Optimal Capital Regulation*

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We study constrained-efficient bank capital regulation in a model with market-imposed equity requirements. Banks hold equity buffers to insure against sudden loss of funding access. However, bank equity is privately costly in the model such that banks choose only partial self-insurance. Equity requirements are occasionally binding as a result. Constrained-efficient regulation requires banks to build up additional equity buffers and compensates them for the cost of equity with a permanent increase in lending margins. When buffers are depleted regulation relaxes market-imposed equity requirements by raising bank future prospects via temporarily elevated lending margins.

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Non-Technical Summary

Financial crises are socially costly and therefore often lead to *ex post* policy interventions. However, policy-makers and researchers also stress the importance of *ex ante* measures, such as bank capital buffers, that reduce the need to rely on *ex post* policy intervention. The literature that trades off *ex post* intervention and *ex ante* measures relates banks' access to funding to the liquidation value of bank assets during a default. We contribute to this literature by relating the bank's decision to default to its future prospects. Our approach is motivated by the fact that a defaulting bank loses its charter value and the fact that the bank's charter value depends (positively) on its future prospects.

In our model, banks engage in risk management (loan loss provisioning) such that they lose access to funding only occasionally. When banks lose access to funding, however, the flow of credit is severely disrupted throughout the model economy. We find that a constrained social planner, or "regulator," would choose to temporarily raise banks' future prospects following times when bank lending is constrained due to limited access to funding. Such an *ex post* action increases the long-term profitability of banks and supports their access to market funding during times of crisis. At the same time, a regulator would impose additional *ex ante* capital buffers that reduce the need to rely on varying bank future prospects *ex post* too much to avoid excessive economic distortions. Regulation trades off requiring banks to hold more costly capital *ex ante* against distortionary increases in bank future prospects *ex post*.

Our results suggests that optimal micro-prudential regulation is more lenient during times of crisis compared with Basel II and that optimal macro-prudential regulation is characterized by capital buffers and dividend payout restrictions, as in Basel III.

1 Introduction

Financial crises are considered to be costly and generally lead to policy interventions (Laeven and Valencia, 2013). Theoretical work finds 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; 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; Begenau, 2014; Clerc et al., 2014). 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.[1] We contribute to this literature by relating the bank's decision to default to its future prospects. Our 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. We derive new implications for bank regulation.

This paper develops a small-scale dynamic, stochastic, general-equilibrium (DSGE) model where the presence of financial intermediaries introduces strong non-linearities (He and Krishnamurthy, 2013; Brunnermeier and Sannikov, 2014). The paper then studies the problem of a constrained social planner, or "regulator," that takes the structure of markets and intermediary (bank) moral hazard as given but internalizes the effect of regulation on market prices and on banks' access to funding. Such a regulator would choose "constrained-efficient" capital requirements, which can be decomposed into a

[1] 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.

mix of implementable policies, such as capital buffers, conservation buffers, capital relief, and recapitalization.

In the model, banks engage in risk management (loan loss provisioning) such that they lose access to market funding only occasionally. But when they do lose access to funding, the flow of credit is severely disrupted throughout the model economy. The contribution of this paper is to characterize constrained-efficient regulation in an economy where banks rely on market funding and where market participants worry about long-term bank prospects. We do this by calibrating our model and solving it numerically. We find that a regulator temporarily raises banks' future prospects following times when bank lending is constrained due to limited access to market funding. Such an *ex post* action increases the long-term profitability of banks and supports their access to market funding during times of crisis. At the same time, a regulator imposes additional *ex ante* capital buffers that reduce the need to rely on varying bank future prospects *ex post* too much and avoid excessive economic distortions. Thus, regulation trades off requiring banks to hold more costly capital *ex ante* against distortionary increases in bank future prospects whenever bank capital is low *ex post*.[2]

Our model has policy implications that can be compared with recent regulatory changes under Basel III. First, we find that market-imposed capital requirements are lower during financial crises. Adherence to rigid micro-prudential 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 (for evidence and theory on "regulatory forbearance," see Huizinga and Laeven, 2012; Repullo, 2012; Repullo and Suarez, 2013). Second, there should be a buffer on top of market-imposed

[2]We assume that bank capital is costly. If bank capital were not costly, then the regulator would require banks to fund themselves only with equity (Admati et al., 2010).

capital requirements—augmenting loan loss provisioning—that can be used to stabilize lending when bank equity is low. However, no dividend payouts are allowed when this buffer is being used. This buffer resembles the capital conservation buffer (CCB) under Basel III. Third, there should be an additional buffer that can be used when the first one is depleted. This buffer can be used for lending. It can also be used for dividend payouts, but only once the first buffer is rebuilt. In practice, this additional buffer resembles the counter-cyclical capital buffer (CCyB) under Basel III. It is crucial that the regulator raises bank future profitability temporarily during the time when banks use the additional buffer, our version of the CCyB, 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 profitability could be supported by recapitalizations financed by taxes on bank lending.

For our calibration, the market-imposed capital requirement is 10 percent during "normal times," i.e., when all capital buffers are fully built up. During normal times, our version of the CCB is set to 1.25 percent, in addition to loan loss provisioning of 1.25 percent, and our version of the CCyB is activated at 3.25 percent. Bank capital during normal times is thus 15.75 percent in the constrained-efficient allocation and 12.75 percent in the laissez-faire competitive equilibrium. Note that banks provision less when buffers are imposed. That is, the sum of the buffers is 4.5 percent, but bank capital during normal times is only 3 percent higher in the constrained-efficient allocation compared with the laissez-faire competitive equilibrium.

The paper now proceeds to the following section where we introduce the model. In section 3, we discuss how our modeling approach of the banking sector allows us to investigate bank capital requirements and analyze the constrained-efficient allocation. In section 4 we perform our numerical analysis, comparing the properties of the model economy against its optimal policy counterpart. Policy implications are also discussed. Finally, section 5 concludes.

2 Model

This section describes an infinite horizon economy in discrete time with time periods $t = 0, 1, 2, \ldots$. There are aggregate productivity shocks $s_t \in S = \{s_L, s_H\} \subset \mathbb{R}^2_{++}$, 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 τ. There is a measure one of identical short-lived firms producing a consumption good and investing using external funds obtained from a measure one of identical banks. Finally, risk-neutral households, also of measure one, value consumption and are endowed with one unit of labor each, which they supply inelastically. Households and banks trade one-period non-contingent bonds with each other.

2.1 Firms

Firms live for one period. They have access to a production technology that turns k units of the consumption good in period t and l units of labor in period $t+1$ into $F(k, l; s_{t+1}) = s_{t+1} k^{\alpha} l^{1-\alpha} + (1-\delta)k$ 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 l 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 capital investment. 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:

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

subject to $\max_l \left\{s_{t+1}k^\alpha l^{1-\alpha} + (1-\delta)k - w_{t+1}(s^{t+1})l\right\} - R_{t+1}(s^{t+1})k \geq 0$ 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:

$$w_{t+1}(s^{t+1}) = (1-\alpha)s_{t+1}k^\alpha l^{-\alpha}, \quad (2)$$

$$R_{t+1}(s^{t+1}) = \alpha s_{t+1}k^{\alpha-1}l^{1-\alpha} + 1 - \delta, \text{ for each } s_{t+1} \in S. \quad (3)$$

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

2.2 Households

Households are risk-neutral and value consumption. They are endowed with one unit of labor in period $t = 1, 2, \ldots$ and are endowed with wage w_0 in period zero. Households discount future consumption using the subjective discount factor $\beta < 1$. Note that households are willing to trade the one-period non-contingent bond in finite quantity as long as its price is equal to β, implying a gross return of $1/\beta$ in an equilibrium of the model.

