case will always be higher than the interest rate in the unconstrained use case. Hence, the condition also implies $i^N < i^{\tilde{U}}$.

where $s^{\tilde{N}|U}$ is the implicit shock size which indicates how much a deviating bank needs to deleverage relative to all other banks that use buffers. Using the expression for loans in the definition of the interest rate in equation (2) yields:

$$i^{\tilde{N}|U} = \underbrace{(s^{\tilde{N}|U})^{-\frac{1}{\mu}}}_{>1} i^U \tag{64}$$

Using these properties for the interest rate and loans in the payoff function in equation (30), we can derive the following expression for the payoff from deviating strategies:

$$V^{\tilde{N}|U} = E + \pi + \frac{1}{1+\rho}\left[(s^{\tilde{N}|U})^{-\frac{1}{\mu}} i^U - i^D - \kappa - \mathbb{E}(\theta') - (\rho - i^D)\omega R^{cbr} - \Delta PD(\theta^{*\tilde{N}|U})\right] s^{\tilde{N}|U} \cdot L^{U'} \tag{65}$$

To ensure that buffer use is not an equilibrium it must be that deviating strategies pay off, i.e. it must be that $V^{\tilde{N}|U} > V^U$. Using the previously derived expression for $V^{\tilde{N}|U}$ and the payoff function for V^U, a sufficient condition for this is given by:

$$[(s^{\tilde{N}|U})^{-\frac{1}{\mu}} i^U \underbrace{- i^D - \kappa - \mathbb{E}(\theta') - (\rho - i^D)\omega R^{cbr} - \Delta PD(\theta^{*\tilde{N}|U})}_{-MC^{\tilde{N}|U}}] s^{\tilde{N}|U} > [i^U \underbrace{- i^D - \kappa - \mathbb{E}(\theta') - (\rho - i^D)\omega CR^U - \Delta PD(\theta^{*U}) - \xi^{U|U}}_{-MC^U}] \tag{66}$$

Now let us define $MC^{\tilde{N}|U} \equiv MC^U - \Delta^{MC}$, plug this into the previous inequality and rearrange, which yields:

$$\Delta^{MC} > \frac{1 - s^{\tilde{N}|U}}{s^{\tilde{N}|U}}\left[i^U - MC^U\right] - \left[(s^{\tilde{N}|U})^{-\frac{1}{\mu}} - 1\right] i^U \tag{67}$$

If we now use the definition of $\Delta^{MC} = MC^U - MC^{\tilde{N}|U}$[20] and rearrange, we get:

$$\xi^{U|U} > (\rho - i^D)\omega[R^{cbr} - CR^{U'}] + \Delta[PD(\theta^{*\tilde{N}|U}) - PD(\theta^{*U})] + \frac{1 - s^{\tilde{N}|U}}{s^{\tilde{N}|U}}\left[i^U - MC^U\right] - \left[(s^{\tilde{N}|U})^{-\frac{1}{\mu}} - 1\right] i^U \tag{68}$$

[20] Which is equal to $\xi^{U|U} + (\rho - i^D)\omega CR^{U'} + \Delta PD(\theta^{*U}) - (\rho - i^D)\omega R^{cbr} - \Delta PD(\theta^{*\tilde{N}|U})$

A6 Proof of proposition 5

For the full model with a minimum capital requirement, costly bank failure, stigma costs, a CBR, and an equity issuance constraint, the first-order conditions for the no use case are the ones from equations (23) and (24):

$$\chi^N = 1 + \psi^N - \frac{1+i^D}{1+\rho}\left[1 + \Delta f(\theta^{*N}|\theta)\right] \tag{69}$$

$$i(L', L^{A'}) = \frac{\mu}{\mu - 1 - \Delta f(\theta^{*N}|\theta)} \cdot \Bigg[i^D + \kappa + \mathbb{E}\left(\theta'\right) + \chi^N(1+\rho)\omega R^{cbr} + \Delta\left(f(\theta^{*N}|\theta)(1+i^D)\frac{E'}{L'} + PD(\theta^{*N})\right)\Bigg] \tag{70}$$

From now on, let variables denoted by ^{N} indicate the unconstrained no use case, and let variables denoted by $^{\tilde{N}}$ indicate the no use case when the equity issuance constraint is binding. From section A4 for the model without the issuance constraint we know that $\chi^N > 0$. Hence, when the issuance constraint is binding, i.e. when $\psi^{\tilde{N}} > 0$, it must also be that $\chi^{\tilde{N}} > 0$ and therefore $CR^{\tilde{N}'} = R^{cbr}$. Moreover, because the issuance constraint is binding, we also know that $d = 0$ and hence $E' = E + \pi$. Using this in the definition of the capital ratio and rearranging, yields:

$$L^{\tilde{N}'} = \frac{E + \pi}{\omega R^{cbr}} \tag{71}$$

This loan choice will be lower than the unconstrained loan choice $L^{N'}$ under no buffer use, because banks do not have sufficient equity to attain this loan choice while still maintaining a capital ratio equal to the CBR. Now define the implied capital ratio under the unconstrained loan choice, but under the available equity as:

$$CR^{L^{N'}} = \frac{E + \pi}{\omega L^{N'}} < R^{cbr} \tag{72}$$

Rearranging equations (71) and (72) for $E + \pi$, setting them equal and rearranging, yields:

$$L^{\tilde{N}'} = \underbrace{\frac{CR^{L^{N'}}}{R^{cbr}}}_{\equiv s^{\tilde{N}} < 1} L^{N'} \tag{73}$$

where $s^{\tilde{N}}$ is the implicit shock size which indicates how much the capital ratio would be below the CBR in case the bank chose the optimal unconstrained loan quantity for the no use case.

