



Capital requirements, risk choice, and liquidity provision in a business-cycle model

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ABSTRACT

This paper develops a dynamic general equilibrium model to quantify the effects of bank capital requirements. Households' preferences for liquid assets imply a liquidity premium on deposits. The banking sector supplies deposits and has excessive risk-taking incentives. I show that the scarcity of deposits created by an increased capital requirement can reduce the cost of capital for banks and increase bank lending. A higher capital requirement also increases banks' monitoring incentives, which improves the efficiency of banks' activities. Under reasonable parameterizations, the marginal benefit of a higher capital requirement related to this channel significantly exceeds the marginal cost, indicating that US capital requirements have been suboptimally low.

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More equity... would restrict their [banks'] ability to provide loans to the rest of the economy. This reduces growth and has negative effects for all.

—Josef Ackermann, former CEO of Deutsche Bank, November 20, 2009

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1. Introduction

What is the optimal capital requirement for banks? Bank regulators and some academics argue that a low capital requirement allows banks to accept too much risk. Bank managers and opposing academics counter that too high of a capital requirement increases banks' funding costs, thereby lowering the supply of credit to the economy. Motivated by this debate, this paper analyzes which level of capital requirement mitigates bank risk-taking without substantially reducing useful bank services, such as the credit supply and liquidity provision.

To do this, I develop a general equilibrium model with banks that allows me to analyze and quantify this important trade-off. In the model, banks matter because of three features. First, a subset of production in the economy depends on bank financing. Second, banks issue risk-free deposits, which households value as safe and liquid assets. I model households' preferences for deposits with a utility function that is increasing in deposits. Third, government

subsidies to banks create excessive risk-taking incentives for banks. I model these subsidies as a reduced-form transfer function that is increasing in size, leverage, and losses in the banking sector. The calibrated model matches important data moments in the US economy and in the US banking sector over the business cycle.

The model yields two key insights. First, I find that the optimal capital requirement in the model is 12.4% of risky assets. This level weighs lower liquidity provision in the form of deposits against higher and more stable consumption. Second, I show that a higher capital requirement can increase the supply of bank credit. This finding is the result of a general equilibrium effect. A higher capital requirement leads to a lower supply of coveted deposits and thus increases households' willingness to hold deposits at a lower deposit rate. As a result, an increase in capital requirements can reduce banks' funding costs and thus increase bank lending.

At first glance, the potential positive effect of a higher capital requirement on bank lending seems counter-intuitive and inconsistent with the available empirical evidence. The conventional wisdom that a higher capital requirement negatively affects lending is based on the assumption that banks funding rates, such as deposit rates, do not materially respond to regulatory changes in the capital requirement. The empirical evidence relies on this assumption to identify the effect of a higher capital requirement on lending. For example, studies such as [Peek and Rosengren \(1995\)](#) exploit capital requirement variations that affect only a subset of banks as opposed to a sector-wide change that could have moved equilibrium interest rates. Otherwise, the response in banks' loan supply could have been driven by other factors, such as changes in the loan demand. Thus, by design, empirical studies identify a partial equilibrium response (i.e., holding equilibrium funding rates constant) to a higher capital requirement.

To see why capital requirements can cause an increase in lending in my model, it is helpful to discuss the thought experiment that motivates the conventional wisdom. Consider a simple model with banks that have two sources of funding: equity and deposits. Assume that deposits are a cheaper source of funding. Thus, banks fund themselves with as many deposits as allowed by the capital requirement, imposed by regulators, and their marginal cost of funding is given by the weighted average of the costs of equity and deposits (with the weights determined by the capital requirement). As usual, banks optimal lending decision equates the marginal benefit of lending with the marginal cost.

Now suppose that a higher bank capital requirement forces banks to increase their equity-capital ratio (i.e., equity to risk-weighted assets) while everything else is assumed to remain unchanged, including the deposit rate. This change increases the weight on relatively expensive equity financing, thereby driving up banks' cost of capital and thus decreasing the level of lending. With fewer loans to fund, banks issue fewer deposits, and thus both the supply of loans and deposits fall. In this thought experiment, the deposit rate is assumed to be unaffected by the decrease in the supply of deposits. A higher bank capital

requirement leads therefore to an unequivocal decrease in the supply of loans.

Now consider a modification of this thought experiment that allows the deposit rate to endogenously respond to the supply of deposits. Assume households derive utility from holding bank deposits like in my model. This has two effects. First, deposits are a cheaper funding source than equity for banks because households are willing to forgo interest on deposits in exchange for a convenience yield on deposits. Second, the convenience yield is decreasing in the amount of deposits because households value deposits less the more abundant they are in the economy. Thus, when a higher capital requirement causes a drop in the supply of deposits, the convenience yield of deposits increases, and the deposit rate decreases. Which effect dominates in equilibrium—the initial increase in banks' equity financing cost caused by the higher weight on equity financing or the subsequent decrease in the deposit rates—is a quantitative question. When the deposit rate channel dominates, banks cost of capital decreases, thereby increasing their optimal level of lending. This discussion thus underscores the importance of quantifying the effects of a higher capital requirement in a general equilibrium framework.

To quantitatively evaluate the trade-offs associated with tighter capital requirements, I build on a standard business-cycle model with aggregate shocks, a representative household, and two production sectors: a bank-independent sector and a bank-dependent sector. Both production sectors produce the same consumption good. The bank-dependent production sector is owned and operated by a representative banking sector. That is, banks invest a portion of their assets on behalf of bank-dependent firms in a decreasing returns to scale production technology. Banks have also access to a monitoring technology that increases the average return of bank-dependent production and lowers its exposure to aggregate shocks. They can choose the share of production they wish to monitor. Monitoring is costly, as modeled by a standard convex monitoring cost function.

Banks are funded with deposits and equity. The Modigliani–Miller capital structure irrelevance principle does not hold for two reasons. First, aside of consumption, households derive utility from holding deposits and thus are willing to pay a convenience yield. Second, the banking sector receives a government subsidy. As a consequence, banks choose as much leverage as they are allowed to choose by regulation. For tractability, I model the subsidy as a reduced-form transfer function that is increasing in size, leverage, and losses in the banking sector. That this transfer function is not microfounded is a weakness of my model, but [Appendix A.1.3](#) shows that the reduced-form government subsidy has similar properties as the implied subsidy in a microfounded model.

I match the model to quarterly US data from the National Income and Product Accounts (NIPA) and the Federal Deposit Insurance Corporation (FDIC) for 1999–2016. The welfare effects mainly depend on two parameters: the sensitivity of the subsidy function to leverage and the elasticity of households' deposit demand. I infer the subsidy's sensitivity to leverage from banks' first-order condition for bank leverage, together with the subsidy estimates

provided by [Gandhi and Lustig \(2015\)](#). The deposit demand elasticity determines how much households dislike supply-shock-driven variations in the deposit-consumption ratio. I calibrate this parameter by targeting the volatility of that ratio and attribute all the observed volatility to supply shocks. Hence, my calibrated elasticity is likely to be a lower bound of the true elasticity in the economy.

The model matches key balance sheet and income statement moments from banks, together with macroeconomic aggregates. Moreover, its dynamics are consistent with many business-cycle moments in the US data that my calibration does not target. For example, it is consistent with the procyclicality and volatility of banks' balance sheet and income statement variables. That it also captures the correlations between NIPA and balance sheet variables makes it particularly suitable for studying the macroeconomic effects of a higher bank capital requirement.

The government subsidy distorts banks' decisions, which gives rise to a welfare improving bank capital requirement. I define the optimal capital requirement in the model as the one that maximizes the welfare of the representative household, as measured by the discounted expected lifetime utility from consumption and bank deposits. To find it, I simulate the model at the calibrated capital requirement level of 9%. Then I calculate the transition path and the new equilibrium for a range of new capital requirement levels. A capital requirement level of 12.4% maximizes welfare.

An increase in the capital requirement from the calibrated level of 9% to the optimal level of 12.4% reduces the supply of deposits by 86 basis points (bps), but it increases consumption by 33 bps and decreases the volatility in consumption by 18%. Bank lending increases by 2.35%, which increases the output of the bank-dependent sector by 11%. The general equilibrium effect associated with an increase in bank lending and thus deposits reduces the deposit rate by 76 bps, leading to an 84 bps fall in banks' cost of capital. In the model, consumption increases because of two effects. First, output in the economy is higher because more lending leads to an increase in banks production. Second, a higher capital requirement leads to more and smoother consumption because banks increase monitoring. The reason for this is simple. When banks decrease leverage because of the higher capital requirement, the value of the government subsidy declines. Smaller government subsidies are paid out in states in which banks make losses. This, in turn, reduces incentives for banks to monitor at suboptimal levels, leading to an increase in monitoring efforts. More monitoring increases the average return on bank-dependent production, which leads to higher consumption. Volatility in the economy decreases because higher monitoring efforts mean that banks lower the fraction of risky bank activities that have a relatively high exposure to the aggregate shock.

