Macroprudential Policy with Capital Buffers

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This paper studies optimal bank capital requirements in a model of endogenous bank funding conditions. I find that requirements should be higher during good times such that a macroprudential "buffer" is provided. However, whether banks can use buffers to maintain lending during a financial crisis depends on the capital requirement during the subsequent *recovery*. The reason is that a high requirement during the recovery lowers bank shareholder value during the crisis and thus creates funding-market pressure to use buffers for deleveraging rather than for maintaining lending. Therefore, buffers are useful if banks are not required to rebuild them quickly.

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1 Introduction

The global financial crisis of 2007–09 exposed taxpayers to potential losses from bank failures and significantly disrupted financial intermediation (Bernanke, 2018). Regulatory standard setters responded to this experience by asking whether banks should hold more capital and, if so, in what form (BCBS, 2010). Higher minimum requirements reduce losses to stakeholders in case of bank failures but may constrain intermediation when it is most scarce—during financial crises. On the other hand, regulatory capital buffers do not constrain intermediation provided that the bank is willing to constrain payouts instead.

This paper develops a model of optimal bank capital and derives implications for bank capital regulation. In the model, banks use equity and (uninsured) debt to fund loans to firms. Uninsured debt is a significant funding source for banks (Figure 1) and, importantly, affects bank actions during financial crises through funding market pressure (Gorton and Metrick, 2012). There are two key frictions in my model that determine how banks use equity and debt. First, bank equity is costly in the sense that bank shareholders demand a higher expected return than holders of bank debt. Second, holders of bank debt are wary of potential bank moral hazard in the sense that they require that bank shareholder value is not too low relative to the size of the bank balance sheet.

These frictions create a challenging risk-management problem for the bank. On the one hand, when bank equity is too low then bank moral hazard concerns imply that banks become funding constrained. Bank lending margins are high precisely during times of low aggregate bank equity, however, because of decreasing returns to scale at the firm level. On the other hand, banks hold costly equity—as a provision in case of low loan repayments—only if there is a strictly positive probability that they actually

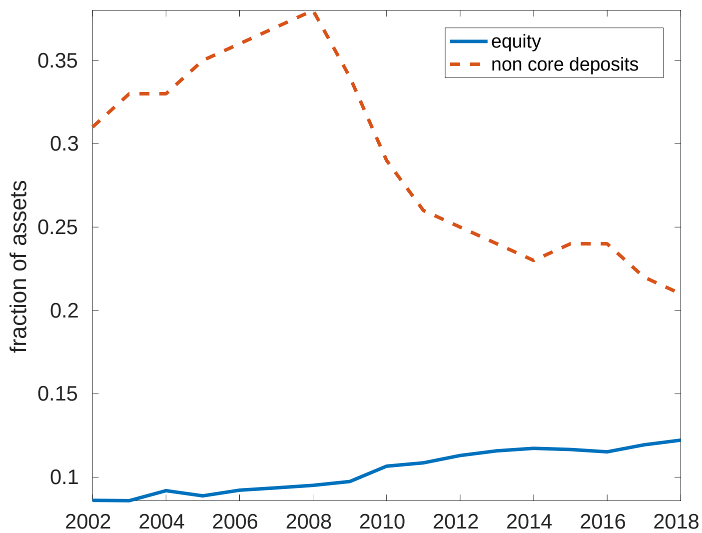


Figure 1: Equity and noncore deposits as a fraction of assets for the largest US bank holding companies (https://www.ffiec.gov/npw/FinancialReport/BHCPRReports).

become funding-constrained. The two frictions therefore imply that banks lose access to the market for debt finance occasionally, at which point there is a credit crunch in the economy.[1]

I study optimal capital regulation in the model by comparing the allocation in competitive equilibrium with the constrained-efficient allocation. Specifically, I interpret the difference between these two allocations as due to optimal capital regulation. There are two general-equilibrium channels that can be exploited in a constrained-efficient allocation. First, it is feasible, in the sense of satisfying bank participation constraints, to require banks to hold more costly equity during times of high loan repayments as long as overall bank profitability is somewhat raised. Second, it is possible to allow low bank equity, and high bank leverage, during times of low loan repayments as long as bank profitability is significantly raised temporarily for a while in a way that satisfies the bank debt funding constraint. In that sense, regulation trades off small and permanent against

[1]There is a growing literature that studies credit crunches as the result of occasionally binding bank funding constraints (Brunnermeier and Sannikov, 2014; Holden, Levine, and Swarbrick, 2017; Martinez-Miera and Repullo, 2017; He and Krishnamurthy, 2019).

large but temporary distortions when taking measures to stabilize loan supply over time.

The main result of the paper is that optimal regulation requires banks to hold more equity when loan supply is high, but also allows banks to hold very little equity when loan supply is low. It is crucial that banks are also allowed to rebuild equity slowly after loan supply has been low—otherwise, loan supply would become very low when banks have very little equity. The reason is that if banks were to anticipate that they would have to rebuild costly equity quickly, then they would have lower shareholder value and, because of increased moral hazard concerns, reduced access to debt funding when equity is low.[2] In other words, regulation must take into account that it cannot stimulate loan supply when bank equity is low by setting an equity requirement that is lower than the one implicitly imposed by the market for debt funding. Optimal regulation therefore not only reduces the regulatory burden during a recovery but also requires banks to increase loan supply somewhat more slowly than they otherwise would. The resulting temporarily higher lending margins further raise bank dividend payout ratios during the time loan supply recovers, and further improves banks' access to debt funding during the time when loan supply is low. In that sense, when banks are offered a stake in the recovery from a credit crunch—through temporarily less onerous regulation and higher profit margins—then the credit crunch is less severe.

Three main policy implications can be derived from the analysis. First, minimum capital requirements should be as low as possible while still discouraging moral hazard.[3] Second, any additional capital that a regulator wishes banks to hold should take the form of "capital buffers." The difference between a minimum requirement and a capital buffer

[2]Hellmann et al. (2000) point out the relationship between costly bank equity and bank lending in a steady state, while Schroth (2016) analyzes the dynamic trade-off in a deterministic economy. This paper studies the dynamic trade-off in a stochastic economy with endogenous financial crises.

[3]This result simply follows from the insight in, for example, Alvarez and Jermann (2000) that debt constraints should not be "too tight."

is that banks are not forced to reduce the size of their balance sheet when they breach the latter. Specifically, banks may reduce equity payouts instead of deleveraging. Third, capital buffers that banks build up during good times are most effective in stabilizing lending during a financial crisis when banks are allowed to rebuild them slowly—while maintaining a high equity payout ratio—during the recovery from a financial crisis.

These policy implications can be compared with recent changes in recommendations for bank regulation under the Basel Accord (BCBS, 2010) denoted "Basel III." First, the analysis suggests that market-imposed capital requirements are lower during financial crises for given bank borrower default rates. Adherence to rigid microprudential capital requirements at all times may therefore not be optimal. In practice, giving banks some discretion in calculating risk-weighted assets during times of crisis can be justified for this reason—since bank margins are high when aggregate bank equity is low.[4] Second, there should be a buffer on top of market-imposed capital requirements—augmenting voluntary bank loan loss provisioning—that can be used to stabilize lending when bank equity is low. However, no equity payouts are allowed when this buffer is being used. This buffer resembles the capital conservation buffer under Basel III. Third, there should be an additional buffer that can be used when the first one is depleted. It can be used for lending. It can also be used for dividend payouts—or, equivalently, it is "released"—but only once the first buffer has been rebuilt. This additional buffer resembles the counter-cyclical capital buffer (CCyB) under Basel III. In my model, it is crucial that the regulator raises bank future profitability temporarily during the time when banks use the additional buffer to pay out dividends. The reason is that otherwise dividend payouts in the face of low bank equity would threaten bank solvency. In practice, bank prof-

[4]For evidence and theory on "regulatory forbearance" see Huizinga and Laeven (2012), Repullo (2013) and Repullo and Suarez (2013). However, my model justifies forbearance only to the extent compatible with the prescription in Bagehot (1873)—to provide funding only to solvent institutions—because the market funding constraint, which rules out default and moral hazard, is imposed at all times.

itability could be supported by recapitalizations financed by taxes on bank lending or by regulatory capital restoration plans that emphasize restrictions on asset growth over restrictions on payouts.[5]

1.1 Related literature

Existing empirical work finds that financial crises are costly in terms of forgone output and generally lead to policy interventions that aim at restoring credit supply (Laeven and Valencia, 2013; Bernanke, 2018). Indeed, existing theoretical work suggests that interventions can improve welfare significantly because of the pivotal role that financial intermediaries play (Bebchuk and Goldstein, 2011; Philippon and Schnabl, 2013; Sandri and Valencia, 2013; Bianchi, 2016; Schroth, 2016). However, theoretical work also stresses the importance of *ex ante* measures, such as capital buffers, which reduce the need to rely on *ex post* policy intervention (Lorenzoni, 2008; Martinez-Miera and Suarez, 2012; Clerc et al., 2015; Malherbe, 2019; Begenau, 2019). The literature that trades off *ex post* intervention and *ex ante* measures relates bank access to funding to the liquidation value of bank assets during a default (e.g., Jeanne and Korinek, 2013). For example, during the 2007–2008 US financial crisis, there was a run in the market for secured bank funding when concerns about bank solvency suddenly emerged.[6] This paper contributes to this literature by relating the bank's decision to default to its future prospects. The approach is motivated by the fact that a defaulting bank loses its charter value, and the charter value depends (positively) on the bank's future prospects. Novel implications for bank

[5] The recapitalizations under the Troubled Asset Relief Program during the 2007–2009 US financial crisis were eventually repaid by participating financial institutions such that the cost of recapitalizations was partly passed on to bank borrowers during the recovery from the crisis. Regulators in practice have more discretion in setting a capital restoration plan when the capital, or buffer, requirement is of type "Pillar 2" rather than "Pillar 1."

[6] The observed run on the repurchase market was characterized by a sudden increase in haircuts (Gorton and Metrick, 2012). Sudden concerns about the solvency of banks reflect a fear that the liquidation value of a given bank asset might be lower when the bank owning the asset defaults.

regulation follow from this approach.[7]

2 Model

This section describes an infinite horizon economy in discrete time. There are aggregate productivity shocks $s_t \in S = \{s_L, s_H\} \subset \mathbb{R}_{++}$, where $Pr(s_t = s_L) = \rho$ in each period $t = 1, 2, \ldots$. The initial state is given as s_0. Define the sets $S^t = S \times S^{t-1}$ for $t = 1, 2, \ldots$ where $S^0 = \{s_0\}$. Let s^t denote the history of productivity shocks up to period t and the initial state, with $s^0 = s_0$, and define the probability measure π_t on S^t. Denote conditional probabilities by $\pi_t(s^{t+\tau}|s^t)$ for any t and $\tau = 1, 2, \ldots$. There is a consumption good.

There are continuums of measure one of identical firms, banks and households, respectively. Firms are short-lived and have access to a production technology. To fund investment firms are reliant on loans from banks. Households are endowed with one unit of labor each, which they supply inelastically, in periods $t = 1, 2, \ldots$ and with $\omega_0 > 0$ units of the consumption good in period $t = 0$. Households trade bank shares among each other, and trade one-period non-contingent bonds with banks.

At the beginning of each period a fraction $1 - \gamma/\beta > 0$ of banks exit.[8] Their equity is distributed among fraction $1 - \gamma/\beta > 0$ of new banks. The shares of new banks are sold to households and the proceeds from the share sale are transferred to households as a lump sum.

[7] Indeed, recent regulatory reforms often reflect concerns about inefficiently high bank risk-taking in the run-up to financial crises while my approach focuses on inefficiently *low* bank risk-taking *during* financial crises. Section 4.3.1 provides further discussion.