2.3 Banks

Banks are risk-neutral and value dividends $d_t(s^t)$. Let $\ell_{t+1}(s^t)$ denote bank lending to firms. Both dividend and lending choices are constrained to be non-negative. In every period $t = 0, 1, 2, \ldots$, banks face budget constraints as follows:

$$d_t(s^t) + \ell_{t+1}(s^t) + \beta b_{t+1}(s^t) \leq R_t(s^t)\ell_t(s^{t-1}) + b_t(s^{t-1}), \text{ for } t = 1, 2, \ldots, \text{ and} \tag{4}$$

$$d_0(s_0) + \ell_1(s_0) + \beta b_1(s_0) \leq a_0, \tag{5}$$

where $b_{t+1}(s^t)$ denotes an bank's purchase of one-period non-contingent bonds at price β for $t = 0, 1, 2, \ldots$ and $a_0 > 0$ denotes given initial bank equity.[3] For $t = 1, 2, \ldots$ define bank equity as $a_t(s^t) = R_t(s^t)\ell_t(s^{t-1}) + b_t(s^{t-1})$.

Banks discount future dividends using the subjective discount factor $\beta < 1$. However, it is assumed that a bank enters an "accident" state at the beginning of each period with constant probability $1 - \gamma/\beta > 0$. When banks experience an accident, they pay all equity—i.e., all loan repayments net of debt—into an "accident fund" and exit the economy. The fund immediately distributes the collected equity among a measure $1 - \gamma/\beta$ of new banks that enter the economy. The assumption captures corporate governance problems and implies that banks effectively discount dividends using the lower discount factor $\gamma < \beta$ such that the value of a bank is $V_0 = \sum_{t=0}^{\infty} \gamma^t \sum_{s^t \in S^t} d_t(s^t)\pi_t(s^t)$.

However, banks will generally not set dividends as high as possible since the timing of bank dividends determines a bank's incentive to engage in moral hazard, which in turn affects 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

[3] Assuming that initial equity is strictly positive ensures that condition (6) can be satisfied at period zero. However, note that bank choices satisfying condition (6) might lead to negative bank equity over time in certain states of the world.

the future dividends it expects to enjoy more than a fraction $\theta \in (0,1)$ of its lending. The reason is that bank assets $\ell_{t+1}(s^t)$ are not liquid and diminish by fraction θ unless monitored by a bank. Banks could thus extract $\theta\ell_{t+1}(s^t)$ by defaulting and threatening creditors not to monitor its assets. This consideration is captured by the following no-default constraint that needs to be satisfied in every period $t = 0, 1, 2, \ldots$ in which the bank wishes to make use of external funding.

$$\sum_{\tau=1}^{\infty} \gamma^{\tau} \sum_{s^{t+\tau}} \pi_t(s^{t+\tau}|s^t) d_{t+\tau}(s^{t+\tau}) \geq \theta\ell_{t+1}(s^t) \tag{6}$$

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 their "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 (6) 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 (for example, a household).

The problem of a bank is thus to choose lending and bonds to maximize its value at date zero subject to (4), (5), (6) and dividend non-negativity. Let $\beta^t\pi_t(s^t)\psi_t(s^t)$ be the multiplier on equation (6) in period t, when $\ell_{t+1}(s^t)$ is chosen. 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:

$$\theta\psi_t(s^t) = \gamma \sum_{s_{t+1}} \pi_t(s^{t+1}|s^t) \left[\lambda_{t+1}(s^{t+1}) \left(R_{t+1}(s^{t+1}) - \frac{1}{\beta}\right)\right]. \tag{7}$$

Equation (7) 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, 2015).

The assumption that banks are more impatient than other participants in the bond market, i.e., $\gamma < \beta$, implies that (6) will occasionally bind. To see this, note that the first-order condition for bank bond holdings,

$$\lambda_t(s^t) = \sum_{s_{t+1}} \lambda_{t+1}(s^{t+1}) \pi_t(s^{t+1}|s^t), \tag{8}$$

implies that the return on equity λ_t converges almost surely. Let $\beta^t \pi_t(s^t) \mu_t(s^t)$ denote the multiplier on dividend non-negativity. The first-order condition for dividends $d_t(s^t)$ is as follows:

$$\lambda_t(s^t) = \left(\frac{\gamma}{\beta}\right)^t + \mu_t(s^t) + \sum_{\tau=0}^{t-1} \left(\frac{\gamma}{\beta}\right)^{t-\tau} \psi_\tau(s^\tau), \tag{9}$$

where s^τ denote sub-histories of s^t. Hence, if the bank no-default constraint (6) 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 (6) is in fact binding almost surely.

In other words, bank equity is valuable because it can be used to relax the bank no-default constraint and allow the bank 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, each bank regards lending income as risky and extends lending only up to the point where their risk-adjusted profitability drops to zero.[4] Banks thus engage in loan loss provisioning as a result of the last-bank standing effect (Perotti and Suarez, 2002).

More formally, equations (8) and (9) reveal that the bank's risk-management problem has both a backward-looking and a forward-looking component. On the one hand, internal funds (equity) in the current period can be used to reduce leverage. Lower leverage reduces 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).

2.4 Competitive equilibrium

Spot markets for labor, contingent bank loans, and one-period non-contingent bonds open in every period t. In every period t, the wage w_t clears the labor market and the returns on loans R_{t+1} clear the market for lending. Definition 1, below, characterizes a competitive equilibrium in terms of lending returns, wages, and bank actions.

Definition 1. *A competitive equilibrium is characterized by lending returns* $\{R_{t+1}(s^{t+1})\}_{t=0,1,2,\ldots}$, *wages* $\{w_t(s^t)\}_{t=1,2,\ldots}$, *as well as bank actions* $\{d_t(s^t), b_{t+1}(s^t), \ell_{t+1}(s^t)\}_{t=0,1,2,\ldots}$ *such that (i) bank actions obey first-order conditions (7), (8) and (9), and (ii) lending returns satisfy* $R_{t+1}(s^{t+1}) = s_{t+1}\alpha\ell_{t+1}^{\alpha-1}(s^t) + 1 - \delta$ *and wages satisfy* $w_{t+1}(s^{t+1}) = s_{t+1}(1-\alpha)\ell_{t+1}^{\alpha}(s^t)$ *for*

[4]The bond market is incomplete exogenously in this paper. Lorenzoni (2008) and Rampini and Viswanathan (2010, 2012) show how contracting frictions limit bank risk-management even if a complete set of contingent securities is potentially available.

$t = 0, 1, 2, \ldots$.

2.5 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:

$$K_{FB} = \left[\frac{\alpha\beta}{1 - \beta(1-\delta)} \right]^{\frac{1}{1-\alpha}}. \tag{10}$$

Note that banks pay strictly positive dividends in a steady state of the competitive equilibrium such that $\mu_t = 0$. It follows from equations (8) and (9) that $\psi_t = \frac{\beta-\gamma}{\gamma}\lambda_t$ in a steady state. Note that banks are always borrowing constrained due to their relative impatience. The amount of steady state lending in a competitive equilibrium follows from equation (7) as follows:

$$K_{CE} = \left[\frac{\alpha\beta}{1 - \beta(1-\delta) + \theta\frac{\beta-\gamma}{\gamma}} \right]^{\frac{1}{1-\alpha}}. \tag{11}$$

It can be seen from equations (10) and (11) 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, $1/\gamma$ for $\theta < 1$. However, 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 $1/\gamma$. The bank no-default constraint (6) 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.