While the assumption of households preference for deposits and the reduced-form subsidy function lead to a tractable model, it also makes the welfare results potentially sensitive to functional forms and parameterizations. For this reason, I analyze the sensitivity of the welfare results to the parameters governing the subsidy function and households' preferences for deposits. This analysis

shows that reducing or increasing the elasticity of deposit demand or the sensitivity of the subsidy function to banks' leverage, size, or losses leave the fundamental effects and trade-offs of a higher capital requirements in the model unaltered. My model also assumes that banks are the only providers of safe and liquid assets. This is akin to assuming that the nonbank supply of these assets is unaffected by changes in the capital requirement, such as for safe assets supplied by the government (e.g., government bonds). I also show robustness of the welfare result to a change in the supply of government bonds that banks can invest in. Across all experiments, the resultant optimal capital requirement levels are close to the optimal level implied by my benchmark calibration, ranging within three percentage points of my optimal benchmark estimate of 12.4%.

This paper connects to the banking literature on optimal capital regulation and to recent work in macro-finance. Relative to nonfinancial firms, banks have unusually high leverage ratios. A strand of the theoretical banking literature has argued that this is optimal because bank debt is safe and liquid (e.g., [Gorton and Pennacchi, 1990](#); [Diamond and Rajan, 2001](#); [Gorton et al., 2012](#); [DeAngelo and Stulz, 2015](#)). Under this view, increasing the bank capital requirement and thus reducing bank leverage ratios could be costly. By contrast, other authors (e.g., [Admati et al., 2012](#)) have argued that a key benefit of increasing banks' capital requirements is that it can lead to less risk-taking by banks. My model captures both this cost and this benefit and thus makes it possible to determine the optimal capital requirement that balances the cost and benefit of imposing a higher level.²

[Bernanke and Gertler \(1989\)](#) and [Kiyotaki and Moore \(1997\)](#) laid the foundation for macroeconomic models with financial frictions. [Bernanke et al. \(1999\)](#) and [Christiano et al. \(2010\)](#) have incorporated credit market imperfections into tractable New Keynesian models. I build on this work to develop a tractable macroeconomic framework focusing on the effects of capital requirements.

This paper is more closely related to work that quantifies the effects of capital requirements and leverage constraints (see, e.g., [Christiano and Ikeda, 2016](#); [Martinez-Miera and Suarez, 2014](#); [Van Den Heuvel, 2008](#); [Nguyen, 2014](#); [De Nicolò et al., 2014](#); [Clerc et al., 2014](#); [Corbae and D'Erasmo, 2018](#)). [Van Den Heuvel \(2008\)](#) is one of the first to use a quantitative general equilibrium growth model with households liquidity demand. Unlike this paper, his work quantifies only the costs of a higher capital requirement on welfare in terms of a reduction in deposits and therefore leaves the question of the optimal level to future research. A common feature of previous work is that a higher capital requirement reduces financial fragility, but it also reduces the amount of lending, which results in lower output (GDP). In my model, the effects on risk-taking and lending activities are still present, but

² [Hanson et al. \(2010\)](#) and [Kashyap et al. \(2008\)](#) argue for higher capital requirements by citing the tax advantage of debt and competitive pressure over cheap funding sources as the leading source for banks' high leverage. [Harris et al. \(2014\)](#), [Malherbe \(2017\)](#), [Phelan \(2016\)](#) and [Bahaj and Malherbe \(2018\)](#) study the effects of capital requirements in stylized models.

I also incorporate the consequences of a change in the supply of bank deposits on the deposit rate in a setting in which households derive utility from deposits. When bank deposits become scarce, households are willing to hold them even if they pay a low interest rate because their convenience yield increases. This lowers banks cost of capital, leading to more—not less—lending in the economy.

The idea that the demand for safe and liquid assets drives down yields and thus can have important effects on the banking sector is at the center of the savings glut hypothesis, first formalized by Caballero et al. (2008) and subsequently discussed by Caballero and Krishnamurthy (2009), Mendoza et al. (2009), Gorton et al. (2012), among others. My model captures this idea and analyzes its importance for optimal bank capital regulation in a quantitative setting.

Finally, this paper presents a first step toward quantifying the optimal capital requirement in a model in which banks have excessive risk-taking incentives and are important for liquidity provision. Begenau and Landvoigt (2018) build on this paper to study the response of the shadow banking system to a higher capital requirement, which is beyond the scope of the current paper.

2. Model

This section presents the model and outlines the key assumptions. I use a general equilibrium model cast in discrete time, with an infinite horizon. The economy produces a single good c using two production technologies, each operated by a different sector. These two sectors are a bank-independent sector (sector f) and a bank-dependent sector (sector B).

2.1. Bank-independent sector

Firms in the bank-independent sector are competitive and rent capital k^f and labor H^f from households to operate a Cobb–Douglas production function. The capital stock in the bank-independent sector is owned by households.

2.1.1. Bank-independent sector production technology

The firms in the bank-independent sector produce output with a Cobb–Douglas technology:

$$y_t^f = Z_t^f (k_{t-1}^f)^\alpha (H_t^f)^{1-\alpha}, \quad (1)$$

where Z_t^f is the productivity level at time t , k_{t-1}^f is the capital stock installed at $t-1$, α is the share of capital, and H_t^f is the number of hours worked. Productivity is stochastic:

$$\log Z_t^f = \rho^f \log Z_{t-1}^f + \sigma^f \epsilon_t^f, \quad (2)$$

where ϵ_t^f is drawn from a multivariate normal distribution.

2.1.2. Bank-independent sector problem

I abstract from financial frictions in the bank-independent sector and assume that bank-independent firms maximize profits:

$$\pi_t^f = \max_{k_{t-1}^f, H_t^f} y_t^f - r_t^f k_{t-1}^f - w_t^f H_t^f,$$

where r_t^f is the return households receive for renting out capital k_{t-1}^f , and w_t^f is the wage households receive for labor hours H_t^f . Because of perfect competition, firms make no profits in equilibrium.

2.2. Capital accumulation

A common capital market is used for capital in bank-dependent production and for that in bank-independent production. Capital in sector $j \in \{f, B\}$ depreciates at a rate of δ^j and accumulates according to

$$k_t^j = i_t^j + (1 - \delta^j) k_{t-1}^j.$$

Adjustments to the stock of capital are costly. When investment deviates from replacing the depreciated capital stock, investors incur a proportional capital adjustment cost of

$$\varphi_j \left(\frac{i_t^j}{k_t^j} - \delta^j \right)^2 k_t^j, \quad (3)$$

where φ_j is the sector-specific adjustment cost parameter.

Capital in the bank-independent sector is owned by households. Capital in the bank-dependent sector is owned by banks.

2.3. Banking sector

Banks play two roles in this economy: first, they produce a good that households consume. Second, households value bank deposits. Banks are owned by households and maximize shareholder value by generating cash flows that are discounted using the stochastic discount factor of households.

There exists a measure of one continuum of infinitely lived, ex ante identical banks. Because all banks are ex ante identical and the shock to the bank-dependent sector is an aggregate shock, banks' choices are perfectly correlated, and I can speak of a representative bank that takes prices as given. That is, I can think of the sum of banks described here as the aggregate banking sector. For this reason, I describe the problem of banks as if it is the problem of the representative bank.

2.3.1. Bank-dependent sector production technology and monitoring

I assume that a subset of production takes place in the bank-dependent sector. The bank-dependent production technology y_t^B has decreasing returns to capital. $Z_t^{B, \text{bad}}$ is the stochastic productivity level of banks' production technology when banks do not monitor. In $t-1$, banks can choose to monitor a share m_{t-1}^B of production in t . In this case, the productivity level of the monitored production share is $Z_t^{B, \text{good}}$. For each $i \in \{\text{good}, \text{bad}\}$, $Z_t^{B, i}$ follows

$$\log Z_t^{B, i} = \mu^{B, i} + \rho^{B, i} \log Z_{t-1}^{B, i} + \sigma^{B, i} \epsilon_t^B, \quad (4)$$

with mean $\mu^{B, i}/(1 - \rho^{B, i})$ and autocorrelation $\rho^{B, i}$. The shock ϵ_t^B is common to all banks and drawn jointly with ϵ_t^f from

$$\begin{pmatrix} \epsilon_t^f \\ \epsilon_t^B \end{pmatrix} \sim \mathcal{N} \left(\begin{bmatrix} 0 \\ 0 \end{bmatrix}, \begin{bmatrix} 1 & \sigma^{fB} \\ \sigma^{fB} & 1 \end{bmatrix} \right),$$

where σ^{fb} is the covariance between ϵ_t^f and ϵ_t^B . For simplicity, I assume $\rho^{B,\text{good}} = \rho^{B,\text{bad}}$.