[8] Banks sometimes face losses from exogenous failures in risk management, "rogue" trading, that might trigger restructuring of the institution by a supervisory authority. I normalize these losses to zero and focus on the effect of restructuring, during which bank shareholders are wiped out, on shareholders' tolerance for retaining equity within banks.

Markets:

There are markets for labor, bonds, bank loans and bank shares. Let $w_t(s^t)$ be the price of one unit of labor in period $t = 1, 2, \ldots$. The supply of labor is fixed at unity because households each supply one unit of labor inelastically. Let $q_{t+1}(s^t)$ be the price of one unit of the consumption good in t to be delivered in $t+1$ in the market for bonds such that $1/q_{t+1}(s^t)$ is the interest rate on bonds. Let $R_{t+1}(s^t)$ denote the interest rate on bank loans. Finally, let $p_t(s^t)$ denote the bank share price including the current dividend. I normalize the supply of bank shares in each period to one.

Household problem:

Households choose consumption c, bonds b^h and bank shares χ to maximize their life-time utility as follows:

$$\max_{\{c_t, b^h_{t+1}, \chi_{t+1}\}_{t=0,1,2,\ldots}} \sum_{t=0}^{\infty} \beta^t \sum_{s^t \in S^t} c_t(s^t)\pi_t(s^t),$$

where $\beta \in (0,1)$ is a discount factor, subject to budget constraints

$$\begin{aligned} c_t(s^t) &+ q_{t+1}(s^t) b^h_{t+1}(s^t) + p_t(s^t)\chi_{t+1}(s^t) \\ &\le w_t(s^t) + T_t(s^t) + b^h_t(s^{t-1}) + D_t(s^t)\chi_{t+1}(s^t) + p_t(s^t)\frac{\gamma}{\beta}\chi_t(s^{t-1}), \text{ for } t = 1, 2, \ldots, \text{ and} \end{aligned}$$

$$c_0(s_0) + q_1(s_0) b^h_1(s_0) + p_0(s_0)\chi_1(s_0) \le \omega_0 + D_0(s_0)\chi_1(s_0) + p_0(s_0),$$

where T_t are lump sum transfers and D_t are bank dividends. Note that households lose fraction $1 - \gamma/\beta$ of banks shares that they hold at the beginning of each period. Optimal household choices are consistent with asset prices that satisfy the following equations:

$$q_{t+1}(s^t) = \beta, \tag{1}$$

$$p_t(s^t) = D_t(s^t) + \gamma \sum_{s^{t+1}} p_{t+1}(s^{t+1}) \pi_t(s^{t+1}|s^t). \tag{2}$$

Equation (2) implies that households effectively discount bank dividends using the lower discount factor $\gamma < \beta$ such that the bank share price at date zero is as follows:

$$p_0(s_0) = \sum_{t=0}^{\infty} \gamma^t \sum_{s^t \in S^t} D_t(s^t) \pi_t(s^t). \tag{3}$$

Firm problem:

Firms live for one period. They have access to a production technology that turns k units of the consumption good in period t and n units of labor in period $t+1$ into $F(k, n; s_{t+1}) = s_{t+1} k^{\alpha} n^{1-\alpha} + (1-\delta)k$ units of the consumption good in period $t+1$, where aggregate productivity s_{t+1} is realized at the beginning of period $t+1$, before n is chosen, and where $\delta \in (0,1)$ is the depreciation rate. It is assumed that firms cannot sell bonds and do not have any internal funds such that they must borrow from a bank to fund physical capital investment k. A firm that is born at the end of period t in state s^t produces in period $t+1$ and maximizes its expected profit subject to solvency in each state of the world:

$$\max_{k \geq 0} \sum_{s_{t+1} \in S} \pi_t(s^{t+1}|s^t) \left[\max_n \left\{ s_{t+1} k^{\alpha} n^{1-\alpha} + (1-\delta)k - w_{t+1}(s^{t+1}) n \right\} - R_{t+1}(s^{t+1}) k \right],$$

subject to $\max_n \left\{ s_{t+1} k^{\alpha} n^{1-\alpha} + (1-\delta)k - w_{t+1}(s^{t+1}) n \right\} - R_{t+1}(s^{t+1}) k \geq 0$ for each $s_{t+1} \in S$. For given wages $w_{t+1}(s^{t+1})$ and bank lending returns $R_{t+1}(s^{t+1})$, the optimal firm labor input and capital investment choices are characterized as follows:

$$
\begin{aligned}
w_{t+1}(s^{t+1}) &= (1-\alpha)s_{t+1}k^{\alpha}(s^t)n^{-\alpha}(s^{t+1}),\\
R_{t+1}(s^{t+1}) &= \alpha s_{t+1}k^{\alpha-1}(s^t)n^{1-\alpha}(s^{t+1}) + 1 - \delta, \text{ for each } s_{t+1} \in S.
\end{aligned}
$$

It is assumed that firm profits accrue to households. Note that profits are zero for any realization of s_{t+1} because of constant returns to scale.

Bank problem:

Banks choose dividends d, bonds b and loans ℓ to maximize shareholder value

$$
V_0(s_0) = \sum_{t=0}^{\infty} \gamma^t \sum_{s^t \in S^t} d_t(s^t)\pi_t(s^t) \tag{4}
$$

subject to budget constraints

$$
d_t(s^t) + \ell_{t+1}(s^t) + q_{t+1}(s^t)b_{t+1}(s^t) \leq R_t(s^t)\ell_t(s^{t-1}) + b_t(s^{t-1}), \text{ for } t = 1, 2, \ldots, \tag{5}
$$

$$
d_0(s_0) + \ell_1(s_0) + q_1(s_0)b_1(s_0) \leq a_0, \tag{6}
$$

a no-default condition

$$
\sum_{\tau=1}^{\infty} \gamma^{\tau} \sum_{s^{t+\tau}} d_{t+\tau}(s^{t+\tau})\pi_t(s^{t+\tau}|s^t) \geq \theta \ell_{t+1}(s^t), \tag{7}
$$

and dividend non-negativity, $d_t(s^t) \geq 0$, for given initial bank equity $a_0 > 0$.

The presence of the no-default condition (7) implies that banks will generally not set dividends as high as possible at all times. The reason is that the timing of bank dividends determines a bank's incentive to engage in moral hazard, which in turn affects the bank's access to external funding. In particular, bank creditors (i.e., households) are willing to provide external funding to a bank as long as the bank values the future dividends it expects to enjoy more than a fraction $\theta \in (0,1]$ of its lending. I motivate this key model feature with the assumption that bank assets $\ell_{t+1}(s^t)$ are not liquid and diminish by fraction θ unless monitored by a bank. A bank could thus extract $\theta\ell_{t+1}(s^t)$ by defaulting and threatening creditors not to monitor their assets. This consideration is captured by the no-default constraint (7) that needs to be satisfied in every period $t = 0, 1, 2, \ldots$ in which the bank wishes to make use of external funding.[9]

2.1 Competitive equilibrium

Definition 1. *A competitive equilibrium is characterized by (i) bank lending returns $\{R_{t+1}(s^{t+1})\}$, bond prices $\{q_{t+1}(s^t)\}$, wages $\{w_{t+1}(s^{t+1})\}$, and bank share prices $\{p_t(s^t)\}$, (ii) household choices for bonds and bank stock holdings $\{b^h_{t+1}(s^t), \chi_{t+1}(s^t)\}$, (iii) bank choices for dividends, bonds and loans $\{D_t(s^t), B_{t+1}(s^t), K_{t+1}(s^t)\}$ and (iv) transfers to households $\{T_t(s^t)\}$ such that given initial bank equity a_0 and household endowment ω_0,*

1. *household choices are optimal given $\{w_{t+1}(s^{t+1})\}$, $\{T_t(s^t)\}$, $\{q_{t+1}(s^t)\}$, $\{p_t(s^t)\}$ and $\{D_t(s^t)\}$,*
2. *bank choices are optimal given $\{R_{t+1}(s^{t+1})\}$ and $\{q_{t+1}(s^t)\}$,*
3. *the market for bonds clears, $b^h_{t+1}(s^t) + B_{t+1}(s^t) = 0$ and $q_{t+1}(s^t) = \beta$,*
4. *the market for bank loans clears, $R_{t+1}(s^{t+1}) = \alpha s_{t+1} K^{\alpha-1}_{t+1}(s^t) + 1 - \delta$,*
5. *the market for labor clears, $w_{t+1}(s^{t+1}) = (1-\alpha) s_{t+1} K^{\alpha}_{t+1}(s^t)$,*

[9] The amount $\theta\ell_{t+1}(s^t)$ that banks can extract by defaulting may exceed their external funding $-b_{t+1}(s^t)$. The idea is that bank creditors would receive all bank assets in case of a bank default even if the "liquidation value" $\theta\ell_{t+1}(s^t)$ exceeds liabilities. When banks fund lending exclusively with equity, such that $b_{t+1}(s^t) \geq 0$, then condition (7) can be interpreted as providing incentives for the bank to keep its lending portfolio. Then $\theta\ell_{t+1}(s^t)$ would be the payment the bank could extract from any acquirer of its portfolio.

6. *the market for bank shares clears,* $\chi_{t+1}(s^t) = 1$*,*

7. *households receive transfers given by* $T_t(s^t) = (1 - \gamma/\beta)p_t(s^t)$*.*

2.2 Analysis of competitive equilibrium

Let $\beta^t \pi_t(s^t)\psi_t(s^t)$ be the multiplier on the no-default condition (7) in period t, when the bank chooses lending $\ell_{t+1}(s^t)$. It determines the change in the value of the bank's internal funds (equity) when the bank loses access to external funding—i.e., when the bank is constrained and cannot sell additional bonds. Let the value of internal funds be $\beta^t \pi_t(s^t)\lambda_t(s^t)$, i.e., the multiplier on the bank budget constraints. Then the first-order condition for bank lending $\ell_{t+1}(s^t)$ can be written as follows:

$$\theta\psi_t(s^t) = \gamma \sum_{s_{t+1}} \pi_t(s^{t+1}|s^t) \left[\lambda_{t+1}(s^{t+1}) \left(R_{t+1}(s^{t+1}) - \frac{1}{\beta}\right)\right]. \tag{8}$$

Equation (8) says that banks are profitable, after adjusting their income for its riskiness, only at times when they lose access to external funding. The reason is that banks are competitive and would immediately compete away any risk-adjusted profit margin if their creditors would allow them to increase leverage. The model thus predicts that lending spreads are elevated during financial crises (Muir, 2017).

The first-order condition for bonds is given by

$$\lambda_t(s^t) = \sum_{s_{t+1}} \lambda_{t+1}(s^{t+1})\pi_t(s^{t+1}|s^t). \tag{9}$$

Let $\beta^t \pi_t(s^t)\mu_t(s^t)$ denote the multiplier on dividend non-negativity. Then the first-order condition for dividends can be written as

$$\lambda_t(s^t) = \left(\frac{\gamma}{\beta}\right)^t + \mu_t(s^t) + \sum_{\tau=0}^{t-1} \left(\frac{\gamma}{\beta}\right)^{t-\tau} \psi_\tau(s^\tau), \tag{10}$$

where s^τ denote sub-histories of s^t. The assumption that banks are more impatient than other participants in the bond market, i.e., $\gamma < \beta$, implies that (7) will occasionally bind, as Proposition 1 shows.