3 Capital Regulation

3.1 Bank no-default constraint and capital requirements

This section discusses how the no-default constraint (6) can be interpreted as a (market-imposed) bank capital requirement. Let a_t denote bank equity and let Π_t denote the value of a bank's charter net of equity, then

$$a_t(s^t) = R_t(s^t)\ell_t(s^{t-1}) + b_t(s^{t-1}) \quad \text{for } t = 1, 2, \dots \text{ and } a_0 \text{ given,} \tag{12}$$

$$\begin{aligned}\Pi_t(s^t) = &\sum_{\tau=1}^{\infty} \gamma^{\tau} \sum_{s^{t+\tau} \in S^{t+\tau}} \left[R_{t+\tau}(s^{t+\tau}) - \frac{1}{\gamma} \right] \ell_{t+\tau}(s^{t+\tau-1}) \pi_t(s^{t+\tau}|s^t) \\ &+ \sum_{\tau=1}^{\infty} \gamma^{\tau} \sum_{s^{t+\tau} \in S^{t+\tau}} \frac{\gamma - \beta}{\gamma} b_{t+\tau}(s^{t+\tau-1}) \pi_t(s^{t+\tau}|s^t).\end{aligned} \tag{13}$$

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 an bank at time t can then be expressed as $V_t(s^t) = a_t(s^t) + \Pi_t(s^t)$. The no-default constraint (6) can then be reformulated as

$$\sum_{s_{t+1} \in S} a_{t+1}(s^{t+1}) \pi_t(s^{t+1}|s^t) \geq \frac{\theta}{\gamma} \ell_{t+1}(s^t) - \sum_{s_{t+1} \in S} \Pi_{t+1}(s^{t+1}) \pi_t(s^{t+1}|s^t). \tag{14}$$

With bank capital defined as expected equity, (14) gives a capital requirement that depends on the expected present value of bank future profits. These capital requirements are micro-prudential in the sense that their purpose is to guarantee the solvency of the bank only. For example, if the value of the bank's charter does not exceed its equity then permissible leverage is given by $\frac{\gamma}{\theta}$. If the bank is expected to have a charter value that is higher than its equity then it is allowed to have higher leverage because the bank future profits serve as "skin in the game."

It is important to note that micro-prudential capital requirements are low in this economy in the sense that banks often hold capital (equity) well above the requirement stipulated by equation (14), implying that equation (14) 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. The following section asks whether this extent is sufficient or whether additional macro-prudential capital regulation is necessary.

In this paper, micro-prudential capital regulation is not concerned with bank leverage beyond the objective of ensuring bank solvency. Macro-prudential capital regulation, on the other hand, may be counter-cyclical and have the objective of reducing leverage *ex ante* to avoid low levels of lending *ex post*, while allowing for particularly high leverage *ex post* at times when lending is particularly low *ex post*.

Relationship to regulatory practice

Bank capital regulation in practice combines micro- and macro-prudential elements, for example, as suggested by guidelines from the Basel Committee on Banking Supervision (2010). Our model can shed light on how regulatory practice is related to notions of market discipline as well as constrained efficiency. We observe that our market-imposed capital requirement (14) resembles micro-prudential capital regulation in practice augmented by regulatory forbearance during times of financial crisis (Huizinga and Laeven, 2012). In that sense, forbearance is not a sign of regulatory capture but rather reflects temporarily elevated margins that banks enjoy during financial crises while their equity is low.

In the remainder of the paper we study constrained-efficient capital requirements, i.e., changes in the allocation of bank equity and lending that increase lending to firms weighted by the marginal product of capital (proportional to our welfare measure) subject to the market-imposed capital requirement (14). We interpret the difference between the constrained-efficient allocation and the competitive equilibrium allocation—in which banks are only constrained by micro-prudential regulation implied by (14)—as resulting from macro-prudential capital regulation. We then compare our macro-prudential regulation with its empirical counterpart. We further discuss how macro-prudential regulatory tools used in practice might be combined toward implementing the optimal macro-prudential regulation, or constrained-efficient allocation, that we identified.

3.2 Optimal capital regulation

The capital requirement given by equation (14) 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 lead to inefficiencies in this economy. The reason is that future asset prices, i.e., future lending returns $\{R_{t+\tau}(s^{t+\tau})\}_{\tau=1,2,...}$, enter equation (14) through expected future profits given by equation (13) at each point in time $t = 0, 1, 2, \ldots$. 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.

Since bank capital is costly, stemming from banks' relative impatience, it is necessary to impose bank participation constraints in periods $t = 0, 1, 2, \ldots,$

$$V_t(s^t) \geq a_t(s^t) \quad \text{for all } s^t \in S^t \text{ for all banks.} \tag{15}$$

Condition (15) ensures that banks prefer continuing being a bank to liquidating their assets. Note that the bank participation constraint is equivalent to $\Pi_t(s^t) \geq 0$. Condition (15) requires that the future profits that banks expect to earn are non-negative. To see why it might be binding in a constraint-efficient allocation, consider the case where 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 constrained-efficient allocation will thus allow for bank leverage or bank rents or both to discourage banks from liquidating themselves (recall the discussion in section 2.5).

Definition 2. *The constrained-efficient allocation is given by sequences of dividends* $\{D_t(s^t)\}_{s^t \in S^t,\, t \geq 0}$ *and bank lending* $\{K_{t+1}(s^t)\}_{s^t \in S^t,\, t \geq 0}$ *such that social welfare*

$$\mathcal{W} \equiv D_0(s_0) + \sum_{t=1}^{\infty} \beta^t \sum_{s^t \in S^t} \left[D_t(s^t) + w_t(s^t) \right] \pi_t(s^t),$$

is maximized subject to

$$w_t(s^t) = s_t(1-\alpha)K_t(s^{t-1})^\alpha,$$
$$R_t(s^t) = s_t\alpha K_t(s^{t-1})^{\alpha-1} + 1 - \delta,$$

market-imposed no-default constraints (6), *bank budget constraints* (4) *and* (5), *dividend non-negativity as well as the bank participation constraint* (15).

In a constrained-efficient allocation, (6) 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 constrained-efficient allocation

Before continuing to the numerical part of the paper, first-order conditions that the constrained-efficient allocation must satisfy are discussed. Let $\beta^t\pi_t(s^t)\psi_t(s^t)$ be the multiplier on the bank no-default constraint (6), $\beta^t\pi_t(s^t)\lambda_t(s^t)$ 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 (15), 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:

$$\lambda_t(s^t) = 1 + \sum_{s_{t+1}} \mu_{t+1}(s^{t+1})\pi_t(s^{t+1}|s^t) + \sum_{\tau=0}^{t} \left(\frac{\gamma}{\beta}\right)^{t+1-\tau} \left[\psi_\tau(s^\tau) + \eta_\tau(s^\tau)\right], \qquad (16)$$

where the terms s^τ denote sub-histories of s^t. Equation (16) 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 2.4 (the bank participation constraint is ignored in competitive equilibrium in section 2.4 since it is satisfied by definition). The 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 constrained-efficient allocation may feature an excess risk premium on bank lending even if banks have further access to external funding, i.e., even if (6) does not bind such that $\psi_t(s^t) = 0$:

$$\theta\psi_t(s^t) + \beta \sum_{s_{t+1}} \left[\lambda_{t+1}(s^{t+1}) - \eta_{t+1}(s^{t+1}) - 1\right] \alpha(1-\alpha)s_{t+1}K_{t+1}(s^t)^{\alpha-1}\pi_t(s^{t+1}|s^t)$$
$$= \beta E_t \left[(\lambda_{t+1} - \eta_{t+1})\left(R_{t+1} - \frac{1}{\beta}\right)\right]. \tag{17}$$

That the second term on the left-hand side of equation (17) is non-negative can be seen by writing the first-order condition for dividends as follows:

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

which is non-negative for all s_{t+1}. Excess bank returns enjoyed by banks therefore have a forward- and a backward-looking component. On the one hand, when the dividend non-negativity constraint is binding in the following period 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, bank returns increase, 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 (6) 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 (17). This in turn leads to higher excess returns over a number of periods, increasing expected bank future profits immediately. The result is that (6) 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 constrained-efficient allocation, the scarcity of bank lending is smoothed out over time.