I assume that monitoring increases the value and efficiency of production because the mean of $Z_t^{B,\text{good}}$ is higher and the standard deviation of $Z_t^{B,\text{good}}$ is lower compared with $Z_t^{B,\text{bad}}$. This means $\mu^{B,\text{good}} > \mu^{B,\text{bad}}$ and $\sigma^{B,\text{good}} < \sigma^{B,\text{bad}}$. These assumptions are consistent with the evidence. For example, Nini et al. (2012) present evidence that suggest a positive role of creditors in firm performance. Dell'Ariccia and Marquez (2006) and Dell'Ariccia et al. (2012) show that tighter lending standards improve bank profitability. It follows that monitoring gives banks a risk choice: a lower m_t^B increases banks exposure to the common shock in $t+1$.

The cost of monitoring is governed by

$$G(m_t^B) = \frac{\phi}{2} (m_t^B)^2,$$

with $\phi > 0$. The variable monitoring intensity m_t^B and convex monitoring cost assumption are standard in the banking literature (e.g., Besanko and Kanatas, 1993; Stein, 2003; Tirole, 2006, p. 360; see also Appendix Section A.1.2. for more discussion and references).

Given the monitoring share choice m_{t-1}^B and capital k_{t-1}^B , banks produce output y_t^B with a decreasing returns to scale technology:

$$y_t^B = \underbrace{(m_{t-1}^B Z_t^{B,\text{good}} + (1 - m_{t-1}^B) Z_t^{B,\text{bad}})}_{:= Z_t^B} (k_{t-1}^B)^v, \quad (5)$$

where $v < 1$.

2.3.2. Banks balance sheet

The balance sheet equates risky assets k_{t-1}^B and riskless assets b_{t-1} (issued by the government) to bank deposits s_{t-1} and equity e_{t-1} :

$$k_{t-1}^B + b_{t-1} = s_{t-1} + e_{t-1}.$$

2.3.3. Banks profits

At the beginning of the period t , the aggregate shocks ϵ_t^B and ϵ_t^f are realized. Banks enter the period with capital k_{t-1}^B , government securities b_{t-1} , bank deposits s_{t-1} , equity e_{t-1} , and a monitoring intensity m_{t-1}^B . Banks receive operating income from the bank-dependent production technology and investment income from riskless government bonds. Bank expenses are interest payments on deposits. Therefore, profits are

$$\pi_t = \underbrace{y_t^B - \delta^B k_{t-1}^B}_{\text{production income}} + \underbrace{r_{t-1}^{\text{gov}} b_{t-1}}_{\text{interest inc.}} - \underbrace{r_{t-1} s_{t-1}}_{\text{interest exp.}}.$$

2.3.4. Market imperfections in the banking sector

Banks are subject to Basel-III-type capital requirements. The Basel III accords stipulate that banks must back a specific percentage of risk-weighted assets with equity. Safe assets, such as government bonds, have a risk weight of 0%. The capital requirement is

$$e_t \geq \xi k_t^B,$$

where ξ determines the amount of equity e_t needed to back risky assets k_t^B .

Banks incur dividend adjustment costs that arise when dividend payouts deviate from the target level \bar{d} . This introduces intertemporal rigidities consistent with the empirical evidence (e.g., Lintner, 1956; Dickens et al., 2002). Following Jermann and Quadrini (2012), the payout cost function takes the following form:

$$f(d_t) = \frac{\kappa}{2} (d_t - \bar{d})^2,$$

where κ governs the size of this cost.³ Outside the steady state, dividend adjustment costs introduce intertemporal rigidities into the balance sheet that make banks' choices of equity dependent on the current level of equity. This is consistent with the evidence in Adrian and Shin (2011). Paying out too much in dividends also can be costly because of an increasing marginal tax rate on equity distributions (see Hennessy and Whited, 2007).

Finally, I assume that the benefits for banks from a government guarantee are captured by a reduced-form transfer function:

$$TR\left(k_{t-1}^B, \frac{e_{t-1} + \pi_t}{k_{t-1}^B}\right) = \omega_1 k_{t-1}^B \exp\left(-\omega_2 \left(\frac{e_{t-1} + \pi_t}{k_{t-1}^B}\right)\right), \quad (6)$$

where ω_1 and ω_2 are positive constants. It is increasing in banks' size k_{t-1}^B and decreasing in banks' after-profit capitalization $(e_{t-1} + \pi_t)/k_{t-1}^B$, the inverse of leverage.

Discussion of assumption

In my model, I take the existence of government guarantees that result in subsidies to the banking sector as given. Eq. (6) captures the benefits from government subsidies, which range from the tax advantage of debt to any government actions that help stabilize banks. Modeling the benefits from government guarantees as a reduced-form subsidy function is a weakness of my model. In Appendix Section A.1.3, I show how this functional form can be derived from first principles and discuss this reduced-form assumption in more detail.

2.3.5. Banks problem

In period t , banks choose capital k_t^B , monitoring intensity m_t^B , equity e_t , government bonds b_t , and deposits s_t to maximize the present value of the stream of future cash flows to shareholders. These cash flows are called dividends. Banks use the cash flows from profits π_t and the government subsidy $TR(\cdot)$ to finance additions to next period's equity capital $e_t - e_{t-1}$, the capital adjustment and monitoring costs, as well as dividend payouts to shareholders. Due to dividend payout costs, the necessary cash flow to payout d_t is $d_t + f(d_t)$. Thus, dividends are

³ The introduction of dividend adjustment costs neither qualitatively nor materially quantitatively affects the results of the model. However, they improve the model's fit of second moments. Given log consumption volatility, second-order moments do not play a large role in the welfare results.

$$d_t = e_{t-1} - e_t + \pi_t - f(d_t) + TR\left(k_{t-1}^B, \frac{e_{t-1} + \pi_t}{k_{t-1}^B}\right) - \underbrace{\varphi_b \left(\frac{i_t^B}{k_t^B} - \delta^B\right)^2 k_t^B}_{\text{capital adjustment costs}} - \underbrace{\frac{\phi}{2} (m_t^B)^2}_{\text{monitoring costs}}.$$

The banks problem is written recursively. Defining $\tilde{e} = e + \pi$ as equity after profits is useful in stating the problem. The vector ε summarizes the two aggregate shocks ε^f and ε^B . Banks state variables are the aggregate state vector X (described in Section 2.6) that includes ε , equity after profits $\tilde{e}(e, k^B, m^B, X)$, and k^B . Banks have unlimited liability: if $\tilde{e} < 0$, they set $d < 0$. Banks discount the future with the pricing kernel $M(X')$ from shareholders. They choose capital k^B , government bonds b' , bank deposits s' , the amount of risk-taking m^B , equity after profits \tilde{e}' , and dividends d to solve

$$V^B(\tilde{e}, k^B, X) = \max_{k^B, b', s', m^B, \tilde{e}', d} d + \mathbb{E}_{\varepsilon'|\varepsilon} [M(X') V^B(\tilde{e}', k^B, X')], \quad (7)$$

subject to

$$\begin{aligned} d &= \tilde{e} - e' - f(d) + TR\left(k^B, \frac{\tilde{e}}{k^B}\right) - \varphi_b \left(\frac{k'^B - (1 - \delta^B)k^B}{k'^B} - \delta\right)^2 k'^B - \frac{\phi}{2} (m'^B)^2, \\ \tilde{e}' &= e' + \pi(k'^B, m'^B, b', s', X'), \\ k'^B + b' &= e' + s', \\ e' &\geq \xi k'^B. \end{aligned}$$

\mathbb{E} is the expectations operator conditional on information known at t .

2.4. Households

Households are identical and live forever. They own capital k^f from the bank-independent sector, rent capital k^f , and inelastically supply labor H^f to its firms. They also own bank equity and determine banks' discount factor.