Proposition 1. *The bank no-default condition binds occasionally.*

Proof. The first-order condition for bank bond holdings implies that the return on equity λ_t converges almost surely. Hence, if the bank no-default constraint (7) were not binding occasionally, then $\psi_t = 0$ almost surely and thus $\lambda_t - \mu_t \to 0$ almost surely. But then dividends are zero almost surely, implying that (7) is in fact binding almost surely. □

Bank equity is valuable because it can be used to relax the bank no-default constraint and allow the bank to lend more and to attract more external funding at exactly those times when bank lending is profitable. Each bank is aware that low realizations of the aggregate shock lower equity of all other banks and increase the probability that other banks will lose access to external funding in the current or some future period. For this reason, banks regard lending income as risky and extend lending only up to the point where their risk-adjusted profitability drops to zero.[10] Banks thus engage in loan loss provisioning as a result of the "last bank standing effect" (Perotti and Suarez, 2002).

Equations (9) and (10) reveal that the bank's risk-management problem has both a forward-looking and a backward-looking component. On the one hand, internal funds (equity) in the current period can be used to reduce leverage. Lower leverage reduces

[10]The bond market is incomplete exogenously in this paper. Lorenzoni (2008) and Rampini and Viswanathan (2010, 2018) show how contracting frictions limit bank risk management even if a complete set of contingent securities is potentially available.

the probability of losing access to market funding and being forced to cut dividends, potentially to zero, in future periods. On the other hand, internal funds in the current period can be used to pay dividends and thus increase access to market funding in all preceding periods through relaxing market-imposed no-default constraints. The model in this paper thus gives an example of how financial intermediaries evaluate risk differently compared with the representative household (He and Krishnamurthy, 2013; Adrian, Etula, and Muir, 2014). This difference in risk perception plays a crucial role in shaping the implications of this paper for financial regulation.

2.3 Deterministic steady state

Suppose $s_L = s_H = 1$ such that the economy does not experience any stochastic fluctuations. Define first-best lending as follows:

$$K_{FB} = \left[\frac{\alpha}{1/\beta - (1-\delta)} \right]^{\frac{1}{1-\alpha}}. \tag{11}$$

It equals the amount of physical capital employed by firms in every period in a frictionless version of the economy in which households would be able to lend to firms directly (without the need to rely on banks for intermediation). Lemma 1 shows that banks provide less than the first-best amount of lending in steady state. The reason is that banks view equity as costly relative to external funding. The required return on bank lending is given by $R_{CE} = 1/\beta + \theta(\beta - \gamma)/\beta\gamma$. This return is higher than the return on external funding, $1/\beta$, but lower than the required return on internal funds, $1/\gamma$.[11]

[11]When banks can hold creditors up to the full amount of lending, i.e., if $\theta = 1$, then only equity is used to fund bank lending and the required return on bank lending becomes $1/\gamma$. In this case, the bank no-default constraint (7) can be interpreted as a no-abandonment or no-sale condition. It keeps the bank from abandoning or selling its assets and extracting $\ell_{t+1}(s^t)$ from the acquirer in exchange for monitoring them and thus facilitating their liquidation.

Lemma 1. *Steady-state lending in the deterministic case in competitive equilibrium is given as follows:*

$$K_{CE} = \left[\frac{\alpha}{1/\beta + \theta(\beta-\gamma)/\beta\gamma - (1-\delta)} \right]^{\frac{1}{1-\alpha}}. \tag{12}$$

Proof. Banks pay strictly positive dividends in a steady state of the competitive equilibrium such that $\mu_t = 0$. It follows from equations (9) and (10) that $\psi_t = \frac{\beta-\gamma}{\gamma}\lambda_t$ in a steady state. Further, banks are always borrowing-constrained due to their relative impatience. The amount of steady state lending in a competitive equilibrium then follows from equation (8). □

3 Macroprudential capital requirements

This section analyzes the model analytically. I will first discuss how the no-default constraint (7) can be interpreted as a market-imposed bank capital requirement. Then, I will present first-order conditions that characterize the second-best allocation and imply a rationale for macroprudential capital regulation in the model economy.

3.1 Bank no-default constraint and capital requirements

Let a_t denote bank equity and let Π_t denote the value of a bank's charter net of equity, or bank future profitability, then

$$a_t(s^t) = R_t(s^t)\ell_t(s^{t-1}) + b_t(s^{t-1}) \quad \text{for } t = 1, 2, \dots \text{ and } a_0 \text{ given,} \tag{13}$$

$$\begin{aligned}\Pi_t(s^t) = &\sum_{\tau=1}^{\infty} \gamma^{\tau} \sum_{s^{t+\tau} \in S^{t+\tau}} \left[R_{t+\tau}(s^{t+\tau}) - \frac{1}{\gamma} \right] \ell_{t+\tau}(s^{t+\tau-1}) \pi_t(s^{t+\tau}|s^t) \\ &+ \sum_{\tau=1}^{\infty} \gamma^{\tau} \sum_{s^{t+\tau} \in S^{t+\tau}} \frac{\gamma-\beta}{\gamma} b_{t+\tau}(s^{t+\tau-1}) \pi_t(s^{t+\tau}|s^t). \end{aligned} \tag{14}$$

Note that the first term in Π_t is the present value of pure profits where the bank's own discount factor is used rather than the bond market discount factor β. Since $\gamma < \beta$, this term is lower for given lending returns than it is when bank profits are discounted using bond prices. The second term reflects the fact that usage of external funding, $b_{t+\tau}(s^{t+\tau-1}) < 0$, is a way for the bank to increase its value. That is, there is a benefit for the bank from front-loading dividends and from back-loading debt repayments as a result of impatience. When bank budget constraints are used to substitute out dividends, the value of a bank at time t can be expressed as the sum of equity and bank future profits as follows:

$$V_t(s^t) = d_t(s^t) + \sum_{\tau=1}^{\infty} \gamma^\tau \sum_{s^{t+\tau}} \pi_t(s^{t+\tau}|s^t) d_{t+\tau}(s^{t+\tau}) = a_t(s^t) + \Pi_t(s^t). \tag{15}$$

The no-default constraint (7) can then be reformulated as follows:

$$\gamma \sum_{s_{t+1} \in S} a_{t+1}(s^{t+1}) \pi_t(s^{t+1}|s^t) \geq \theta \ell_{t+1}(s^t) - \gamma \sum_{s_{t+1} \in S} \Pi_{t+1}(s^{t+1}) \pi_t(s^{t+1}|s^t). \tag{16}$$

With bank capital defined as discounted expected equity, (16) gives a capital requirement that depends on the expected present value of bank future profits. This capital requirement is microprudential in the sense that its purpose is to guarantee the solvency of the bank only. For example, if the value of the bank does not exceed its equity, then permissible leverage is given by $1/\theta$. If the bank is expected to have positive future profits, then it is allowed to have higher leverage because future profits serve as "skin in the game."

It is important to note that microprudential capital requirements are low in this economy, in the sense that banks often hold capital (equity) well above the requirement stipulated by equation (16), implying that equation (16) will bind only occasionally. The reason is that banks seek to protect their charter value; that is, they risk-adjust income from lending to avoid low equity (and binding capital requirements) in states where the return on lending is high (loan loss provisioning). In that sense, market-imposed capital requirements already induce prudent behavior to some extent. Section 3.2 asks whether this extent is sufficient or whether additional macroprudential capital regulation is necessary.

3.2 Optimal capital regulation

The capital requirement (16) gives rise to a pecuniary externality, in the sense of Greenwald and Stiglitz (1986). Hence, an exclusive reliance on loan loss provisioning motivated by market discipline may leave some inefficiencies in this economy unaddressed. The reason is that future asset prices, i.e., future lending returns $\{R_{t+\tau}(s^{t+\tau})\}$ enter (16) through expected future profits given by equation (14) at each point in time. A constrained social planner can therefore affect capital requirements, and thus permissible bank leverage, by affecting these future asset prices (as in Schroth, 2016). This paper focuses on how a constrained social planner can stabilize aggregate lending in the economy over time, by exploiting the pecuniary externality, and thus improve upon self-interested (competitive) individual provisioning by banks.

Because banks consider equity to be costly, relative to external funding, it is necessary to impose bank participation constraints in periods $t = 0, 1, 2, \ldots$ as follows:

$$V_t(s^t) \geq a_t(s^t) \quad \text{for all } s^t \in S^t. \tag{17}$$

Condition (17) ensures that banks prefer continuing to be banks rather than liquidating their assets. Note that the bank participation constraint is equivalent to $\Pi_t(s^t) \geq 0$. Condition (17) requires that the future profits that banks expect to earn are non-negative.

The condition would never be violated in a competitive equilibrium because banks are free to reduce lending and increase dividends. To see why it might be binding in a constrained-efficient—or second-best—allocation, consider the case in which bank lending is first best and bank debt is zero, such that the first term in Π_t is negative while the second is zero. A second-best allocation will thus allow for bank leverage or bank rents or both to discourage banks from liquidating themselves.

Definition 2. *The second-best allocation is given by sequences of dividends $\{D_t(s^t)\}$, bank bond holdings $\{B_{t+1}(s^t)\}$ and bank loans $\{K_{t+1}(s^t)\}$ such that household lifetime utility*

$$\mathcal{W} \equiv \sum_{t=0}^{\infty} \beta^t \sum_{s^t \in S^t} c_t(s^t)\pi_t(s^t)$$

is maximized subject to household budget constraints

$$c_t(s^t) - \beta B_{t+1}(s^t) = w_t(s^t) - B_t(s^{t-1}) + D_t(s^t), \text{ for } t = 1, 2, \dots, \text{ and}$$
$$c_0(s_0) - \beta B_1(s_0) = \omega_0 + D_0(s_0),$$

bank budget constraints

$$D_t(s^t) + K_{t+1}(s^t) + \beta B_{t+1}(s^t) = R_t(s^t)K_t(s^{t-1}) + B_t(s^{t-1}), \text{ for } t = 1, 2, \dots, \text{ and}$$
$$D_0(s_0) + K_1(s_0) + \beta B_1(s_0) = a_0,$$

initial bank equity a_0 and household endowment ω_0, prices for labor and loans

$$w_{t+1}(s^{t+1}) = s_{t+1}(1-\alpha)K_{t+1}(s^t)^{\alpha},$$
$$R_{t+1}(s^{t+1}) = s_{t+1}\alpha K_{t+1}(s^t)^{\alpha-1} + 1 - \delta,$$

market-imposed no-default constraints

$$\sum_{\tau=1}^{\infty} \gamma^{\tau} \sum_{s^{t+\tau}} \pi_t(s^{t+\tau}|s^t) D_{t+\tau}(s^{t+\tau}) \geq \theta K_{t+1}(s^t),$$

dividend non-negativity, $D_t(s^t) \geq 0$*, as well as bank participation constraints*

$$D_t(s^t) + \sum_{\tau=1}^{\infty} \gamma^{\tau} \sum_{s^{t+\tau}} \pi_t(s^{t+\tau}|s^t) D_{t+\tau}(s^{t+\tau}) \geq R_t(s^t) K_t(s^{t-1}) + B_t(s^{t-1}), \text{ for } t = 1, 2, \ldots, \text{ and}$$

$$D_0(s_0) + \sum_{\tau=1}^{\infty} \gamma^{\tau} \sum_{s^{\tau}} \pi_t(s^t|s_0) D_{\tau}(s^{\tau}) \geq a_0.$$

In a second-best allocation, the no-default constraint can be relaxed by increasing future profits. However, while an increase in future bank profits mitigates a severe credit crunch, it also creates socially costly distortions in future bank lending.