Deterministic steady state

Analyzing the constrained-efficient allocation in deterministic steady state reveals that the trade-offs faced by the constrained planner are dynamic rather than static. Note that the bank participation constraint does not bind strictly since there is no benefit to having equity buffers in the deterministic case. Then multipliers are constant and satisfy $\psi = (\lambda - 1)(\beta - \gamma)/\gamma$ by equation (16). The constrained-efficient amount of bank lending can then be obtained from equation (17) as a function of the value of bank equity as follows:

$$K_{SB}(\lambda) = \left[\frac{\beta\alpha \left(1 - (1-\alpha)\frac{\lambda-1}{\lambda}\right)}{1 - \beta(1-\delta) + \theta\frac{\beta-\gamma}{\gamma}\frac{\lambda-1}{\lambda}} \right]^{\frac{1}{1-\alpha}}. \tag{18}$$

For the bank participation constraint to hold, that bank lending must be lower than K_{CE} since it holds with equality in a deterministic steady state of the competitive equilibrium. Hence, it must be the case that $K_{SB}(\lambda) \leq K_{CE}$. Since $\gamma < \beta$, the effect of initially scarce bank equity on the steady state value of bank equity decays geometrically by equation (16). 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

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

The constrained-efficient allocation is identical to the competitive-equilibrium allocation in steady state of the deterministic economy.[5]

4 Numerical analysis

This section puts the theory developed in sections 2 and 3 to use. Table 1 summarizes the choices of model parameter values used in this section. The choice of consumer discount factor β implies an annual risk-free interest rate of around 6 percent. The depreciation rate and capital income share are set to 12 percent and 35 percent, respectively. Our choice for θ implies a market-imposed capital requirement of 10 percent in normal times, when bank future profits are zero. This number is in line with observed micro-prudential capital requirements in advanced economies. The parameters characterizing the productivity shock process are chosen to allow the model to generate large crises. In particular, the shock process must be able to generate bank losses that are large relative to bank cash flows such that bank equity is reduced. This feature is crucial for the market-imposed capital requirement to have non-linear effects on bank lending. Note that because shocks are independent and identically distributed (i.i.d.) they must be

[5]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).

parameter	value	target
β	0.94	risk-free interest rate
γ	0.93	crisis frequency
δ	0.12	average replacement investment
α	0.35	capital income share
θ	0.10	average bank leverage
(z_L, z_H, ρ)	(0.8,1.05,0.2)	several large crises

Table 1: Model parameter values

quite large.[6] The parameter γ that determines the bank's relative cost of equity is set such that the economy spends around 6 percent of the time in a financial crisis. We say that the economy experiences a financial crisis in period t if bank lending is depressed by 5 percent or more (see Figure 1).

In section 3 it was shown that when the bank no-default conditions bind in a constrained-efficient allocation then lending returns are increased 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 economic distortions such that a constrained-efficient allocation would also require banks to hold more equity on average. 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 2 compares the constrained-efficient allocation with the competitive equilibrium allocation for a given sequence of shocks. In particular, the high shock occurs

[6]Shocks can be smaller when there is positive persistence in productivity shocks (e.g., Paul, 2016).

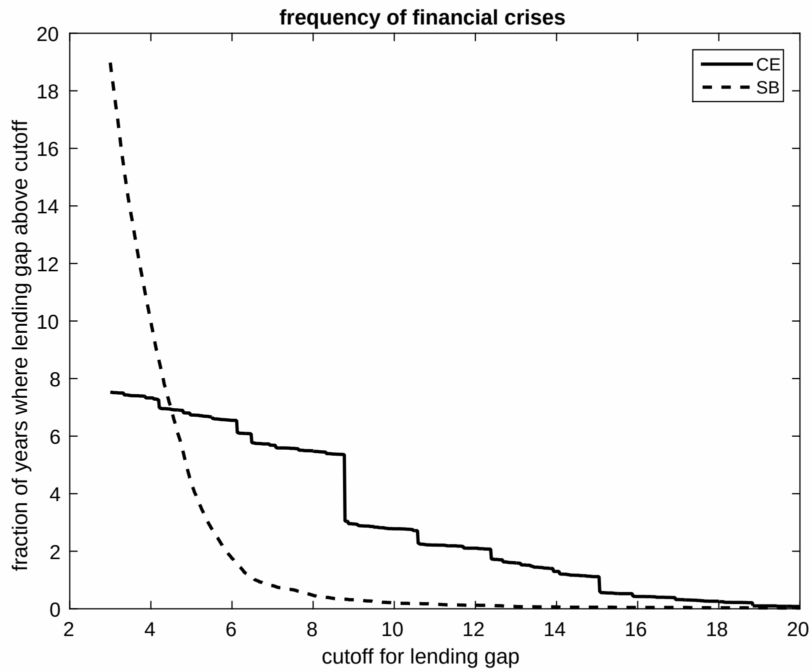


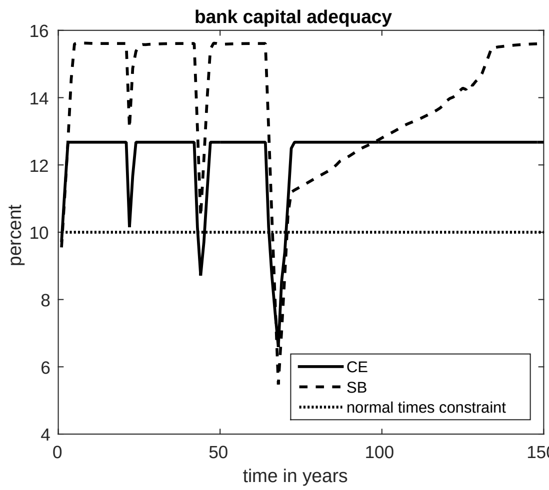
Figure 1: Frequency of low lending in a stochastic steady state (average over $30,000$ simulated periods) in laissez-faire competitive equilibrium allocation (CE) and constrained-efficient allocation (SB).

between successive occurrences of the low shock for $1, 2$ and 4 times, respectively. We make sure that the high shock occurs sufficiently many times before each occurrence of low shocks for the economy to reach normal times when bank future profits are zero. Figure 2(a) shows that banks in competitive equilibrium hold a capital buffer of 2.75 percent. A constrained planner would require an additional buffer of 3 percent such that bank capital in the constrained-efficient allocation during normal times reaches 15.75 percent. Bank capital can be lower than 10 percent when a low productivity shock occurs while bank capital is still low.

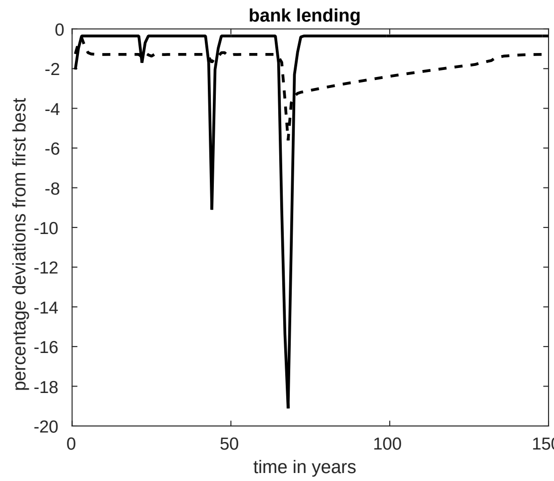
Bank lending during normal times is lower in the constrained-efficient allocation than it is in competitive equilibrium, as can be seen in Figure 2(b). The reason is that banks must be compensated with a higher expected return on lending when they are required to hold additional capital buffers because of the relatively higher cost of capital compared with external funding. However, bank lending is stabilized significantly in the constrained-efficient allocation compared with the competitive equilibrium. The reason is that 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 constrained-efficient 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, though it recovers more slowly during the time banks are allowed to earn their future profits.

Figure 3 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 constrained-efficient 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, lending returns shoot up sharply in competitive equilibrium, but banks are still forced to deleverage and reduce their reliance on external funding drastically. In contrast, banks increase their reliance on external funding during a financial crisis in the constrained-efficient allocation.