2.4.1. Preferences

Households value consumption c and money-like assets in the form of deposits s that generate utility in the period they are acquired and pay interest in the following period. Similar to Christiano et al. (2010), here the utility function is defined over consumption and bank deposit s_t in a money-in-the-utility specification:

$$U(c_t, s_t) = \log c_t + \theta \frac{s_t^{1-\eta}}{1-\eta}, \quad (8)$$

where $\theta > 0$ is the utility weight on deposits, and η governs the curvature of the deposit-consumption ratio.

Discussion of assumption

Several rationales can explain liquidity demand. These include exposure to liquidity shocks like in Diamond and

Dybvig (1983) and transaction and liquidity costs like in Baumol (1952) and Tobin (1956). Feenstra (1986) shows that transaction-based money demand can be represented by a money-in-the-utility function. Strong empirical evidence supports the existence of a demand for liquidity and a convenience yield on liquid assets (Gorton et al., 2012; Krishnamurthy and Vissing-Jorgensen, 2012; Nagel, 2016). I provide more detail in Appendix Section A.1.1

2.4.2. Households problem

I define the net worth n_{t-1} of households after the realization of shocks ε_t^B and ε_t^f (summarized by the vector ε_t) and after intraperiod decisions (e.g., labor market decisions) have been made as

$$n_{t-1} = (1 + r_{t-1})s_{t-1} + (r_t^f + 1 - \delta)k_{t-1}^f + w_t^f H^f.$$

That is, households receive a return on s_{t-1} deposits (chosen last period) and income from supplying labor H^f and capital k_{t-1}^f to the bank-independent sector.⁴ Households do not hold bonds.⁵ Households also receive income from holding Θ_{t-1} bank shares (chosen last period) that pay dividends d_t and are valued at p_t per unit of bank shares:

$$\text{Income from bank equity} = (d_t + p_t)\Theta_{t-1}.$$

Taxes T are lump sum. Households' value function is written recursively. Variables with superscript $'$ indicate the next period's value. The value function depends on n , k^f , Θ , and the aggregate state vector X . Households maximize their value function by choosing consumption c , deposits s' , capital k'^f , bank shares Θ' , and net worth n' :

$$V^H(n, k^f, \Theta, X) = \max_{\{c, s', k'^f, \Theta', n'(X')\}} U(c, s') + \mathbb{E}_{\varepsilon'|\varepsilon} [\beta V^H(n'(X'), k'^f, \Theta', X')], \quad (9)$$

subject to the budget constraint

$$\begin{aligned} c + s' + \left(1 + \varphi_f \left(\frac{k'^f - (1 - \delta^f)k^f}{k'^f} - \delta\right)^2\right) k'^f + p(X)\Theta' \\ = n - T + [d(X) + p(X)]\Theta, \end{aligned} \quad (10)$$

and the definition for net worth tomorrow:

$$n'(X') = (1 + r(X))s' + (r^f(X') + 1 - \delta^f)k'^f + w^f(X')H^f. \quad (11)$$

⁴ Given the fixed labor supply H^f , the production inputs earn their marginal product. The wage is $w_t^f = (1 - \alpha)y_t^f$, and the net return on k_{t-1}^f is $r_t^f = \alpha y_t^f$.

⁵ Even if households were given the choice, they would not want to invest in bonds. Bonds earn the same interest rate as deposits because they are risk-free and receive a risk weight of zero in banks' capital requirement constraint. But bonds do not provide a liquidity benefit. If the rates were not equal, there would be an arbitrage opportunity. If bonds were cheaper than deposits, banks could issue more deposits to buy bonds. This would drive up bond prices. If bonds were more expensive, banks would not want to hold bonds.

Households incur capital adjustment costs per unit of capital k'^f ; see Eq. (3). The stochastic discount factor in the economy is given by

$$M(X'|X) = \beta \left(\frac{U_c(c(X'), s')}{U_c(c(X), s)} \right).$$

2.5. Government

The government follows a balanced budget rule whereby it maintains debt levels of $B_{t+1} = B_t$ so that

$$TR_t + r_t^{\text{gov}} B_t = T_t. \quad (12)$$

2.6. Recursive competitive equilibrium

Shocks occur first, and decisions are made subsequently. Then a new period starts again. The state vector X contains the aggregate net worth of banks \tilde{E} , the aggregate net worth of households N , the aggregate capital stock of households K^f , the aggregate capital stock of banks K^B , the monitoring intensity M^b , the aggregate shock vector ε , and the productivity levels of the bank-independent sector Z^f and banks, $Z^{B,\text{good}}$ and $Z^{B,\text{bad}}$.

Definition. Given an exogenous government debt policy B ,⁶ a recursive competitive equilibrium is defined by a pricing kernel $M(X)$; prices: $w^f(X)$, $r^f(X)$, $p(X)$, $r(X)$, and $r^{\text{gov}}(X)$; value functions for households V^H and banks V^B ; households' policy functions for consumption P_c^H , deposits P_B^H , capital $P_{K^f}^H$, bank equity shares $P_{H^B}^H$, and labor supply $P_{H^f}^H$; banks' policy functions for capital $P_{K^B}^B$, monitoring efforts $P_{M^b}^B$, bonds P_B^B , deposits P_B^B , equity $P_{H^B}^B$, and dividends P_D^B ; and \mathcal{X} the function governing the law of motion for X such that

1. Given the price system and a law of motion for X :
 - (a) the policy function $P_{K^B}^B$, $P_{M^b}^B$, P_B^B , P_B^B , $P_{H^B}^B$, and P_D^B and the value function for banks V^B solve the Bellman equation, defined by Eq. (7).
 - (b) the policy functions P_c^H , P_B^H , $P_{K^f}^H$, $P_{H^B}^H$, and $P_{H^f}^H$ and the value function for households V^H solve the Bellman equation, defined by Eq. (9).
2. $w^f(X)$ and $r^f(X)$ satisfy the optimality conditions of bank-independent firms.
3. For all realization of shocks, the policy functions imply
 - (a) market clearing for
 - (i) government bonds: $P_B^B = B$
 - (ii) deposits: $P_B^B = P_B^H$
 - (iii) capital: $P_{K^f}^H = k'^f$ and $P_{K^B}^B = k'^B$ and

$$k'^f + k'^B = i'^f + i'^B + (1 - \delta^f)k^f + (1 - \delta^B)k^B,$$

with i'^f and i'^B denoting each sector's investment in its capital stock

- (iv) labor: $P_{H^f}^H = H^f$
- (v) bank shares: $\Theta = 1$
- (vi) consumption:

$$c = y^B + y^f + (1 - \delta^f)k^f + (1 - \delta^B)k^B - \frac{\kappa}{2}(d - \bar{d})^2 - k'^f \left(1 + \varphi_f \left(\frac{i'^f}{k'^f} - \delta^f \right)^2 \right) - k'^B \left(1 + \varphi_b \left(\frac{i'^B}{k'^B} - \delta^B \right)^2 \right) - \frac{\phi}{2}(m'^B)^2$$

- (b) consistency with aggregation: $n = N$, $\tilde{e} = \tilde{E}$, $k^f = K^f$, and $k^B = K^B$.

4. The government budget constraint in Eq. (12) is satisfied.
5. The law of motion for X is consistent with the policy functions, rational expectations, and $X' = \mathcal{X}(X)$.

Appendix Section A.2 lists the full set of equilibrium equations.

3. The trade-off from a higher capital requirement

This section summarizes the effects of a higher capital requirement in the nonstochastic steady state. This is the equilibrium in which $Z^{B,\text{good}}$, $Z^{B,\text{bad}}$, and Z^f are constants.

Definition. Given an exogenous government debt policy B , a steady-state equilibrium is defined by constant values for all variables such that the equilibrium definition in Section 2.6 is satisfied.

3.1. A higher deposit demand decreases the deposit rate

That households value bank deposits as modeled by Eq. (8) implies that deposits deliver a convenience yield. Consequently, it is optimal for banks to increase leverage as much as regulation allows for it, even in the absence of government guarantees. DeAngelo and Stulz (2015) show this mechanism in a stylized model. The convenience yield (the left-hand side (LHS) of Eq. (13)) comes from households' first-order condition with respect to deposits and equals the marginal increase in utility from increasing deposits by \$1, keeping the marginal utility of consumption constant:

$$\frac{\partial U(c, s)}{\partial s} \times \left(1 / \frac{\partial U(c, s)}{\partial c} \right) = \left(\frac{r^e - r}{1 + r^e} \right), \quad (13)$$

where $\partial U(c, s) / \partial s' = \theta s^{-\eta} c^{\eta-1}$ is the marginal utility of deposits, and $\partial U(c, s) / \partial c = 1/c - \theta s^{1-\eta} c^{\eta-2}$ is the marginal utility of consumption. Both are positive. The return on equity is r^e , and the return on deposits equals their yield r . As long as households derive value from holding an additional unit of deposits (i.e., the LHS of Eq. (13) is positive), the cost of equity financing exceeds the cost of debt financing.