3.3 Analysis of the second-best allocation

Let $\beta^t \pi_t(s^t) \psi_t(s^t)$ be the multiplier on the bank no-default constraint, $\beta^t \pi_t(s^t) \lambda_t(s^t)$ be the multiplier on the bank budget constraint, $\beta^t \pi_t(s^t) \eta_t(s^t)$ be the multiplier on the participation constraint, and $\beta^t \pi_t(s^t) \mu_t(s^t)$ the multiplier on dividend non-negativity. The first-order conditions for bonds and dividends can be combined as follows:

$$\lambda_t(s^t) = 1 + \sum_{s_{t+1}} \mu_{t+1}(s^{t+1}) \pi_t(s^{t+1}|s^t) + \sum_{\tau=0}^{t} \left(\frac{\gamma}{\beta}\right)^{t+1-\tau} \left[\psi_{\tau}(s^{\tau}) + \eta_{\tau}(s^{\tau})\right], \tag{18}$$

where the terms s^{τ} denote sub-histories of s^t. Equation (18) shows that the return on bank equity is forward-looking as well as backward-looking. The constrained planner values current equity more if it is more likely that equity will be scarce in future periods, as indicated by binding dividend non-negativity constraints in the next period. However, the constrained planner also internalizes how higher equity in the current period can be used to increase the current dividend and thus relaxes bank no-default and participation constraints in all previous periods. Note that this intuition is almost the same as that in Section 2.2 (the bank participation constraint is ignored in Section 2.2 because it is satisfied by definition in competitive equilibrium). A key difference is that the constrained planner is not impatient with respect to dividends and thus tends to value bank equity more highly. However, the bank participation constraint keeps the planner from back-loading dividends too much and from building up too much equity. The reason is that higher levels of equity necessitate higher rents from bank lending since the planner must deliver the return on bank equity $1/\gamma$.

The first-order condition for bank lending reveals that the second-best allocation may feature an excess risk premium on bank lending even if banks have further access to external funding, i.e., even if the no-default constraint does not bind such that $\psi_t(s^t) = 0$:

$$\begin{aligned}\theta\psi_t(s^t) + \beta \sum_{s_{t+1}} \left[\lambda_{t+1}(s^{t+1}) - \eta_{t+1}(s^{t+1}) - 1\right] \alpha(1-\alpha) s_{t+1} K_{t+1}(s^t)^{\alpha-1} \pi_t(s^{t+1}|s^t) \\ = \beta \sum_{s_{t+1}} \left[\lambda_{t+1}(s^{t+1}) - \eta_{t+1}(s^{t+1})\right] \left(R_{t+1}(s^{t+1}) - \frac{1}{\beta}\right) \pi_t(s^{t+1}|s^t). \qquad (19)\end{aligned}$$

That the second term on the left-hand side of equation (19) is non-negative can be seen by writing the first-order condition for dividends as follows:

$$\lambda_{t+1}(s^{t+1}) - \eta_{t+1}(s^{t+1}) - 1 = \mu_{t+1}(s^{t+1}) + \sum_{\tau=1}^{t} \left(\frac{\gamma}{\beta}\right)^{t+1-\tau} \left[\psi_\tau(s^\tau) + \eta_\tau(s^\tau)\right],$$

which is non-negative for all s_{t+1}. Therefore, excess returns enjoyed by banks, given by the term on the right-hand side of equation (19), have a forward- and a backward-looking component. On the one hand, when the dividend non-negativity constraint is binding in the following period, $\mu_{t+1}(s^{t+1}) > 0$, then bank returns increase, which increases bank equity in that period and makes dividend non-negativity constraints bind less. On the other hand, when no-default or participation constraints have been binding in the past, $\psi_\tau(s^\tau) > 0$ or $\eta_\tau(s^\tau) > 0$, then bank returns increase, thus relaxing those constraints by increasing banks' ability to increase dividends in subsequent periods.

In summary, the intuition is as follows. When the no-default constraint binds, lending is severely reduced in the economy and excess lending returns shoot up. As a result, the value of bank internal funds increases, and this increase is long-lived by equation (19). This in turn leads to higher excess returns over a number of periods, increasing expected bank future profits immediately. The result is that the no-default constraint is being relaxed such that lending returns shoot up by less, at the social cost of somewhat higher lending returns over a number of future periods. That is, in a second-best allocation, the scarcity of bank lending is smoothed out over time.

3.3.1 Deterministic steady state

Analyzing the second-best allocation in deterministic steady state reveals that the trade-offs faced by the constrained planner are dynamic rather than static. Indeed, Lemma 2 shows that the second-best allocation is identical to the competitive-equilibrium allocation in steady state of the deterministic economy.[12]

Lemma 2. *Steady-state lending in the deterministic case in the second best is the same as in competitive equilibrium.*

Proof. The bank participation constraint does not bind strictly because there is no benefit

[12] This is not the case when $\gamma = \beta$, since then the constrained planner would backload distortionary rents in a way that lowers the steady-state level of bank lending in the deterministic economy (see Schroth, 2016). The expressions $K_{SB}(\lambda)$ and λ in the proof of Lemma 2 are not continuous as $\gamma \nearrow \beta$ because the no-default constraint is slack in steady state when $\gamma = \beta$. The value of equity is decreasing when $\gamma < \beta$ and constant if $\gamma = \beta$.

from having precautionary equity buffers in the deterministic case. Then multipliers are constant and satisfy $\psi = (\lambda - 1)(\beta - \gamma)/\gamma$ by equation (18). The second-best amount of bank lending can then be obtained from equation (19) as a function of the value of bank equity as follows:

$$K_{SB}(\lambda) = \left[\frac{\alpha \left(1 - (1-\alpha)\frac{(\lambda-1)}{\lambda}\right)}{\frac{1}{\beta} + \theta \frac{(\beta-\gamma)}{\beta\gamma} \frac{(\lambda-1)}{\lambda} - (1-\delta)} \right]^{\frac{1}{1-\alpha}}.$$

For the bank participation constraint to hold, bank lending must be lower than K_{CE} because the bank participation constraint binds weakly in a deterministic steady state of the competitive equilibrium. Hence, it must be the case that $K_{SB}(\lambda) \leq K_{CE}$. Because $\gamma < \beta$, the effect of initially scarce bank equity on the steady-state value of bank equity decays geometrically by equation (18). The value of bank equity in steady state therefore depends only on the multiplier on the no-default constraint in steady state. As a result, $K_{SB}(\lambda) = K_{CE}$ and

$$\lambda = 1 + \frac{1}{1-\alpha} \frac{\theta(\beta - \gamma)/\beta\gamma}{1/\beta + \theta(\beta-\gamma)/\beta\gamma - (1-\delta)}.$$

□

4 Numerical analysis

This section analyzes the model numerically to illustrate and further characterize the dynamics discussed in Section 3. I will first discuss the choices for numerical values of model parameters and then compare the competitive-equilibrium allocation to the second-best allocation.

4.1 Calibration

Table 1 summarizes the choices of model parameter values used in the numerical analysis. The time period is one year. The choice of consumer discount factor β implies an annual interest rate on household savings of around 6 percent. This rate is between the long-run safe return of 1–3 percent and the long-run risky return of 7 percent as reported in Jordà et al. (2019). The depreciation rate and capital income share are set to 12 percent and 35 percent, respectively. The firm productivity process is normalized to have unit mean and the probability of the low shock realization is set to $\rho = 0.2$. Note that s_H is fully determined by ρ and s_L.

The parameter values for θ, s_L, and γ are chosen jointly such that three model moments match their respective targets. The first model moment is bank equity relative to bank lending in normal times during which bank equity and lending is constant as long as realized firm productivity is s_H. I set its target to 12.5 percent which is the average ratio of equity capital to total assets in 2019 of bank holding companies in the United States with assets of $10 billion and over.[13]

The second model moment is the decrease in the bank equity to lending ratio when low firm productivity is realized during normal times. I set its target to 2.5 percent. This value implies a significant decrease in bank capital from low loan repayment. However, this decrease is smaller than the 4.4 percentage points decline in aggregate regulatory equity capital generated by the 2018 supervisory bank stress test of the Federal Reserve Board for the case of a severe stress scenario.[14] My model generates bank losses com-

[13]This data can be found at https://www.ffiec.gov/npw/FinancialReport/BHCPRReports. The model assumption of a fixed leverage target that banks aim to achieve during normal times is consistent with empirical evidence in Gropp and Heider (2010).

[14]Details on the stress test can be found at https://www.federalreserve.gov/supervisionreg/dfa-stress-tests.htm. The average regulatory equity capital ratio, in terms of risk-weighted assets, was 12.2 percent in 2019 which is close to the average ratio of equity over total assets of 12.5 percent.

parable to those considered by regulatory stress tests as the result of multiple adverse shocks. Specifically, a 4.4 decline in equity capital would require two or more realizations of low firm productivity and would have a likelihood of less than 4 percent.

The third model moment is the fraction of periods during which the "lending gap," the difference between actual bank lending and first-best lending K_{FB}, is at least 5 percent. I set its target to 0.06. Using data from Schularick and Taylor (2012) for the time period 1870–2008, Boissay, Collard, and Smets (2016) report that on average financial crises occur in developed countries once every 42 years and last 2.32 years. Therefore, a developed economy is expected to spend a fraction $1/42 \cdot 2.32 = 0.055 \approx 0.06$ of years in a financial crisis. In their panel study of more recent financial crises Laeven and Valencia (2018) find that developed countries tend to spend between one and two years in a financial crisis during the time period 1970–2017. Depending on the cutoff for the size of the lending gap used to define a financial crisis in the model economy, the competitive equilibrium spends between 2 and 8 percent of years in a financial crisis (see solid line in Figure 2).

The resulting value for θ implies a market-imposed equity requirement of 10 percent in normal times, when bank future profits are zero. Thus, banks hold a 2.5 percent voluntary equity buffer on top of the market-imposed requirement during normal times. One realization of low firm productivity during normal times wipes out this buffer and brings banks close to becoming funding constrained. The value for γ implies a cost of equity that is around one percentage point higher than the return on savings. This moderate cost of equity is nevertheless consistent with a plausible frequency of financial crises in the model.

The competitive-equilibrium allocation is obtained by using policy function iteration and the constrained-efficient allocation is obtained by using value function iteration. See

Table 1: Model parameter values

parameter	value	target
β	0.94	return on savings
γ	0.93	financial crisis frequency
δ	0.12	average replacement investment
α	0.35	capital income share
θ	0.10	bank leverage
(s_L, s_H, ρ)	(0.8,1.05,0.2)	bank loss from one shock

Appendix A.1 for details on the computational methods used.

4.2 Competitive-equilibrium vs second-best capital buffers

In Section 3 it was shown that when the bank no-default condition binds in a second-best allocation, then lending returns become elevated for some time. Elevated future lending returns increase bank future profits and relax the no-default condition in the current period. The economic impact of a credit crunch, during which banks are forced to reduce lending due to insufficient access to external funding, is therefore mitigated. However, granting future profits to banks creates costly economic distortions such that a second-best allocation would also require banks to hold more equity during normal times. The idea is to limit use of an increase in future profits to the most severe credit crunches. As a result, banks are asked to increase their loan loss provisioning and can withstand more adverse shocks before the economy enters a credit crunch. On the rare occasions when the economy does enter a credit crunch, despite higher provisioning, lending is stabilized by increasing bank future profits.