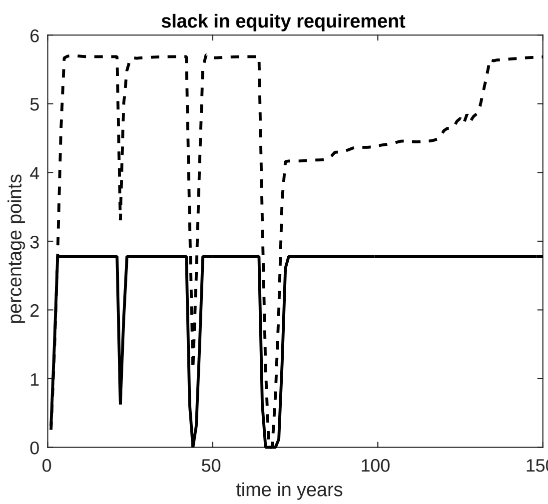
Since bank capital is costly, $\gamma < \beta$, the extent to which the constrained planner is able to backload dividends to relax market-imposed no-default conditions during a financial crisis is limited. As a result, the dividend payout ratio increases during and following financial crises. Banks resume paying dividends earlier in the constrained-efficient allocation, compared with the competitive equilibrium, and rebuilding equity buffers takes a backseat to resuming dividend payouts in the aftermath of financial crises.



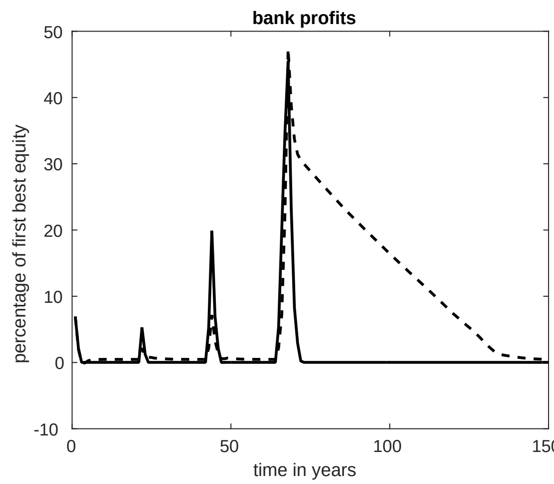
(a) Aggregate bank capital



(b) Aggregate bank lending

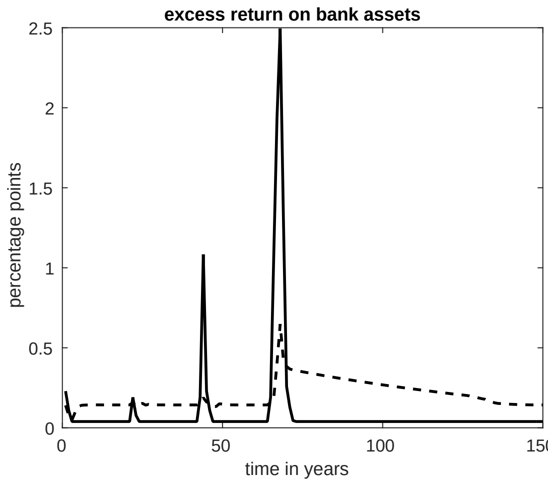


(c) Slack in no-default condition

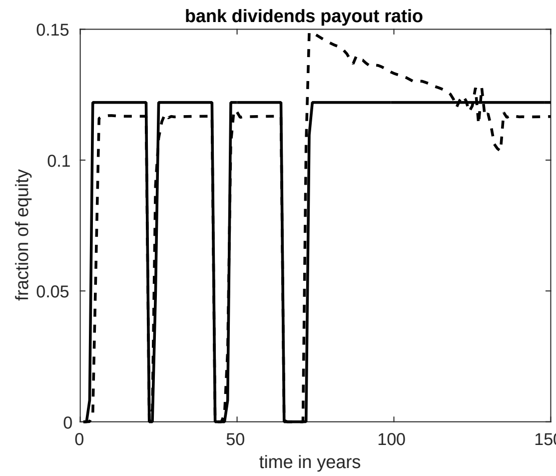


(d) Future profits

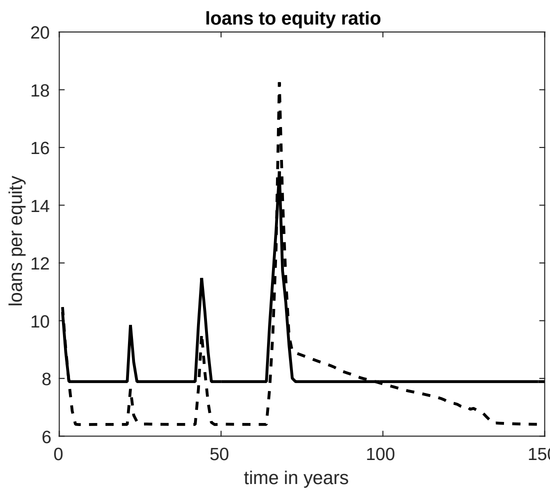
Figure 2: Panel (a) shows bank capital relative to bank lending, $\left[{}^{\gamma E_t A_{t+1}}/_{K_{t+1}} - 1\right] \cdot 100$, where E_t denotes conditional expectations at time t. Panel (b) shows bank lending relative to first-best lending, $\left[{}^{K_{t+1}}/_{K_{FB}} - 1\right] \cdot 100$. Panel (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, ${}^{\Pi_t}/_{\beta\theta K_{FB}} \cdot 100$.



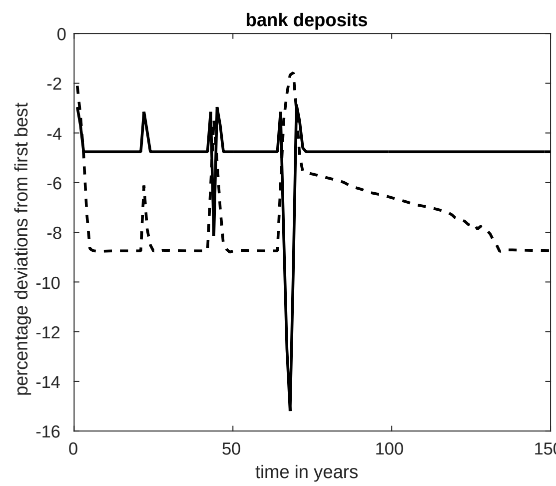
(a) Expected excess lending returns



(b) Aggregate dividends



(c) Leverage



(d) Aggregate bank external funding

Figure 3: 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.

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 risk during crises, compared with banks in the competitive equilibrium, since any potential future equity scarcity can be partially offset by upward adjustments in future profits and since lending returns increase less during crises. 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 constrained-efficient allocation features lower reliance of banks on external funding in normal times, the planner allows banks to substitute lost equity with external funding quite aggressively during times of financial crisis.

Figure 4 shows the economy for a particular draw of productivity shocks. The competitive equilibrium features a severe credit crunch during years 85–90. This credit crunch is much less severe in the constrained-efficient 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.