The convenience yield of deposits varies with the quantity of deposits s . With $\eta > 1$, a reduction in s makes deposits more desirable, increasing the convenience yield. This drives down the deposit rate r and increases the spread between r^e and r .

⁶ Government securities are not a choice variable in this model. The government should optimally set $B = \infty$, financing the securities with nondistortionary taxes. The question of how to set government securities and the capital requirement jointly is only interesting if the choice of government securities involves a trade-off; however, this question is outside the scope of this paper.

3.2. The bank capital requirement is binding

In the nonstochastic steady state and for every combination of the parameters, the capital requirement constraint of banks is binding if households derive utility from deposits (positive convenience yield) or if banks receive transfers from the government that encourage deposit financing over equity financing. This can be seen from the first-order condition of banks with respect to equity:

$$\mu = \frac{r^e - r}{1 + r^e} + \omega_2 TR \left(1, \frac{\tilde{e}}{k^B} \right) \left(\frac{1 + r}{1 + r^e} \right), \quad (14)$$

where μ is the Lagrange multiplier on the capital requirement constraint in Eq. (7). With a positive convenience yield on deposits (Eq. (13)), the capital requirement constraint is binding (i.e., $\mu > 0$). The marginal transfer (the second term on the right-hand side (RHS) of Eq. (14)) is also positive and thus tightens the constraint. By increasing equity, banks forgo the convenience yield on deposits and the marginal subsidy.

3.3. The optimal size of the banking sector

Because of the decreasing returns to scale in the production technology, the banking sector has an optimal size that is determined by the first-order conditions for equity (Eq. (14)) and k^B :

$$\begin{aligned} & \underbrace{\frac{TR}{k^B} \left(1 + \omega_2 (1 - \nu) \frac{y^B}{k^B} \right)}_{:= \frac{\partial TR}{\partial k^B} > 0} + (1 + r^B - \delta^B) \\ &= \underbrace{\xi (1 + r^e) + (1 - \xi) (1 + r)}_{\text{Funding cost of } k^B}, \end{aligned} \quad (15)$$

where $r^B \equiv \nu y^B / k^B$. Given equity r^e and debt r funding rates, the optimal size of the banking sector trades off the benefits (on the LHS) and the costs of risky assets (on the RHS). The subsidy drives a wedge between the funding costs and the return on risky assets. The funding cost of k^B is the weighted average of the return paid to shareholders $(1 + r^e)$ and creditors $(1 + r)$. Holding the RHS constant, the higher the subsidy, the lower the required marginal productivity of risky assets. This implies that banks are larger in a world with subsidies than in a world without, consistent with the evidence in Gandhi and Lustig (2015).

3.4. The monitoring choice and excessive risk-taking incentives

The monitoring intensity m^B determines the production weight on good projects that feature a lower exposure to the aggregate shock and a higher payoff. Thus, m^B allows banks to modulate the effective exposure to the aggregate shock ε^B and the expected payoff of risky assets. The presence of the subsidy distorts the monitoring choice. The first-order condition with respect to m^B ,

$$\phi m^B = \beta [Z^{B,\text{good}} - Z^{B,\text{bad}}] (k^B)^\nu (1 - \omega_2 TR / k^B), \quad (16)$$

shows that the optimal monitoring choice without the subsidy ($\omega_2 = 0$) maximizes the expected payoff of risky

assets. The subsidy creates a wedge that decreases the optimal monitoring intensity, thus reducing the expected return of bank-dependent production and increasing its risk. Intuitively, the subsidy compensates banks during times when profits are low, thereby increasing their willingness to load up on aggregate risk.

3.5. The effects of an increase in the capital requirement

The conventional argument against a higher capital requirement is the higher cost of funding loans. This argument implicitly assumes that banks' funding costs are invariant to changes in the capital requirement. In my model, this is not the case. From Eqs. (13) and (14), the capital requirement constraint is binding. Increasing ξ leads to, ceteris paribus, higher funding costs for k^B (i.e., the RHS of Eq. (15) goes up) as the weight on equity financing increases. To balance Eq. (15), the LHS has to increase as well. Ignoring the first term in Eq. (15), the LHS can only increase when risky assets such as loans generate a higher return. With the standard expression for $r^B = \nu Z^B (k^B)^{\nu-1}$ and $\nu < 1$, banks increase the return on risky assets by reducing k^B . Thus, banks reduce leverage by holding equity constant and reducing assets. This summarizes the conventional wisdom about banks' lending response to a higher capital requirement.

In general equilibrium, an additional response can trigger the counterintuitive reduction in funding costs after an increase in the capital requirement. When banks comply with the higher capital requirement by delevering, they reduce their supply of deposits to the economy. Eq. (13) determines the response of the deposit rate to a change in deposits. As long as households value deposits more the scarcer they become ($\eta > 1$), a reduction in the supply of deposits will drive down the interest rate on deposits. If the reduction in the interest rate is large enough, banks' cost of capital falls, giving banks incentives to increase lending.

Next, I discuss why a higher capital requirement reduces risk-taking incentives. A reduction in leverage marginally reduces the subsidy from risk-taking in Eq. (16), causing banks to choose higher levels of m^B . Risk-taking via leverage and less monitoring is thus a complementary activity. An increase in m^B leads to an increase in the average productivity level of banks' investment. More monitoring also lowers banks' exposure to aggregate risk, reducing the volatility of bank-dependent output and thus total output.

The capital requirement trades off a reduction in liquidity provision via deposits against an increase in consumption and a reduction in volatility fueled by more efficient bank investments. The next section addresses the size of these effects.

3.6. Key parameters

Before explaining how I quantify the model, let's highlight the parameters that matter most for the welfare results. The magnitude of the fall in r depends on the curvature parameter η in the utility function of the households. In addition, the parameter ω_2 matters for the optimal risk

Table 1

Mapping the model to the data.

This table lists model objects in the left column and their data counterparts in the right column.

Model	NIPA and FDIC balance sheet and income statement
y^B : bank output	Income—interest income on securities
k^B : bank capital	Assets—securities—cash—fixed assets
y^F : firm output	NIPA GDP—bank output
k^F : firm capital	NIPA capital stock — k^B
c : consumption	NIPA consumption
s : deposits	Total bank debt
π : profits	Net income+noninterest expense
r : deposit rate	Total interest expenses/total bank debt
e : equity	Tier 1 equity

The FDIC data can be downloaded from their website.

choice of banks. A high value for ω_2 implies a larger sensitivity of the subsidy to leverage. In [Tables 9](#) and [10](#), I will show how changing these parameters affects the welfare results.

4. Mapping the model to the data

I calibrate the model to quarterly US data from 1999 Q1 to 2016 Q4. This period reflects a deregulated banking system that arguably started with the passing of the Gramm–Leach–Bliley Act. The bank-independent sector is mapped to NIPA data, whereas the bank-dependent sector is mapped to aggregate commercial banks and savings institutions data collected by the FDIC. The FDIC collects balance sheet and income statement data from all depository institutions. I convert dollar values into thousands of 2009 US dollars per capita, using St. Louis Fed population numbers. [Table 1](#) summarizes how I map model objects to the data. I discuss the rationale for my choices in the next section.

4.1. Parameterization

The calibrated parameters can be divided into three groups. The parameters in the first group (Panel A of [Table 2](#)) are directly matched with their data counterpart. I choose the parameters of the second group (Panel B of [Table 2](#)) such that the steady-state equilibrium conditions of the model are consistent with the selected data moments. The remaining parameters are sensitive to second moments ([Tables 3](#) and [4](#)) and thus require me to solve and simulate the model. Given a parameterization, I solve the model using local perturbation methods (see Tommaso Mancini Griffoli's Dynare [user guide](#)). I simulate the model 1000 times for 300 periods, and I discard the first 150 periods. I use the other half to calculate the model-implied second moments that I then use for the calibration. This leaves several moments I can use to check the fit of the model (see [Section 4.2](#)).