Figure 3 compares the second-best allocation with the competitive-equilibrium allocation for the following sequence of firm productivity shocks:

$$\{s_H, \ldots, s_H, s_L, s_H, \ldots, s_H, s_L, s_L, s_H, \ldots, s_H, s_L, s_L, s_L, s_L, s_H, \ldots, s_H\}.$$

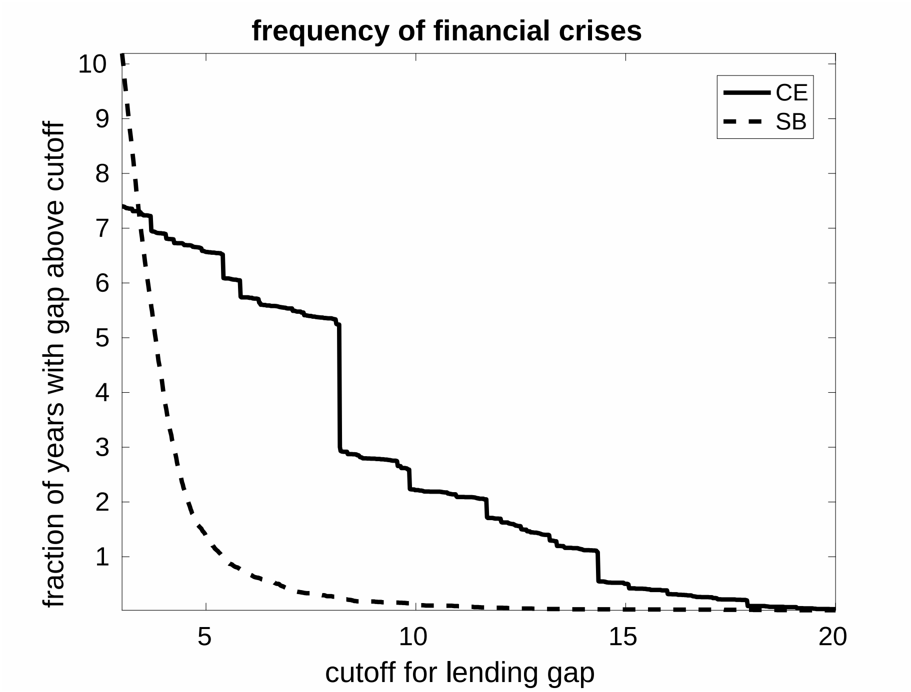


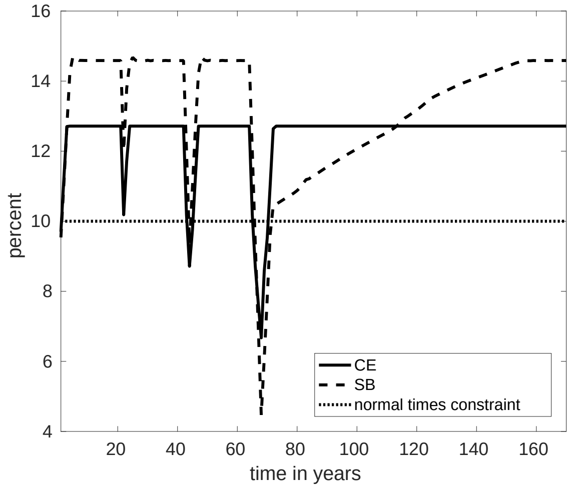
Figure 2: Frequency of low lending in a stochastic steady state (average over 30, 000 simulated periods) in laissez-faire competitive-equilibrium allocation (CE) and second-best allocation (SB).

This sequence produces three impulse responses that illustrate the non-linear effect of shocks to bank balance sheets on bank lending. Define aggregate bank equity as $A_t(s^t) = R_t(s^t)K_t(s^{t-1}) + B_t(s^{t-1})$ where K_t denotes aggregate bank lending and $B_t < 0$ denotes aggregate bank bond holdings. Figure 3(a) shows that banks in competitive equilibrium hold a voluntary capital buffer of 2.5 percent on top of the market-imposed equity requirement. One low realization of firm productivity gets absorbed by this buffer and therefore has only limited effect on bank lending. However, a low realization of firm productivity when this voluntary buffer is used up has a large effect on bank lending as Figure 3(b) shows. A constrained planner would require an additional buffer of 2 percent such that bank capital in the second-best allocation during normal times reaches 14.5 percent. In a second-best, therefore, banks are resilient enough to withstand losses from up to two realizations of low firm productivity.

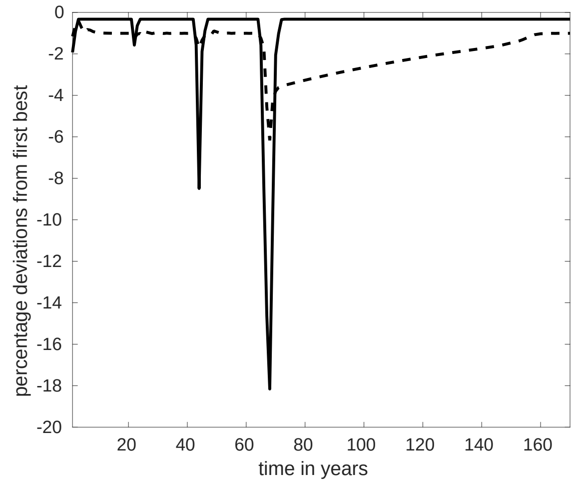
Bank lending during normal times is lower in the second-best allocation than it is in competitive equilibrium. The reason is that banks must be compensated with a higher expected return on lending when they are required to hold additional capital buffers because of the relatively higher cost of capital compared with external funding. However, bank lending is stabilized significantly in the second-best allocation compared to the competitive equilibrium. This is because the constrained planner can increase bank future profits at relatively low cost to offset decreases in bank equity whenever low-productivity shocks occur. The planner can deliver future profits at low cost to banks because the planner smooths out the associated economic distortions over time. That is, in contrast to the competitive equilibrium, the second-best allocation delivers bank future profits by increasing long-term lending returns somewhat rather than increasing short-term lending returns a lot. Bank lending thus drops by less during financial crises, but it also recovers more slowly during the time banks are allowed to earn their future profits.

Figure 4 shows that expected excess returns are positive in normal times to compensate banks for the cost of capital buffers. Lending returns are more smoothed out in the second-best allocation; returns shoot up by less since financial crises are much less severe, but they stay elevated for longer to deliver increases in bank future profits more cheaply. During a financial crisis, there is a sudden spike in lending returns in competitive equilibrium as banks reduce the size of their balance sheet drastically because of decreased access to external funding. In contrast, banks increase their reliance on external funding during a financial crisis in the second-best allocation (Figure 4(d)).

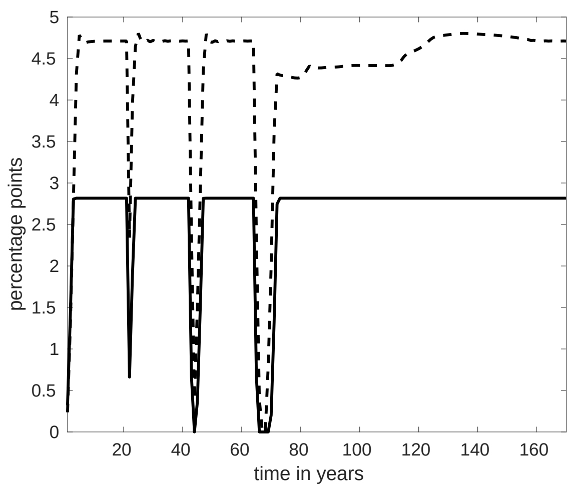
Because bank capital is costly, $\gamma < \beta$, the extent to which the constrained planner is able to backload dividends to relax market-imposed no-default conditions during a financial crisis is limited. As a result, the dividend payout ratio increases temporarily



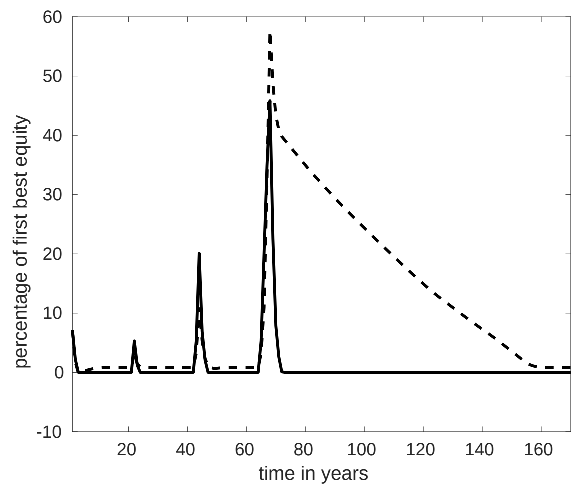
(a) Aggregate bank capital



(b) Aggregate bank lending

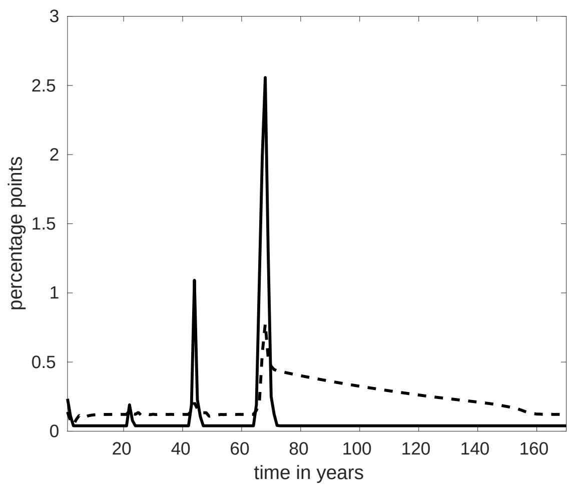


(c) Slack in no-default condition

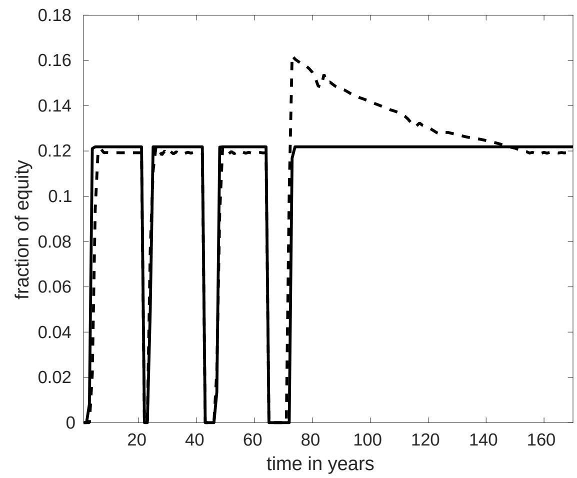


(d) Future profits

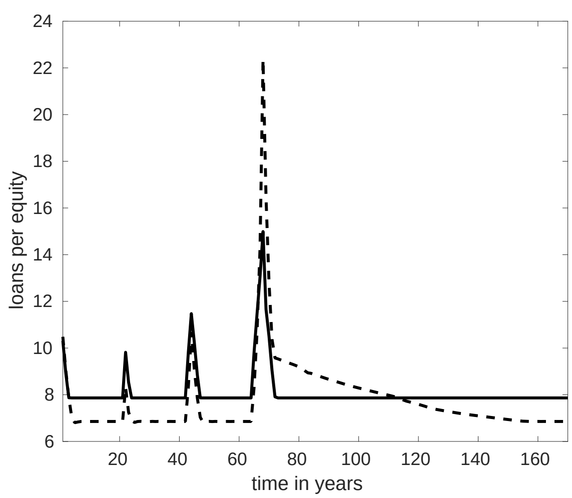
Figure 3: Panel (a) shows bank capital relative to bank lending, $\left[\gamma E_t A_{t+1}/K_{t+1} - 1\right] \cdot 100$, where E_t denotes conditional expectations at time t. Panel (b) shows bank lending relative to first-best lending, $\left[K_{t+1}/K_{FB} - 1\right] \cdot 100$. Panel (c) shows the slack in the market-imposed no-default condition, $\left[\gamma E_t V_{t+1}/\theta K_{t+1} - 1\right] \cdot 100$. Finally, panel (d) shows bank future profits relative to first-best equity, $\Pi_t/\beta\theta K_{FB} \cdot 100$.