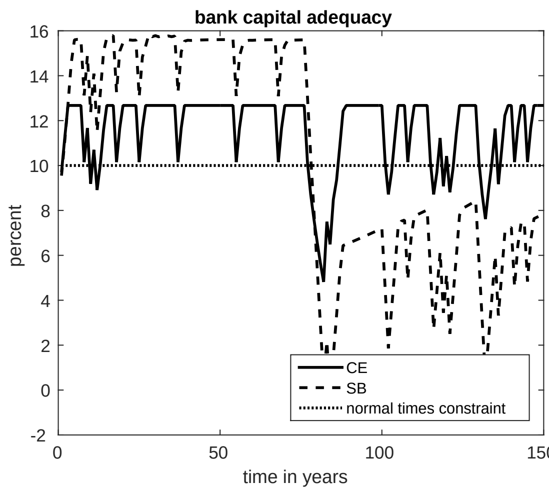
The constrained-efficient allocation is characterized by macro-prudential capital regulation that avoids sharp reductions in bank lending and economic activity but, at the same time, can lead to a very persistent decline in lending and economic activity. One crucial assumption in our analysis is that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

4.1 Policy implications

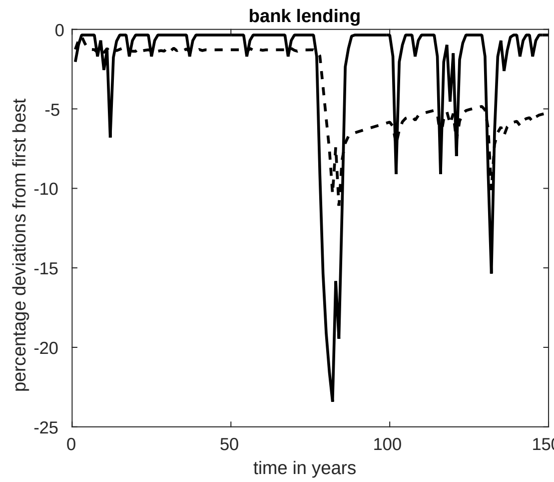
The constrained-efficient allocation shows that there is a net benefit from requiring banks to hold additional equity. Such capital buffers are always on in the sense that banks should build them up gradually in good times while paying out dividends at the same time. High non-linearities as well as this 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 constrained-efficient allocation than in competitive equilibrium such that the net effect on welfare is positive.

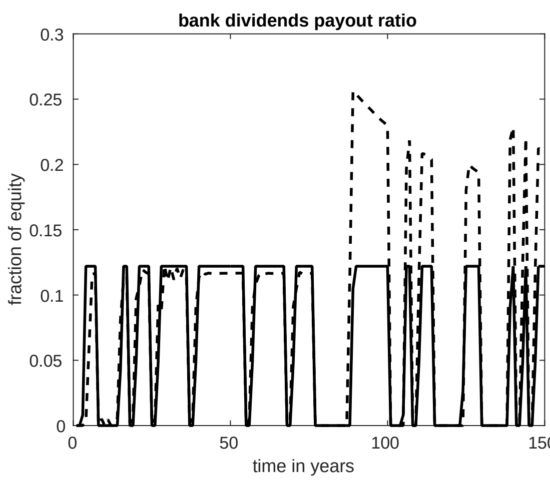
The constrained-efficient allocation is related to the capital conservation buffer (CCB) and the counter-cyclical capital buffer (CCyB), as introduced by Basel Committee on Banking Supervision (2010). While the CCB is always on during normal times and can be used during crisis times, its use is limited to funding bank lending to firms. The CCyB, on the other hand, can be used to pay dividends as well. Note that our version of the CCyB is always on because we consider i.i.d. aggregate productivity shocks. Our analysis suggests the following timing for applying the CCB and the CCyB. First, small



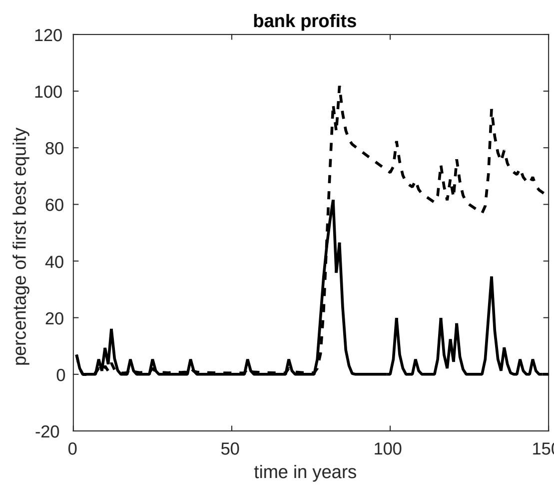
(a) Aggregate bank capital



(b) Aggregate bank lending



(c) Aggregate dividends



(d) Future profits

Figure 4: Economy for a random sequence of productivity shocks. 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 aggregate bank dividend payout ratio, ${}^{D_t}/_{A_t}$. Finally, panel (d) shows bank future profits relative to first-best equity, ${}^{\Pi_t}/_{\beta\theta K_{FB}} \cdot 100$.

and medium losses will be partially absorbed by the CCB. Banks use the CCB as well as retained earnings to avoid a sharp decrease in lending. Second, once banks have rebuilt the CCB, they are allowed to pay dividends again even though the CCyB is not rebuilt yet. Following this interpretation, Figure 2(a) implies that our version of the CCB is 1.25 percentage point, while our CCyB is 4.50 percentage points.

Note that these capital buffers supersede individual bank provisioning of 2.75 percentage points such that the sum of macro-prudential buffers is 5.75 percent above the micro-prudential requirement, but only 3 percent above normal-times capital held by banks in a laissez-faire competitive equilibrium. Alternatively, banks' individual provisioning could be defined as any capital buffer banks accumulated once the dividend payout ratio has reached its normal-times level. By this interpretation, our CCyB is rebuilt when capital is 14.5 percent, implying a CCyB of 3.25 percent and voluntary loan loss provisioning of 1.25 percent, on top of the CCB of 1.25 percent during normal times.

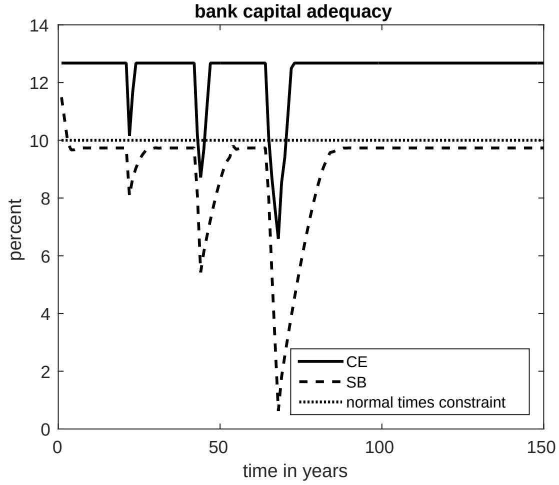
4.1.1 Is a capital buffer harsh on banks?

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 (15) 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.

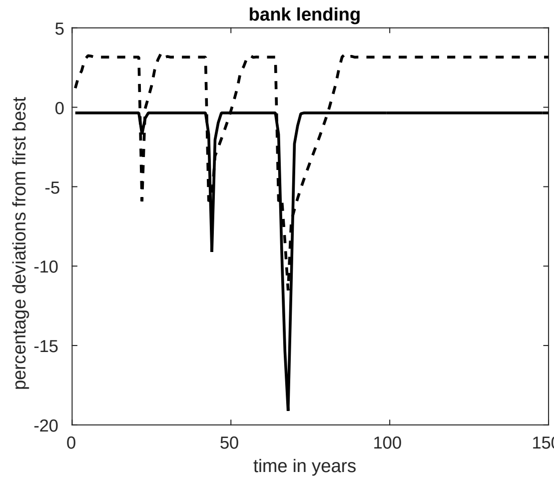
Figures 5 and 6 compare the laissez-faire competitive equilibrium with the constrained-efficient allocation for the case in which bank dividends do not enter the planner welfare criterion at all. For example, a constrained planner may value bank dividends less in the case where foreigners enjoy some of these dividends. Figure 5 shows that a constrained planner that does not 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 overall high volatility of bank lending.

Leverage is higher in the constrained-efficient allocation but severe credit crunches can be avoided by increasing bank future profits whenever banks experience low lending returns (Figures 5(b) and 5(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.