Finding the data counterpart of the bank output is nontrivial. GDP can be measured with the value added, expenditure, or income approach. Bank income is a part of GDP and can be viewed as the value added from the banking sector. In the model, the bank-dependent output is produced with capital, and banks extract all rents.

Thus, bank income should capture the rents to capital in bank-dependent production. The calibration uses this analogy and measures bank-dependent production output as the sum over interest and noninterest income net of interest income from securities using the aggregate bank income statement. The value added by firms is measured as the difference between total GDP from the NIPA tables and banks' value added. According to this measure, banks account for roughly 5% of GDP. This number is consistent with that in [Philippon \(2015\)](#). The assumption that banks can extract all the rents from bank-dependent production results in a conservative estimate for the share of bank-dependent output. I compute bank-independent GDP as the residual of total GDP and the banking sector value added. If banks cannot capture all the rents, I would assign too much GDP to the bank-independent sector and thus understate the benefit from a higher lending response to an increase in the capital requirement.

I define banks' risky assets as the total assets net of government securities, fixed assets, and cash to obtain the data counterpart for k^B . This capital measure implies a bank-capital-to-bank-output ratio of roughly 12. Using the data on risky assets and aggregate bank income, the decreasing returns to scale parameter $\nu = 0.47$ matches the income-to-risky-assets ratio in the data. This parameter governs how much bank-dependent output can be generated with one unit of risky assets. In the model, the amount of government debt B is exogenous. I set B to the average level of riskless assets on banks' balance sheets, that is, the sum of government securities and cash. The average of riskless assets amounts to \$16.75 (expressed in thousands of 2009 dollars per capita). I map bank deposits in the model to total bank debt, including nondeposit bank debt. Even though banks are mostly funded with deposits, nondeposit debt is an important funding source for large banks that tend to benefit from implicit too-big-to-fail guarantees as shown by [Gandhi and Lustig \(2015\)](#). In this sense, the definition of “safe and liquid” also extends to nondeposit debt. In [Appendix Section A.1.1](#), I provide evidence for the existence of a convenience yield on total bank debt. Therein, [Fig. A.1](#) shows that the convenience yield on total bank debt measured by the spread between the Aaa-rated corporate bonds and the interest rate on aggregate bank debt declines with the quantity of total bank debt, normalized by GDP.

The depreciation rates δ^B and δ^F are jointly determined such that (1) the resource constraint ([Section 2.6](#) condition 3a.vi) is satisfied in the steady state, and (2) the weighted average of the two sector-specific depreciation rates equals the NIPA capital consumption rate of 0.0203. The weights are determined by how much capital (i.e., bank assets) banks hold relative to the capital stock in the economy based on NIPA data. The capital-output ratio in the firm sector is seven. The firm Cobb–Douglas function parameter α is chosen to match the share of salaries and wages in GDP, where $\alpha = 0.34$. The growth rate Γ is computed using real GDP data, which results in an annualized growth rate of 3%. The time preference rate ($\beta = 0.97$) is picked such that it is consistent with the steady-state investment optimality condition and the marginal product of capital in the bank-independent sector. In the model, households

Table 2

Parameters: directly set or matched to first-order moments.

Panel A presents the parameter values that are directly matched to their data counterpart. Panel B presents the parameter values that are selected to jointly satisfy steady-state conditions of the model, together with the target moments listed in the right column. Source: NIPA, FDIC, and Cociuba et al. (2012).

Panel A: Parameters selected without steady-state conditions		
Parameter	Function	Target moments
$\Gamma = 1.0021$	Average growth rate p.c.	Per capita quarterly GDP growth
$\rho^f = 0.95$	z^f productivity process	Firm TFP persistence from literature
$\sigma^f = 0.008$		firm TFP volatility
$H^f = 1.42$	Average hours (1/1000)	Hours: Simona Cociuba
$B = 16.75$	Riskless securities	Banks balance sheet cash + securities
$\rho^B = 0.76$	Persistence of Z^B	persistence of HP-filtered $\log(y^B/k^B)$
$\sigma^{fB} = 0.22$	Corr: ϵ^B and ϵ^f	Corr: TFP and HP-filtered $\log(y^B/k^B)$
Panel B: Parameters selected using steady-state conditions		
Parameter	Function	Target moments
$\alpha = 0.3431$	Firm production	Firm labor share in firm GDP
$\beta = 0.9744$	Discount rate	Capital output ratio in firm sector
$\delta^B = 0.0441$	Bank depreciation rate	Bank investment
$\delta^f = 0.0195$	Firm depreciation rate	δ = weighted average of δ^f and δ^B
$E^f = 17.4187$	Effective hours	Matches Cobb–Douglas y^f
$v = 0.4721$	Bank production	Bank income to asset ratio
$\xi = 0.0925$	Capital constraint	Avg. Tier 1 capital over risk-weighted assets
$\theta = 0.0215$	Deposit utility weight	Interest rate spread on bank debt
$\omega_1 = 0.0819$	Subsidy parameter	Tax benefit of debt 4.3% (Graham, 2000)
$\omega_2 = 18.206$	Subsidy parameter	Banks profits and subsidy (Gandhi and Lustig, 2015)

The data on hours are from Simona Cociuba's website. The units of data are in thousands of 2009 US dollars per capita.

Table 3

Second moment parameters.

This table presents the joint calibration results of parameters that govern second moments in the model.

Parameter	Function	Target moment	Data	Model
$\eta = 1.40$	s/c elasticity	$\frac{SD(s/c)}{SD(GDP)}$	1.61	1.61
$\varphi_f = 0.05$	Adjustment cost of k^f	$\frac{SD(I)}{SD(GDP)}$	4.70	4.28
$\varphi_B = 0.10$	Adjustment cost of k^B	$\frac{SD(I^B)}{SD(GDP)}$	47.29	47.56
$\kappa = 0.01$	Dividend payout costs	$\frac{SD(d)}{SD(GDP)}$	28.01	13.40

To calculate the model equivalent to the target moments in the data, I simulate the model 1000 times for 300 periods. I discard the first 150 periods and calculate the corresponding moments. SD represents standard deviation.

Table 4

Monitoring and bank productivity.

This table presents the parameters that govern banks' monitoring choice m^B and the bank productivity processes.

Parameter	Function	Target moment	Data	Model
$\mu_g = 0$	Mean of $\log Z^{B, \text{good}}$	Normalization		
$\mu_b = -0.0014$	Mean of $\log Z^{B, \text{bad}}$	Mean $\log Z^B = 0$	Normalization	0.0001
$\sigma^{B, \text{good}} = 0.0799$	SD of $\log Z^{B, \text{good}}$	SD(RORiskyAssets)	0.121	0.121
$\sigma^{B, \text{bad}} = 0.0808$	SD of $\log Z^{B, \text{bad}}$	Mean $Z^{B, \text{good}} - \text{Mean } Z^{B, \text{bad}}$	0.32%	0.35%
$\phi = 0.0165$	Monitoring cost par.	SD of Δ in lending standards	20%	20%

These parameters are jointly calibrated by simulating the productivity process and the model equivalent of the change in lending standards (monitoring intensity) 1000 times for 300 periods. I discard the first 150 observations and calculate the corresponding moments. The standard deviation (SD) of the weighted average of banks' risky asset projects is mapped to the standard deviation of the return on risky assets (RORiskyAssets) in the data. It equals the ratio the of end of the periods net interest income plus interest income on securities plus noninterest income less noninterest expense to the beginning of the periods risky assets (assets–cash–securities). In the model, Z^B is the weighted average productivity level of banks' risky projects. That is, $Z^B = m^B Z^{B, \text{Good}} + (1 - m^B) Z^{B, \text{Bad}}$. The target spread moment is the average pretax excess return on the aggregate loan portfolio of banks relative to a maturity and credit-matched replicating portfolio based on investment-grade corporate bonds from Vanguard. The Senior Loan Officer Opinion Survey on Bank Lending Practices, published quarterly by the Federal Reserve Board, reports various measures of changes in the lending standards. I use the average of the changes in the lending standards in small firms, loans to medium-size to large firms, consumer credit without credit cards, and consumer credit cards for the 1991 Q1–2016 Q4 period. Doing so yields an average volatility of 20%. All data moments are calculated over the 1999 Q1–2016 Q4 period.

supply labor inelastically. I use this fact to normalize hours worked to a constant, using the hours series constructed and kept updated by Cociuba et al. (2012). The number of average hours worked in the firm sector is around 1417 h (at an annual rate), so $H^f = 1.42$. To match the Cobb–Douglas function restriction with the data-implied values, I convert hours into effective hours. In the model, I call this parameter E^f , which is roughly 17.42. To parameterize firms productivity process Z^f , I decompose GDP into its factor components. Then I apply the Hodrick–Prescott (HP) filter to the series and calculate its standard deviation. Doing so gives $\sigma^f = 0.008$. I take the persistence parameter from the literature that uses a value of $\rho^f = 0.95$.