Let us now assume that all banks choose not to use buffers. Using the definition of the interest rate from equation (2) and plugging in the expression for L' from equation (73) yields the following expression for the aggregate interest rate:

$$i^{\tilde{N}} = \frac{\lambda - log(s^{\tilde{N}} \cdot L^{N'})}{\epsilon} = i^N \underbrace{- \frac{log(s^{\tilde{N}})}{\epsilon}}_{> 0} \tag{74}$$

Now let us look at deviating strategies, i.e. what would the payoff be for a bank that chose to use buffers when all other banks do not use buffers. Denote all variables from deviating strategies by $^{U|\tilde{N}}$. Without loss of generality, we restrict our exposition to cases where $i^U < i^{\tilde{N}}$, i.e. where the interest rate in the unconstrained use case is smaller than the interest rate in the constrained no use case. If this were not the case, then deviating strategies would never be optimal. For these cases, we know that $L^U > L^{\tilde{N}}$, i.e. deviating banks want to supply more loans to the market. Given the presence of an equity issuance constraint, the maximum loan quantity that can be supplied by deviating banks is given by the following expression (when $d = 0$):

$$\underbrace{\frac{R^{cbr}}{CR^{U|\tilde{N}'}}}_{\equiv n > 1} L^{\tilde{N}'} = L^{U|\tilde{N}'} \geq L^{U'} \tag{75}$$

Using this expression for the maximum loan quantity that deviating banks can supply in the definition of the interest rate in equation (2) yields:

$$i^{U|\tilde{N}} = \underbrace{n^{-\frac{1}{\mu}}}_{< 1} i^{\tilde{N}} \tag{76}$$

Using these properties for the interest rate and loans for deviating banks in the payoff function in equation (30), we can derive the following expression for the payoff from deviating strategies:

$$V^{U|\tilde{N}} = E + \pi + \frac{1}{1+\rho}\left[n^{-\frac{1}{\mu}} i^{\tilde{N}} - i^D - \kappa - \mathbb{E}(\theta') - \xi^{U|N} \right. \tag{77}$$
$$\left. -(\rho - i^D)\omega CR^{U|\tilde{N}'} - \Delta PD(\theta^{*U|\tilde{N}})\right] n \cdot L^{\tilde{N}'}$$

If we want that no buffer use is an equilibrium it must be that deviating strategies do not pay off, i.e. it must be that $V^{\tilde{N}} > V^{U|\tilde{N}}$. Using the previously derived expression for $V^{U|\tilde{N}}$ and the payoff function for $V^{\tilde{N}}$, a sufficient condition for this is given by:

$$[i^{\tilde{N}} \underbrace{-i^D - \kappa - \mathbb{E}(\theta') - (\rho - i^D)\omega R^{cbr} - \Delta PD(\theta^{*\tilde{N}})}_{-MC^{\tilde{N}}}] > \tag{78}$$
$$[n^{-\frac{1}{\mu}} i^{\tilde{N}} \underbrace{-i^D - \kappa - \mathbb{E}(\theta') - (\rho - i^D)\omega CR^{U|\tilde{N}'} - \Delta PD(\theta^{*U|\tilde{N}}) - \xi^{U|N}}_{-MC^{U|\tilde{N}}}] n$$

Now let us define $MC^{\tilde{N}} = MC^{U|\tilde{N}} - \Delta^{MC}$, plug this into the previous inequality and rearrange, which yields:

$$\Delta^{MC} > \frac{n-1}{n}\left[\frac{n^{\frac{\mu-1}{\mu}} - 1}{n-1} i^{\tilde{N}} - MC^{\tilde{N}}\right] \tag{79}$$

If we now use the definition of $\Delta^{MC} = MC^{U|\tilde{N}} - MC^{\tilde{N}}$[21] and the fact that $i^{\tilde{N}} = i^N - \frac{log(s^{\tilde{N}})}{\epsilon}$ and rearrange we get:

$$\xi^{U|N} > (\rho - i^D)\omega\left[R^{cbr} - CR^{U|\tilde{N}'}\right] + \Delta\left[PD(\theta^{*\tilde{N}}) - PD(\theta^{*U|\tilde{N}})\right] +$$
$$\frac{n-1}{n}\left[\frac{n^{\frac{\mu-1}{\mu}} - 1}{n-1} \underbrace{\left(i^N - \frac{log(s^{\tilde{N}})}{\epsilon}\right)}_{i^{\tilde{N}}} - MC^{\tilde{N}}\right] \tag{80}$$