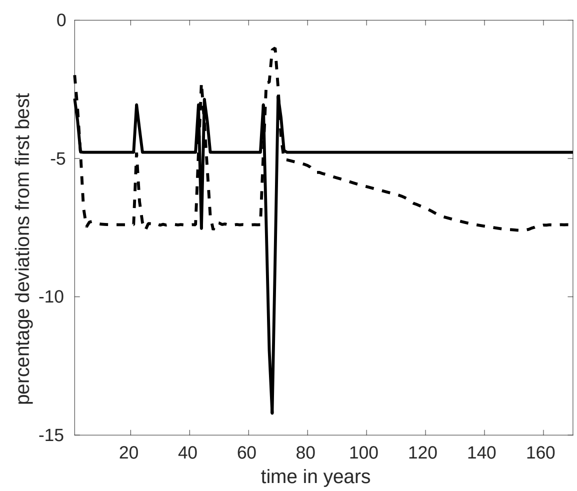
(a) Expected excess lending returns



(b) Aggregate dividends



(c) Leverage



(d) Aggregate bank external funding

Figure 4: Panel (a) shows expected excess returns, $[\beta E_t R_{t+1} - 1] \cdot 100$. Panel (b) shows the aggregate bank dividend payout ratio, D_t/A_t. Panel (c) shows bank leverage, $K_{t+1}/\gamma E_t A_{t+1}$, which is inversely related to the capital adequacy ratio. Finally, panel (d) shows bank external funding.

following financial crises. Banks resume paying high levels of dividends earlier in the second-best allocation, compared with the competitive equilibrium, such that, in particular, rebuilding equity buffers takes a backseat to resuming dividend payouts in the aftermath of financial crises.

The constrained planner allows banks to have higher leverage during financial crises. On the one hand, the planner can satisfy market-imposed no-default conditions more easily by increasing bank future profits at relatively small cost. On the other hand, the planner is less averse to bank income risk because lending returns increase less during crises—the reason is that future equity scarcity can be partially offset by upward adjustments in future profits. Even though the planner prescribes additional equity buffers in normal times, the planner perceives equity to be relatively less scarce during times of financial crisis and is consequently less protective of it. Thus, while the second-best allocation features lower reliance of banks on external funding in normal times, the planner allows banks to aggressively replace lost equity with external funding during times of financial crisis.

Figure 5 shows the economy for a realization of productivity shocks. The competitive equilibrium features a severe credit crunch during years 85–90. This credit crunch is much less severe in the second-best allocation. However, the economy takes a much longer time to recover from it. The constrained planner uses bank equity more aggressively to maintain lending when bank earnings are low because of low-productivity shocks. The future profits that the planner must promise banks become large, and with them so does the dividend payout ratio. Subsequent low shocks deplete bank equity at periods when it has not yet had time to be rebuilt such that the planner has to adjust promised bank future profits upward repeatedly. As a result, bank margins remain elevated—and bank lending remains depressed—for many years.

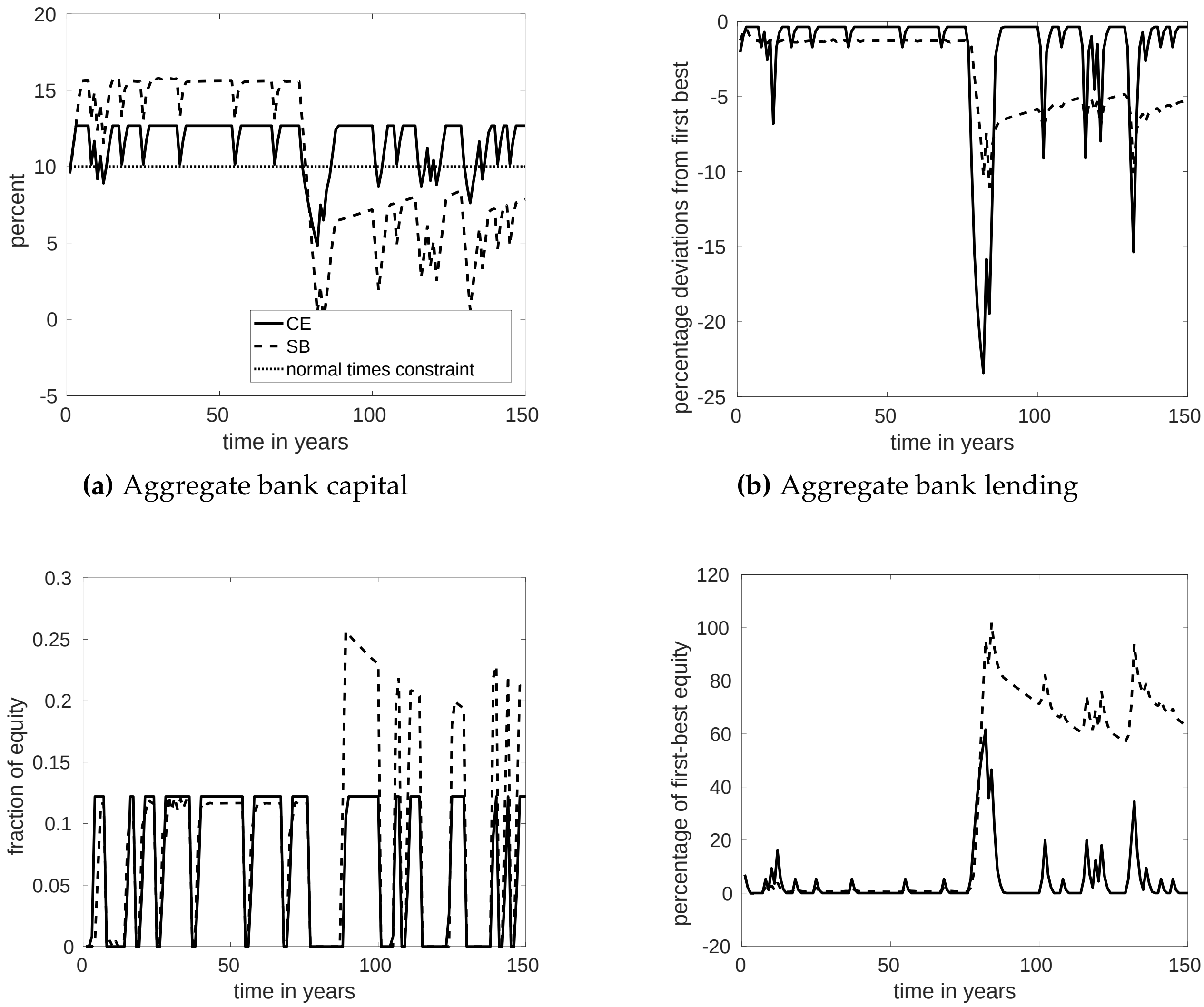
The second-best allocation is characterized by macroprudential capital regulation that avoids sharp reductions in bank lending and economic activity but, at the same time, can lead to a very persistent decline in lending and economic activity. One crucial assumption in my analysis is that the constrained planner can honor its promise to deliver bank future profits.

4.3 Policy implications and further discussion

The second-best allocation shows that there is a net benefit from requiring banks to hold additional equity. Such capital buffers are "always on" in the sense that banks should build them up gradually in good times while paying out dividends at the same time. Strong non-linearities as well as this gradualism imply that it is too late to turn on the capital buffer once the economy experiences financial stress in the form of losses on bank balance sheets.

Banks should be allowed to use capital buffers during credit crunches—for lending to firms and, eventually, for dividend payments. In case the economy is still in a credit crunch by the time capital buffers are exhausted, bank future rents can be increased to continue to stabilize lending. Bank future rents should be provided by distributing economic distortions over multiple periods, which has the side effect of slowing down the recovery from credit crunches. Credit crunches are much less severe in the second-best allocation than in competitive equilibrium such that the net effect on welfare is positive.[15]

[15] The second best achieves higher welfare uniformly across every point of the state-space of the competitive equilibrium. Specifically, for given bank equity a_0 the constrained planner achieves higher welfare compared with the competitive equilibrium when assuming banks are initially promised the shareholder value V_0 they can generate in competitive equilibrium for given a_0.



(a) Aggregate bank capital

(b) Aggregate bank lending

(c) Aggregate dividends

(d) Future profits

Figure 5: Economy for a random sequence of productivity shocks. Panel (a) shows bank capital relative to bank lending, $[\gamma E_t A_{t+1}/K_{t+1} - 1] \cdot 100$, where E_t denotes conditional expectations at time t. Panel (b) shows bank lending relative to first-best lending, $[K_{t+1}/K_{FB} - 1] \cdot 100$. Panel (c) shows aggregate bank dividend payout ratio, D_t/A_t. Finally, panel (d) shows bank future profits relative to first-best equity, $\Pi_t/\beta\theta K_{FB} \cdot 100$.

4.3.1 Relationship to regulatory practice

In practice, there is a broad consensus among regulators that banks should hold more capital *on average* (e.g., Fender and Lewrick, 2016). Regulators have also identified a number of "externalities" that determine what they consider the desired level of capital *over time*. Examples of such externalities are temporarily high levels of debt that might expose borrowers to sudden changes in asset prices, or exchange rates, together with associated feedback effects (e.g., Lorenzoni, 2008; Bianchi and Mendoza, 2011). Another externality might be low bank provisioning stemming from a temporary scope to use accounting discretion that might expose the economy to sudden bank deleveraging (Beatty and Liao, 2011).[16]

Determining the desired level of bank capital likely requires regulator judgment because not all these externalities might be equally important at a given time. Indeed, while the Savings and Loan crisis was clearly related to insufficient recognition of risk by banks, the recent financial crisis was related to excessive borrowing as well as banks' hidden exposures.[17]

In this paper, I focus on a different externality that is related to the price of bank equity. This externality is always important because it arises *ex post*, conditional on a

[16]The Bank of Spain developed a backward-looking provisioning scheme that partially curbs this discretion by relying on expected losses calculated based on past data (Saurina and Trucharte, 2017). Borio (2018) discusses the implications of backward- and forward-looking accounting schemes, respectively, on the effectiveness of prudential regulation. A forward-looking scheme may use market prices to limit bank accounting discretion which may force banks to recognize too many losses when markets are illiquid during a crisis and may thus needlessly exacerbate ongoing costly asset transfers or "fire sales" (Plantin, Sapra, and Shin, 2008). However, timely loss recognition may not translate into lower regulatory capital in case of solvent banks (Badertscher, Burks, and Easton, 2012) and may, in case of banks close to insolvency, increase social welfare by forcing them to deleverage which prevents costly bank failure (Repullo and Suarez, 2013). Beatty and Liao (2014) summarize the literature on how accounting regimes affect bank actions.

[17]Regulation often follows a holistic approach in assessing buildup of systemic risk *ex ante*. One motivation for this is that the set of informative "early warning indicators" that contribute to determining the macroprudential policy stance tends to evolve over time (Aldasoro, Borio, and Drehmann, 2018; van Oordt, 2018). In general, challenges in measuring financial distress consistently (Romer and Romer, 2017) might contribute to challenges in designing a consistent framework to forecast financial distress.

financial crisis occurring. Specifically, promising banks future profits during a financial crisis lowers concerns about bank moral hazard, and thereby reduces pressure on banks to deleverage. The analysis in this paper suggests that regulation should take seriously its ability to affect bank profitability *ex post* in a way that complements the existing regulatory focus on addressing risk buildup *ex ante*. Regulation can affect bank profitability in the aftermath of a financial crisis, for example, by regulatory capital restoration plans that emphasize restrictions on asset growth over restrictions on payouts.[18]

4.3.2 Is a capital buffer harsh on banks?

Requiring banks to accumulate an additional capital buffer imposes costs on the economy since bank equity is costly, $\gamma < \beta$, and since the bank participation constraint (17) states that a bank cannot be forced to continue operating when its value falls short of its equity. An increased level of equity lowers the profits banks earn from leverage and makes it necessary for a constrained planner to compensate banks with profits from higher lending returns. In other words, the planner must allow banks to earn a higher return on assets such that banks can achieve their required return on equity with reduced leverage. A planner thus trades off the benefit from increased resilience against the cost of more distorted lending returns when considering the size of a bank's capital buffer. Since bank dividends enter the planner welfare criterion stated in definition 2, the planner chooses a positive capital buffer.