The parameter ξ denotes the Tier 1 capital requirement in the model. In accordance with Basel III, banks should hold at least 6% of Tier 1 equity relative to risk-weighted assets. This ratio will increase to 7% from 2019 onward. Because the capital requirement and definition of risk-weighted assets has changed over my sample period, and banks maintain a buffer over the threshold to prevent regulatory corrective action, instead of directly applying this rule, I choose the sample period average of the ratio of Tier 1 equity to risky assets as defined in Table 1. This leads to a value of $\xi = 9.28\%$.

Next, I describe the calibration of the parameters that govern the subsidy function. The scalar ω_1 in the subsidy function is calibrated to a 4.3% (net of personal taxes) tax benefit of debt relative to the equity market value of banks, as estimated by Graham (2000). The second subsidy parameter ω_2 governs the sensitivity of the subsidy function to leverage after the realization of profits. The first-order conditions of the model yield an expression for the sensitivity of bank profits to the subsidy. I use this expression and target bank profits as well as the subsidy estimate of Gandhi and Lustig (2015).

Households have log utility with respect to consumption for simplicity. The preference for deposits in the model is governed by parameters η and θ . Given η , the scalar θ determines the size of the convenience yield in the steady state (see Eq. (13)) and therefore the spread between the rate on riskless assets with and without a convenience yield. In the steady state, bank equity is riskless, and its return matches $1 + r^e = 1/\beta\Gamma^{-1}$. The interest rate on bank debt is 0.86% per quarter. This implies a θ value of 0.0215.

The final set of parameters is determined using an iterative calibration procedure. Given a vector of guesses, I repeatedly simulate the model and jointly match model moments to data targets until the distance between the model- and data-generated moments is minimized. The parameters in this set govern the curvature of liquidity demand, the capital adjustment costs, the dividend adjustment costs, the bank productivity process, and the monitoring cost.

The curvature parameter η in the utility determines how much the deposit-consumption ratio can vary in the model. For this reason, I target the volatility of the bank debt to consumption ratio relative to the volatility of GDP in the data. The adjustment costs parameters φ_f , φ_B , and κ target the relative volatility (relative to GDP) of aggregate investment, bank investment, and bank dividends,

respectively. Table 3 presents the data targets and compares them to the model generated moments.

The parameters of the bank productivity process are the monitoring cost parameter ϕ and the four parameters (μ_i and σ_i , $i \in \{\text{good}, \text{bad}\}$) that govern the processes $Z^{B,\text{good}}$ and $Z^{B,\text{bad}}$ and therefore Z^B . I normalize the mean of $\log Z^{B,\text{good}}$ to be zero; $\mu_g = 0$. Using μ_b , I also normalize the unconditional log productivity level of banks to zero:

$$\mathbb{E}[\log Z^B] = \mathbb{E}[\log (m^B Z^{B,\text{good}} + (1 - m^B) Z^{B,\text{bad}})] = 0.$$

The volatility of $\sigma^{B,\text{good}}$ matches $(\mathbb{V}[\log Z^B])^{1/2}$ to the volatility of the return on risky assets in the data. The volatility of $\sigma^{B,\text{bad}}$ is set such that

$$\mathbb{E}[Z^{B,\text{good}}] - \mathbb{E}[Z^{B,\text{bad}}] = 0.32\%$$

per quarter. This spread corresponds to the average pretax excess return on the aggregate loan portfolio of banks relative to a maturity and credit-matched replicating portfolio based on investment-grade corporate bonds from Vanguard. In other words, the compensation for actively monitoring a loan portfolio earns, on average, 0.32% per quarter relative to holding a passive corporate bond portfolio. The monitoring cost parameter targets the volatility of quarterly changes of the share of banks that tighten their lending standards as reported by the “Senior loan officer opinion survey on bank lending practices,” published by the Federal Reserve Board. Through the lens of my model, I can interpret movements in the net fraction of banks tightening their lending standards as movements in the monitoring intensity. In my model, the monitoring cost parameter ϕ governs the strength (i.e., volatility) of these movements. The higher ϕ , the costlier it is for banks to monitor a larger fraction of assets. If I disaggregate the assets in my model to the bank level and then compute the volatility, a higher ϕ would mean a lower volatility of the share of banks that tighten their lending standards, like in the data. Since the tightening fraction of banks is a standardized measure (normalized around 0 and ranging between -1 and 1), a volatility of 20% means that two-thirds of the time the net fraction of banks tightening their standards is between -20% and 20% . Since 56% assets are monitored, parameter ϕ is set such that two-thirds of the time m^B ranges between 45% and 67%: a volatility of 20%. The implied monitoring cost in the steady state is consistent with the monitoring cost estimate by Ma and Craig (2018). Table 4 lists these bank productivity parameters.

4.1.1. Discussion of calibrated values

The value of κ is quite low compared with the value used in Jermann and Quadrini (2012), where $\kappa = 0.146$. Dividend adjustment costs have (almost) no effect on banks’ decision in the full dynamic model. Also, dividend adjustment costs do not affect the steady state, where dividends equal their target.

The value of η is critical for the sign and the size of the expansionary effect of capital requirements. When $B = 0$, capital requirements are expansionary as long as $\eta > 1$. By targeting the volatility of the ratio of total bank debt to consumption, the calibrated value of η attributes all variations to supply shocks. Consequently, I find an elasticity that is likely to be a lower bound. The value I find

Table 5

Untargeted volatilities.

This table presents the volatility of key variables as measured by their standard deviation (SD) in the data (D) and relative to GDP. The last column presents the relative volatility of model simulated data (M) to model simulated GDP volatility.

1999 Q1–2016 Q4	SD(D)	Rel. SD(D)	Rel. SD(M)
GDP	1.10	1.00	1.00
Bank GDP	6.34	5.74	9.41
Assets	1.56	1.41	1.66
Banks debt	1.76	1.59	1.61
Risky assets	2.86	2.58	2.29
Consumption	0.89	0.81	0.38
Profits	11.51	10.42	24.34

The model matches the standard deviation of GDP in the data. To compute the standard deviation, I log and HP filter both the data and the model-simulated time series.

Table 6

Business-cycle correlations.

This table reports the correlation of key variables with GDP in the model and in the data. 1999 Q1–2016 Q4.

	Data	Model
Bank output	0.62	0.38
Investment	0.96	0.98
Bank assets	0.29	0.17
Bank deposits	0.23	0.17
Bank risky assets	0.48	0.17
Equity	0.35	0.35
Dividend	0.40	0.38
Deposit rate ^a	0.66	0.50
Consumption	0.91	0.90
Banks profits	0.37	0.37
Banks investment	0.39	0.28
Monitoring	−0.50	−0.41

The data are the ratio of the HP-filtered cycle component of the logged variable to the HP-filtered trend of GDP, using 1,600 as the smoothing parameter. The data counterpart for monitoring is the time series of the fraction of banks tightening their lending standards that is published in the “Senior loan officer opinion survey on bank lending practices” by the Federal Reserve Board.

^a Variables are not logged.

is consistent with that in other calibrations (Christiano et al., 2010) and with money demand elasticity estimates (Lucas and Nicolini, 2015). Finally, the complementarity between bank debt and consumption implied by $\eta > 1$ is also consistent with the procyclicality of banks' balance sheet variables in the data (see Section 4.2), which the model captures.

4.2. Business-cycle statistics

In this section, I discuss the quantitative fit of the model by looking at its business-cycle properties. I simulate the model like before: I use the benchmark calibration and apply the HP filter to the simulated data with a smoothing parameter of 1600. I use these data to compute volatilities and the business-cycle correlations reported in Tables 5 and 6. In Appendix Section C.2 I also report cross-correlation results.

Table 5 reports the volatility of the key variables in the model. While the model captures the volatility of GDP and the banks assets, debt, and profits, it overstates

the volatility of the banks income. The shocks essentially follow a one-factor model that is calibrated to match the volatility of the ratio y^B/k^B . For this reason, the model cannot jointly match the volatility of k^B and y^B . This does not affect the results because agents care about the volatility of consumption and the volatility of bank debt relative to consumption, which the model matches. A low consumption volatility is common in business-cycle models.