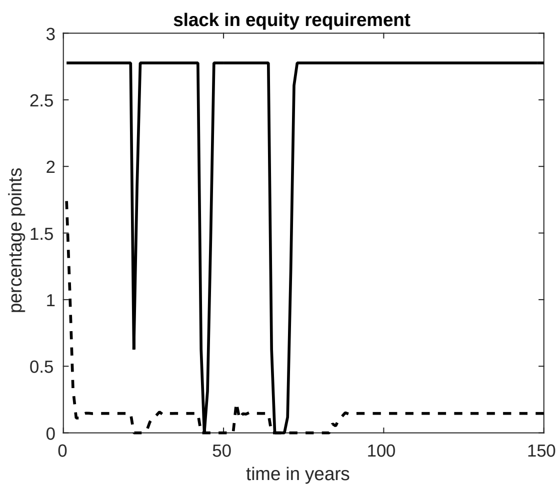
Intuitively, when the planner does not value bank dividends, a high level of bank equity has a social cost that is excessive because of the bank participation constraint (15). As a result of market incompleteness, high realized lending returns lead to bank equity that is too high such that a planner 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.



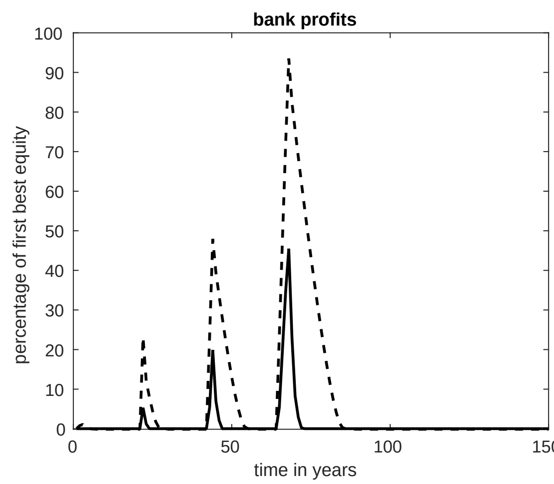
(a) Aggregate bank capital



(b) Aggregate bank lending

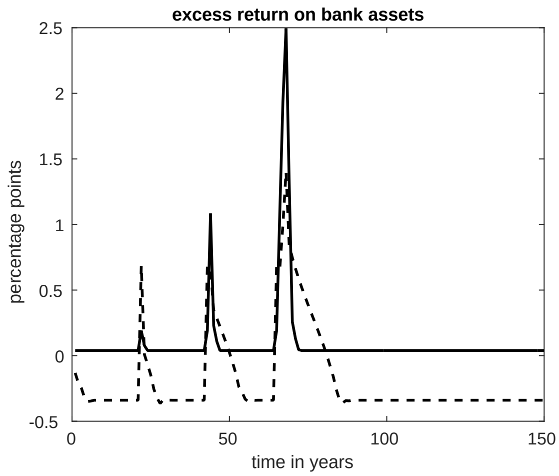


(c) Slack in no-default condition

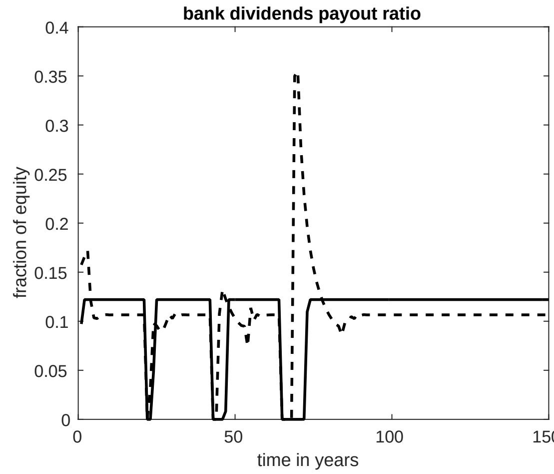


(d) Future profits

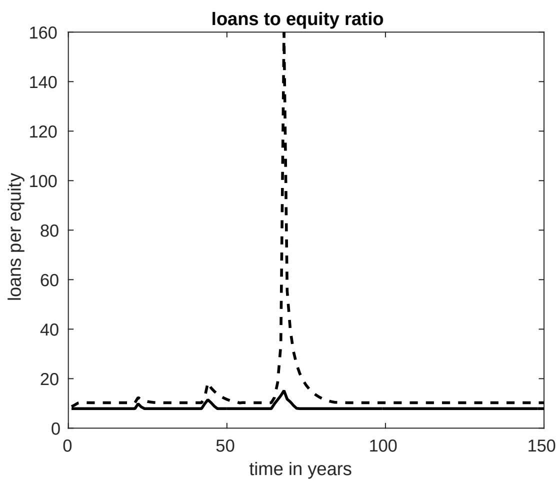
Figure 5: Case in which constrained planner does not value bank dividends. Panel (a) shows bank capital relative to bank lending, $\left[\gamma E_t A_{t+1}/K_{t+1} - 1\right] \cdot 100$, where E_t denotes conditional expectations at time t. Panel (b) shows bank lending relative to first-best lending, $\left[K_{t+1}/K_{FB} - 1\right] \cdot 100$. 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, $\Pi_t/\beta\theta K_{FB} \cdot 100$.



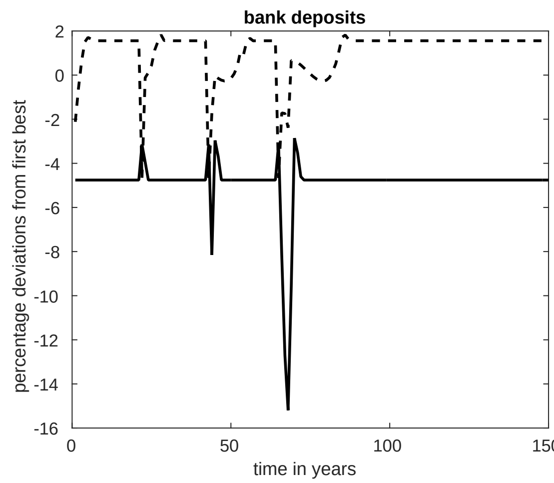
(a) Expected excess lending returns



(b) Aggregate dividends



(c) Leverage



(d) Aggregate bank external funding

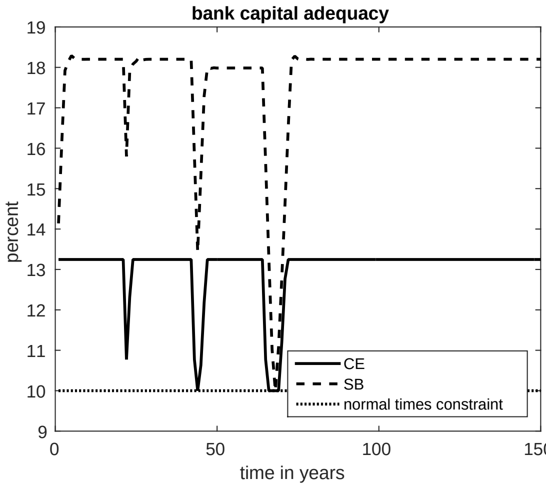
Figure 6: Case in which constrained planner does not value bank dividends. Panel (a) shows expected excess returns, $[\beta E_t R_{t+1} - 1] \cdot 100$. Panel (b) shows the aggregate bank dividend payout ratio, D_t/A_t. Panel (c) shows bank leverage, $K_{t+1}/\gamma E_t A_{t+1}$, which is inversely related to the capital adequacy ratio. Finally, panel (d) shows bank external funding.

A constrained planner that does not value bank dividends would require bank 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 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.