Figures 6 and 7 compare the laissez-faire competitive equilibrium with the second-best allocation for the case in which bank dividends do not enter the planner welfare criterion at all. For example, a constrained planner may value bank dividends less for political economy reasons. Figure 6 shows that a constrained planner that does not

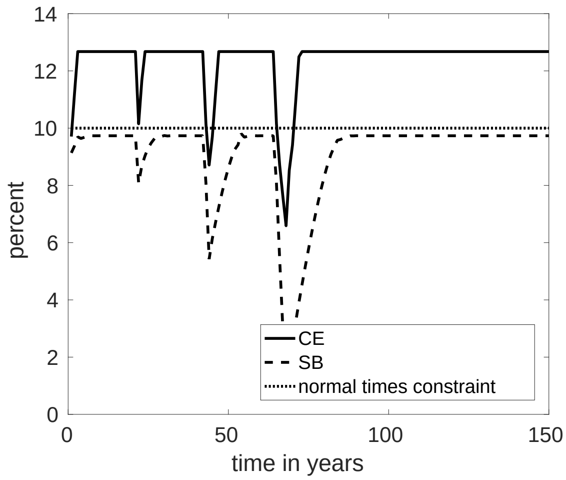
[18]Regulators in practice have discretion designing a capital restoration plan when the capital, or buffer, requirement is of type "Pillar II."

value bank dividends at all would ask banks to hold less equity than they do in the competitive equilibrium. In fact, the planner chooses bank lending above the first-best level during normal times. The reason is that the planner prefers that bank cash flows during normal times support wages rather than dividends—even at the cost of imposing losses on banks, lower bank equity and, compared with the case in which the planner values dividends directly, higher volatility of bank lending.

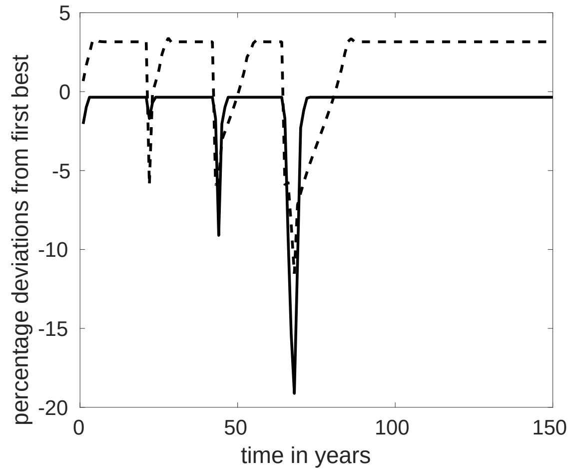
Leverage is higher in the second-best allocation, but severe credit crunches can be avoided by increasing bank future profits whenever banks experience low lending returns (Figures 6(b) and 6(d)). The bank participation constraint is satisfied—despite incurring losses in expectation during normal times—by anticipated temporary increases in profits that are large and frequent. Banks are not profitable during normal times but break even overall, since the planner treats them favorably during times of financial crisis.

Intuitively, when the planner does not value bank dividends, a high level of bank equity has a social cost that is excessive because of the bank participation constraint (17). As a result of market incompleteness, high realized lending returns lead to bank equity that is too high such that a planner prescribes lending above the first-best level, as well as negative expected lending returns, to achieve the desired lower level of equity. However, the planner still uses bank future profits to stabilize bank lending over time.

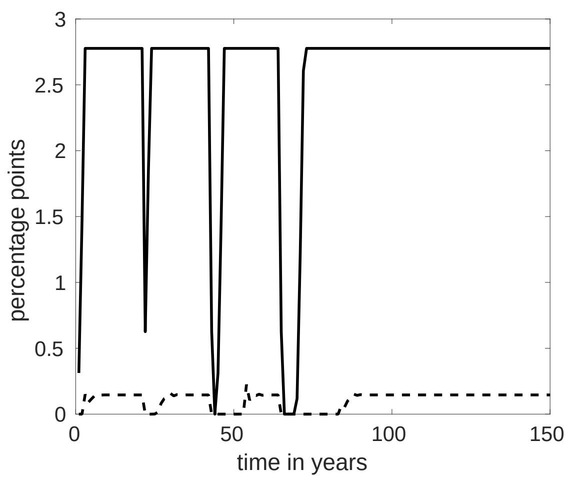
A constrained planner that does not value bank dividends would require banks to hold less equity and to lend excessively in good times. Such a planner would not see any reason to impose capital buffers even if credit-to-GDP measures are elevated—in fact, high credit-to-GDP becomes a policy implication. In contrast, a planner that values bank dividends requires banks to hold more equity and somewhat restrict lending in good times. In that sense, a capital buffer is not harsh on banks because it is imposed



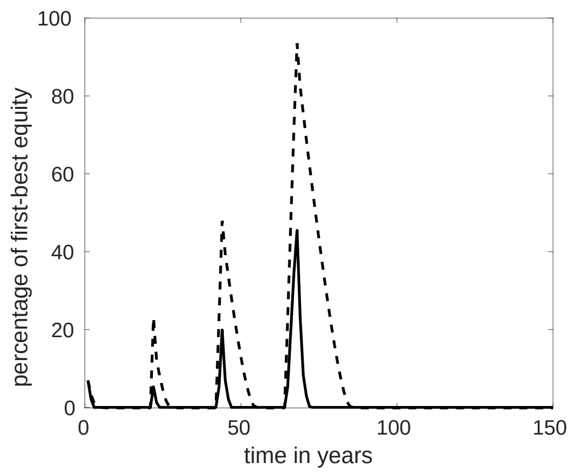
(a) Aggregate bank capital



(b) Aggregate bank lending

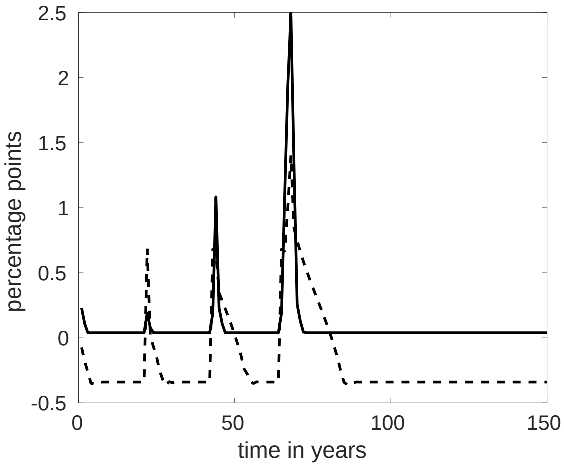


(c) Slack in no-default condition

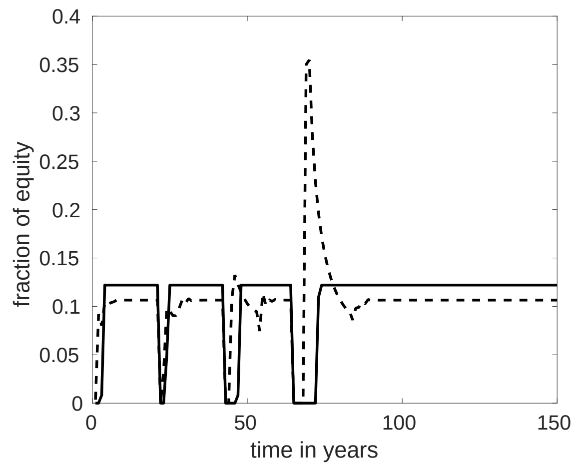


(d) Future profits

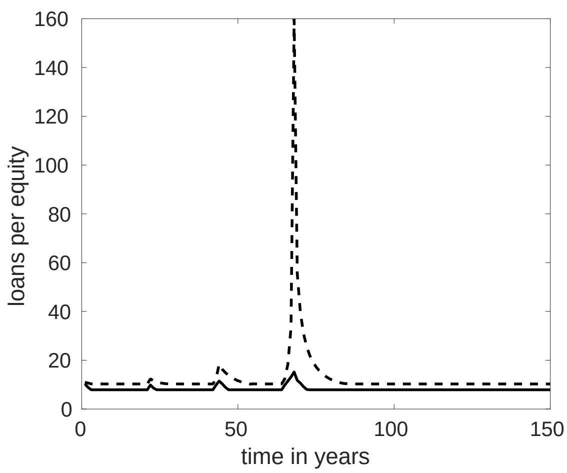
Figure 6: Case in which constrained planner does not value bank dividends. Panel (a) shows bank capital relative to bank lending, $\left[\gamma E_t A_{t+1}/K_{t+1} - 1\right] \cdot 100$, where E_t denotes conditional expectations at time t. Panel (b) shows bank lending relative to first-best lending, $\left[K_{t+1}/K_{FB} - 1\right] \cdot 100$. Panel (c) shows the slack in the market-imposed no-default condition, $\left[\gamma E_t V_{t+1}/\theta K_{t+1} - 1\right] \cdot 100$. Finally, panel (d) shows bank future profits relative to first-best equity, $\Pi_t/\beta\theta K_{FB} \cdot 100$.