Whenever this condition is satisfied, no buffer use will be an equilibrium even when the equity issuance constraint is binding, and banks will deleverage to meet

[21] Which is equal to $\xi^{U|N} + (\rho - i^D)\omega CR^{U|\tilde{N}'} + \Delta PD(\theta^{*U|\tilde{N}}) - (\rho - i^D)\omega R^{cbr} - \Delta PD(\theta^{*\tilde{N}})$

the CBR. As $\frac{n\frac{\mu-1}{\mu}-1}{n-1} \leq 1$, a simplified condition where we set this expression equal to one implies that the stigma condition above is also satisfied. If market power is low, this simplification will not have big quantitative implications for the minimum needed individual stigma. Hence, we can write:

$$\begin{aligned} \xi^{U|N} &> (\rho - i^D)\omega\left[R^{cbr} - CR^{U|\tilde{N}'}\right] + \Delta\left[PD(\theta^{*\tilde{N}}) - PD(\theta^{*U|\tilde{N}})\right] + \\ & \frac{n-1}{n}\left[\underbrace{\left(i^N - \frac{log(s^{\tilde{N}})}{\epsilon}\right)}_{i^{\tilde{N}}} - MC^{\tilde{N}}\right] \end{aligned} \tag{81}$$

A7 Proof of proposition 6

From the proof in Section A6 we already know that in an equilibrium with buffer usability constraints, i.e. an equilibrium where banks deleverage to meet the CBR when they become equity constrained, banks will not maintain voluntary capital buffers above the CBR. Moreover, in Section A6 we have shown that:

$$L^{\tilde{N}'} = \underbrace{\frac{CR^{L^{N'}}}{R^{cbr}}}_{\equiv s^{\tilde{N}} < 1} L^{N'} \tag{82}$$

and

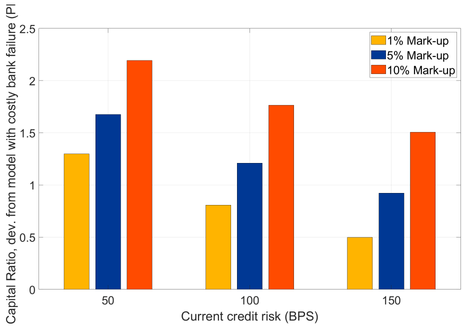
$$i^{\tilde{N}} = i^N \underbrace{-\frac{log(s^{\tilde{N}})}{\epsilon}}_{>0} \tag{83}$$

The expression for the failure threshold is simply given by plugging in the equilibrium interest rate $i^{\tilde{N}}$ and equilibrium capital ratio R^{cbr} into equation (6). Finally, from the proof in Section A4 we know that $PD(\theta^{*N}) < PD(\theta^{*U})$. Hence, as $i^{\tilde{N}} > i^N$, and the failure threshold is increasing in the interest rate charged by banks, it must also be that $PD(\theta^{*\tilde{N}}) < PD(\theta^{*U})$.

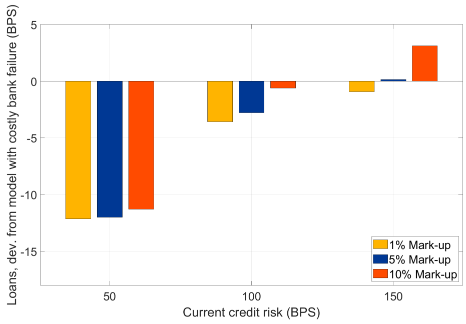
Appendix B: Additional charts

Figure B1: Effect of a CBR on capital ratios, lending, PDs, and default thresholds

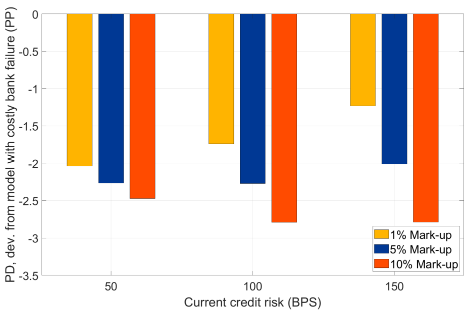
(a) Effect on capital ratio choice



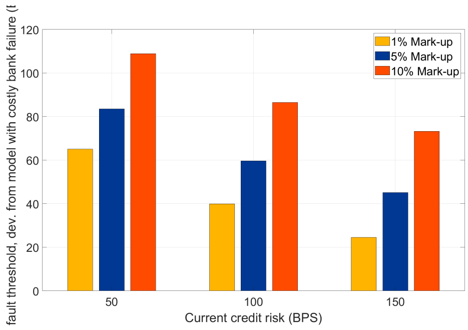
(b) Effect on bank lending



(c) Effect on bank PD



(d) Effect on default threshold



Notes: For the calibration of model parameters see Table 1. The benchmark model calibration is represented by the yellow bars.

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