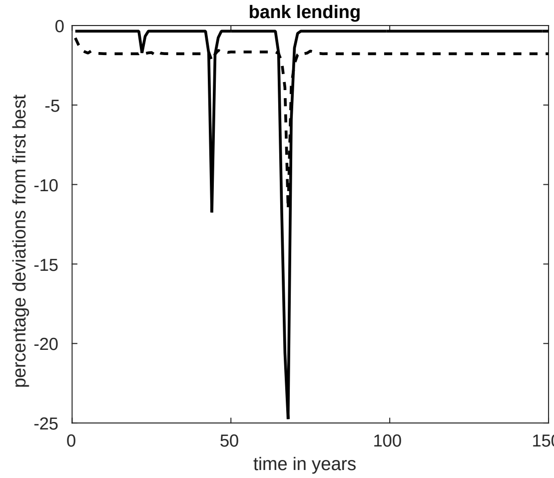
4.1.2 Tighter-than-necessary micro-prudential capital requirements

Figures 7 and 8 compare competitive equilibrium and constrained-efficient allocation for the case in which bank future profits do not enter the bank no-default constraint. This case can be interpreted as a micro-prudential regulator imposing a bank no-default condition that is tighter than the no-default constraint (6) imposed by market participants. The condition is then tighter than necessary to prevent default (Kehoe and Levine, 1993; Alvarez and Jermann, 2000). The additional tightness is ad hoc and not derived from macro-prudential concerns. The constrained-efficient allocation can then be interpreted as the best allocation a macro-prudential regulator can achieve, taking a tight micro-prudential constraint as given.

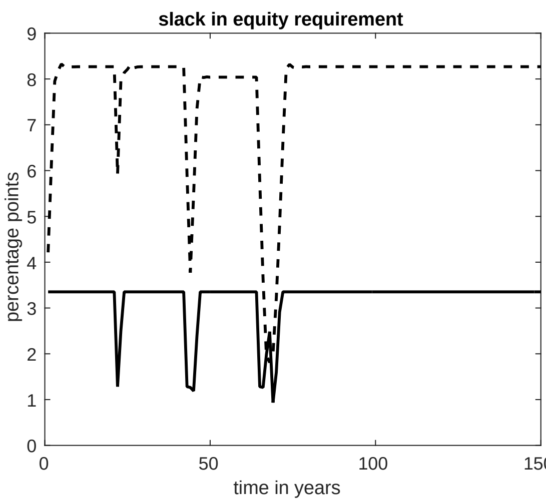
Both individual loan loss provisioning and additional capital buffers are now higher. However, the constrained planner does not raise bank future profits to alleviate financial crises. The reason is that for a given tight micro-prudential bank no-default constraint there is no scope for the macro-prudential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



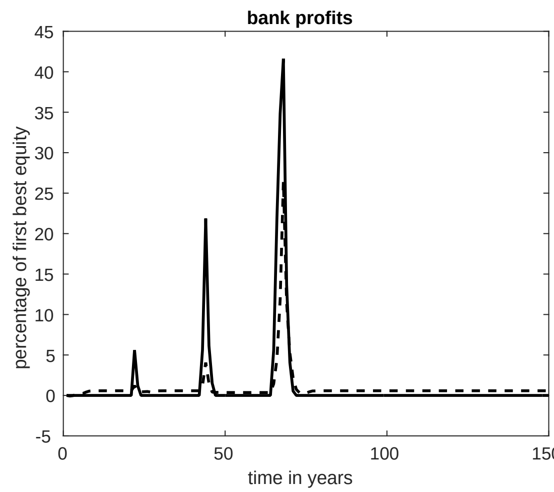
(a) Aggregate bank capital



(b) Aggregate bank lending

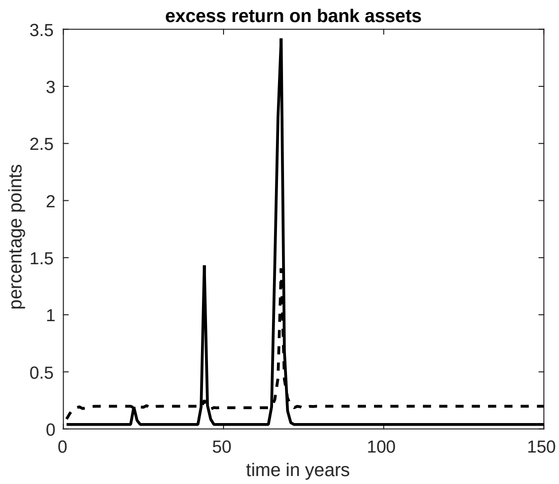


(c) Slack in no-default condition

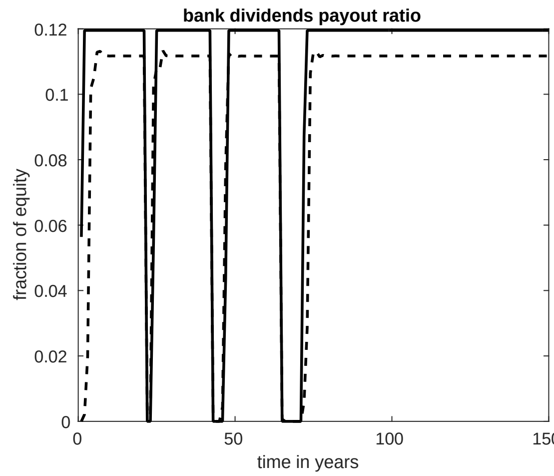


(d) Future profits

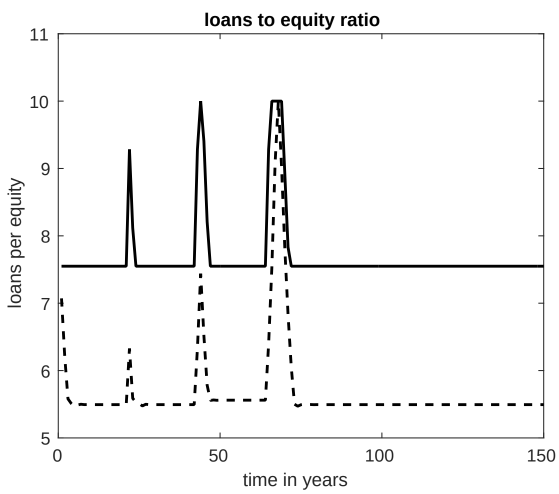
Figure 7: Case in which capital requirements do not depend on future profits. Panel (a) shows bank capital relative to bank lending, $\left[\gamma E_t A_{t+1}/K_{t+1} - 1\right] \cdot 100$ where E_t denotes conditional expectations at time t. Panel (b) shows bank lending relative to first-best lending, $\left[K_{t+1}/K_{FB} - 1\right] \cdot 100$. 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, $\Pi_t/\beta\theta K_{FB} \cdot 100$.



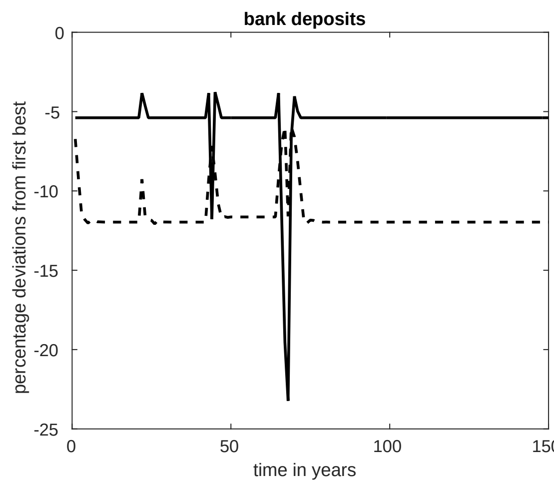
(a) Expected excess lending returns



(b) Aggregate dividends



(c) Leverage



(d) Aggregate bank external funding

Figure 8: 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. The constrained-efficient allocation takes into account all possible macro-prudential concerns and reveals two necessary regulatory tools. First, additional capital buffers should be imposed *ex ante*. Because of the strong non-linearities present in the model, such buffers should be always activated. Second, capital requirements should be reduced *ex post* during severe credit crunches. Bank default at increased levels of leverage is avoided by granting higher future profits to banks. A macro-prudential regulator would affect bank profitability dynamically to smooth out the scarcity of bank lending over financial cycles.

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