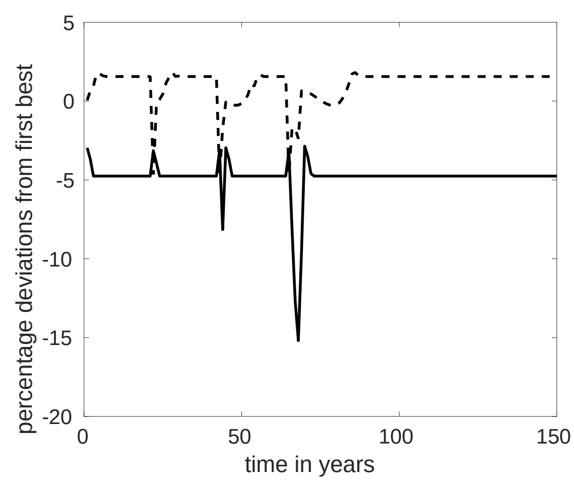
(a) Expected excess lending returns



(b) Aggregate dividends



(c) Leverage



(d) Aggregate bank external funding

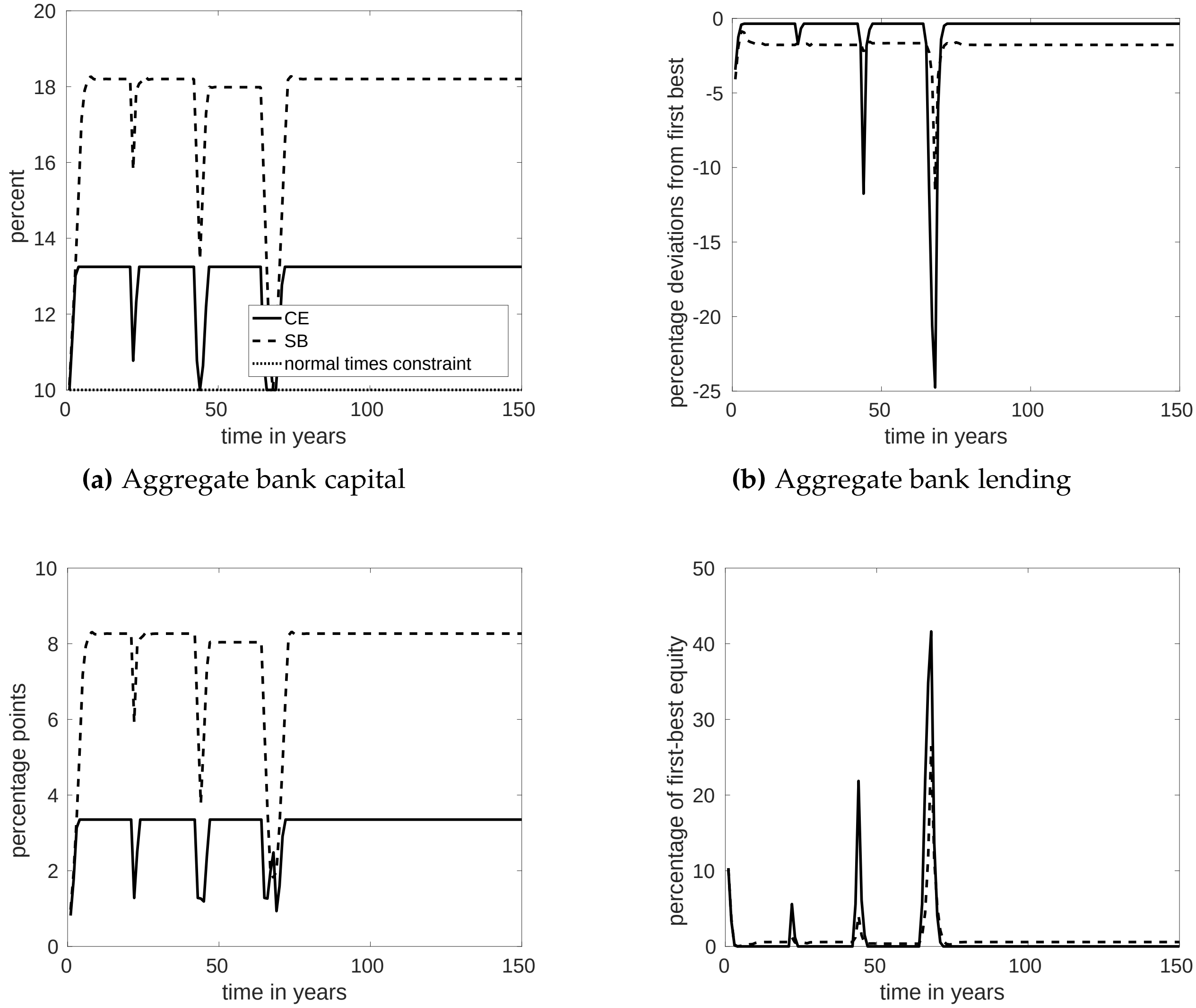
Figure 7: Case in which constrained planner does not value bank dividends. Panel (a) shows expected excess returns, $[\beta E_t R_{t+1} - 1] \cdot 100$. Panel (b) shows the aggregate bank dividend payout ratio, ${}^{D_t}/_{A_t}$. Panel (c) shows bank leverage, ${}^{K_{t+1}}/_{\gamma E_t A_{t+1}}$, which is inversely related to the capital adequacy ratio. Finally, panel (d) shows bank external funding.

by the planner that values bank well-being directly. A planner would always—whether valuing dividends or not—stabilize bank lending during credit crunches by adjusting future bank profits upward.

4.3.3 Tighter-than-necessary microprudential capital requirements

Figures 8 and 9 compare competitive equilibrium and second-best allocation for the case in which bank future profits do not enter the bank no-default constraint. This case can be interpreted as a microprudential regulator imposing a bank no-default condition that is tighter than the no-default constraint (7) imposed by market participants. The condition is then tighter than necessary to prevent default (it is "too tight" in the sense of Kehoe and Levine, 1993; Alvarez and Jermann, 2000). The additional tightness is ad hoc and not derived from macroprudential concerns. The second-best allocation can then be interpreted as the best allocation a macroprudential regulator can achieve, taking a tight microprudential constraint as given.

Both individual loan loss provisioning and additional capital buffers are now higher. However, the constrained planner does not raise bank future profits to alleviate financial crises. The reason is that for a given tight microprudential bank no-default constraint, there is no scope for the macroprudential regulator to support bank lending in times of financial crisis.



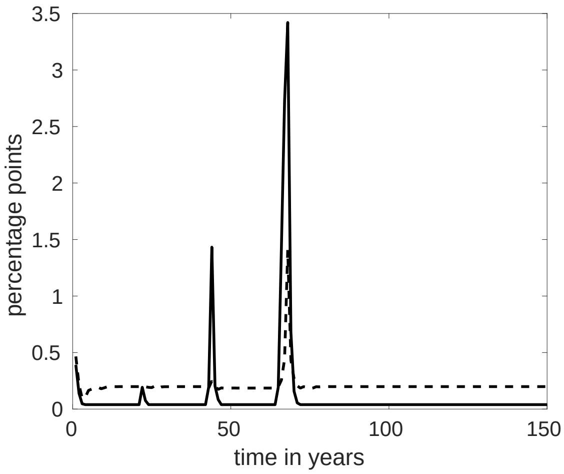
(a) Aggregate bank capital

(b) Aggregate bank lending

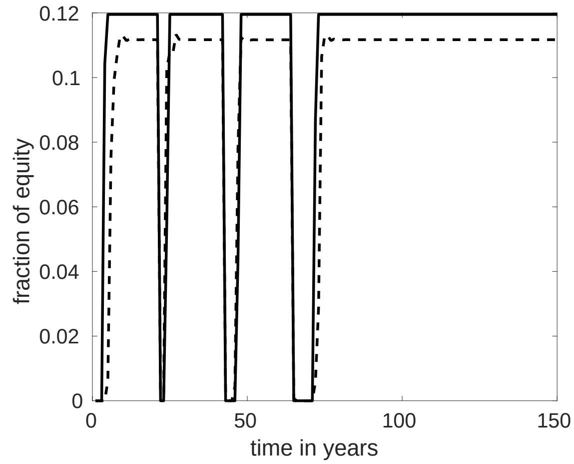
(c) Slack in no-default condition

(d) Future profits

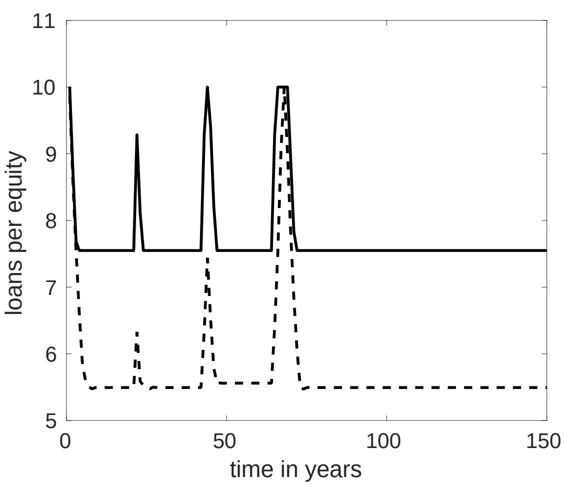
Figure 8: Case in which capital requirements do not depend on future profits. Panel (a) shows bank capital relative to bank lending, $\left[\gamma E_t A_{t+1}/K_{t+1} - 1\right] \cdot 100$ where E_t denotes conditional expectations at time t. Panel (b) shows bank lending relative to first-best lending, $\left[K_{t+1}/K_{FB} - 1\right] \cdot 100$. Panel (c) shows the slack in the market-imposed no-default condition, $\left[\gamma E_t V_{t+1}/\theta K_{t+1} - 1\right] \cdot 100$. Finally, panel (d) shows bank future profits relative to first-best equity, $\Pi_t/\beta\theta K_{FB} \cdot 100$.



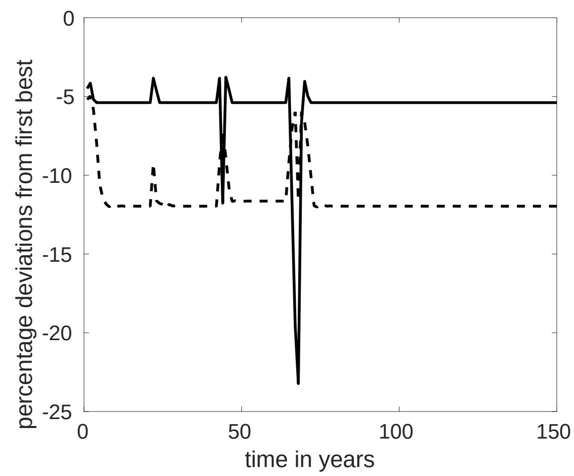
(a) Expected excess lending returns



(b) Aggregate dividends



(c) Leverage



(d) Aggregate bank external funding

Figure 9: Case in which capital requirements do not depend on future profits. Panel (a) shows expected excess returns, $[\beta E_t R_{t+1} - 1] \cdot 100$. Panel (b) shows the aggregate bank dividend payout ratio, D_t/A_t. Panel (c) shows bank leverage, $K_{t+1}/\gamma E_t A_{t+1}$, which is inversely related to the capital adequacy ratio. Finally, panel (d) shows bank external funding.

5 Conclusion

Banks may lose access to external funding on occasion. This can create a socially costly credit crunch in the economy during which banks are forced to reduce their lending activity. This paper studies constrained-efficient capital regulation that aims to prevent and mitigate such credit crunches and derives two implications for macroprudential policy. First, additional capital buffers should be imposed *ex ante*. Such buffers should be always activated during good economic times because strong non-linearities present in the model imply that it is too late to build up buffers when when bank economic losses start to materialize. Second, capital buffers should be reduced *ex post* during severe credit crunches and temporarily thereafter. Bank default at increased levels of leverage is avoided by granting higher future profits to banks. A macroprudential regulator would affect bank profitability dynamically to smooth out the scarcity of bank lending over financial cycles.

The analysis in the paper shows that capital buffers should be large eventually—however, banks should be given sufficient time to rebuild them during recoveries from financial crises. The idea is to prevent harsh treatment of banks in the immediate aftermath of a crisis to avoid adding to concerns about bank moral hazard *during* crises. The pressure on banks to return external funding during a crisis is then lessened such that they can use buffers to maintain lending as much as possible. The CCyB under Basel III is time-varying and therefore can be designed to take into account these implications.

An important avenue for future research is therefore implementation. Specifically, a “buffer rule” needs to be formulated that depends on lagged values of measures of financial system health to slow down the rebuilding of buffers after crises. The rule also needs to be linked to capital restoration plans that emphasize restrictions on asset growth over restrictions on dividend payouts. Finally, it can be checked whether a particular implementation, a choice of buffer rule and accompanying capital restoration plans, would leave scope for banks to react strategically (Farhi and Tirole, 2012). Implementation will also benefit from a quantitative evaluation of the channels highlighted in this paper and of their interaction with other relevant channels such as liquidity considerations.

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A Appendix

A.1 Computational method

I solve for the competitive-equilibrium allocation using policy function iteration (e.g. Rendahl, 2014) over the multiplier on the bank dividend non-negativity constraint. The endogenous state variable is bank equity. The present value of bank dividends for each level of bank equity is given by a shareholder value function. At each step in the policy function iteration I also use updated policy functions to update the shareholder value function. Only limited iterations on the shareholder value function can be performed at each step of the outer policy function iteration to achieve convergence of the latter (dampening). Policy function convergence then implies shareholder value function convergence.

I solve for the constrained-efficient allocation using standard value function iteration over household lifetime utility. The endogenous state variables are bank equity and bank shareholder value. It is necessary to impose a "promise keeping" constraint that ensures that shareholder value promised to banks in a period, to satisfy the bank no-default condition, is actually delivered to banks in the following period by some combination of dividend and (continuation) shareholder value.