Table 6 summarizes the business-cycle correlations of the model and compares them to the data. The model generates realistic business-cycle correlations of consumption, investment, and banks output, investments, assets, debts, risky assets, equity, dividends, interest on debt, profits, and monitoring.

Without being a calibration target, the model captures the countercyclicality of bank monitoring. This means that banks relax lending standards during booms and tighten them during a recession. They do so for the following reason. Banks are more profitable during booms. Profitability lowers the subsidy and in turn reduces banks' incentives to accept excessive risk. Hence, they choose less risky and more efficient projects by monitoring more, increasing profits, and lowering the subsidy even further.

Movements in the interest rate come from movements in the ratio of marginal utilities of deposits and consumption. Because deposits are procyclical, the marginal utility of deposits is countercyclical, inducing the deposit rate to comove with GDP.

The good performance of the model in terms of business-cycle correlations is not merely an artifact of the positive correlation, $\rho_{Bk} > 0$, between the bank-dependent and bank-independent sector shock. Indeed, the model correlations coming from a calibration with $\rho_{Bk} = 0$ are essentially identical. The reason is the curvature on the deposit-consumption ratio in the utility, $\eta > 1$. In a boom, agents want to consume more and with $\eta > 1$; they also demand more liquidity from banks, leading to an expansion of banks' balance sheets. The comovement between bank investment and aggregate investment is thus enhanced by the complementarity between consumption and deposits.

5. Welfare

Next, I discuss how a regulator should optimally set the capital requirement of banks.

5.1. Optimal capital requirement

I solve for the equilibrium presented in Section 2.6 for a range of capital requirement levels. Next, I simulate the model under the benchmark capital requirement of $\xi = 9.25\%$. To find the optimal capital requirement taking into account the transition effects, I use the policies from each model solution that corresponds to a different value of ξ to simulate time paths for consumption and deposits, starting at a random point τ on the time path of the benchmark capital requirement. This procedure is repeated over a number of simulations, starting with the new regime each

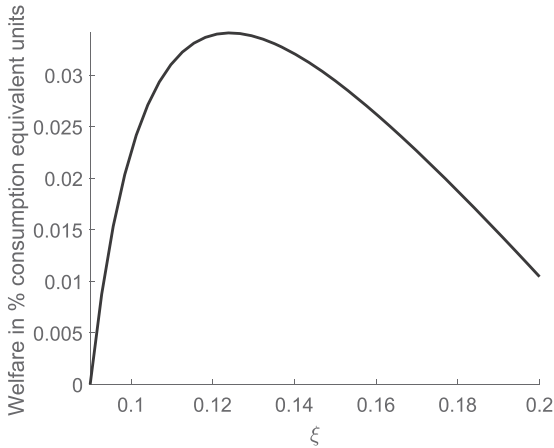


Fig. 1. Optimal level of the risk-based capital ratio. Welfare is calculated by evaluating households value function for different capital requirement levels for which the economy transitioned from the initial equilibrium with $\xi = 9.25\%$. Welfare is in % consumption equivalent units.

time at a different point, τ , on the old regime's time path.⁷ Then, for each ξ , I evaluate the realized utility and compute the households' value function for the period before the new regime is introduced by discounting the time path of utility. Finally, I average across simulations. That is, I find the scalar ξ^* such that the value function is maximized:

$$\max_{\xi^*} \mathbb{E}_0 \left(\sum_{t=\tau}^T \beta^t U(c_t, s_t \mid \xi_t = \xi^* \forall t \geq \tau) \right),$$

where $T \rightarrow \infty$.

Fig. 1 presents welfare in percentage consumption equivalent units, which is the implied percentage change in consumption if the economy moves from the $\xi = 9.25\%$ regime to any other regime on the x-axis. The value function reaches its maximum at $\xi = 12.38\%$, which is above the level that commercial banks and savings institutions currently hold on their balance sheet. I interpret 12.38% as applying mostly to large banks because the model is calibrated to aggregate data that are dominated by the largest banks. Indeed, the four largest banks alone hold over 50% of the assets of US banks. Note also that this level is based on the benchmark capital requirement of 9.25% (the average capital ratio over my sample period) and not the regulatory capital ratio of 6% under Basel III.

When the capital requirement is increased, banks reduce the supply of deposits and increase equity (see the transition path from the old to the new capital requirement in Appendix Fig. B.1). As discussed in Section 3, banks' response to an increase in the requirement can be divided into two steps. First, keeping the deposit rate constant, a higher capital requirement requires banks to finance a larger share of loans k^B (banks' risky assets) with relatively more expensive equity. Even though the return on equity decreases with an increase in ξ , because equity

becomes less risky, banks' funding costs increase as long as the return on equity does not fall by more than 30%, which is quantitatively implausible for an three percentage point increase in ξ . Thus, the increase in ξ leads to a higher cost of capital for banks. In response, banks' loan supply has to fall to equate the marginal benefit of loans to the marginal costs (Eq. (15)). With fewer loans to fund and a higher capital requirement, banks reduce their deposit supply. Second, the reduction in the supply of deposits reduces the deposit rate (Eq. (13)), which works against the increase in the cost of capital. The net effect depends on the elasticity of households' deposit demand. If the elasticity is not too large, the deposit rate falls enough to reduce banks' overall funding costs. In this case, Eq. (15) implies that banks actually increase lending. Section 6 discusses how variations in η affect this welfare experiment.

The reduction in the cost of capital makes an expansion of the banking sector attractive. To comply with the higher capital requirement, banks increase equity. However, it takes time to expand the balance sheet because loans, that is, banks' risky assets, slowly accumulate over time. Fig. B.1 shows the time path of capital in the banking sector (left panel) and in the nonbanking sector (right panel).

As described in Section 3, banks not only increase their assets but also increase monitoring. This means that banks' risky assets become more efficient and less risky. The capital requirement lowers the benefit from the subsidy, encouraging banks to choose more efficient levels of risk.

The expansion in bank loans leads to an increase (albeit a small one) in output and therefore consumption. The optimal capital requirement trades off the reduction in household welfare because of the reduction in bank deposits against the increase in household welfare because of the reduction in economic volatility and higher consumption levels.

5.2. Model properties under the optimal capital requirement

Changing the capital requirement from 9.25% to 12.38% amounts to an increase of 33%. Table 7 shows how the benchmark economy (averaged over simulations and time paths) under $\xi = 9.25\%$ differs from the economy under $\xi = 12.38\%$. The third row of each block in Table 7 presents the percentage change between new (second row) and old (first row) regime levels. The fourth row presents the average difference in the volatility.

Households like the higher capital requirement because it leads to higher consumption (+0.33%) and lower consumption volatility (−18.95%). To reach this new level of capital requirement, the equilibrium level of deposits falls by 0.86%.

A 84.6% reduction in the deposit rate leads to an overall reduction in banks' cost of capital from 1.23% to 0.39%. This reduction makes banks lending much more profitable and encourages banks to increase the credit supply by 2.35%. The bank-dependent sector output increases by roughly 11%. The reduction in banks' cost of capital also boosts their profits (not reported here) by 45%.

The model is designed to speak to the quality and quantity of risky bank activities. Banks increase their monitoring activity by 6.5% under the higher capital

⁷ I start the simulation at a different point of the state space to ensure that the results are independent of the particular starting point of the simulation.

Table 7

How does the economy change under the new capital requirement.

This table reports the average level of selected variables prior to changing the capital requirement (old level), after an increase in the capital requirement (new level), the corresponding percentage change, and the percentage change in the volatilities between the new and the old level.

	Output	Consumption	Bank output	Assets	
Old level	73.35	60.80	3.28	65.79	
New level	74.82	60.99	3.65	66.95	
%Δ in levels	0.02	0.33	11.28	1.76	
%Δ in volatility	−16.80	−18.95	−11.98	−9.87	
	ROA ^{Banks}	Subsidy/ k^B	Monitoring	log Z^B	
Old level	2.5%	1%	0.41	0	
New level	2.8%	0.4%	0.44	1 bps	
%Δ in levels	12.91	−58.98	6.57	27.43	
%Δ in volatility	−18.15	−20.15	16.20	−0.10	
	Equity	k^B	Deposits	r	Bank fund. costs
Old level	4.53	49.04	61.25	0.89%	1.23%
New level	6.21	50.19	60.73	0.13%	0.39%
%Δ in levels	44.67	2.35	−0.86	−84.55	−69.77
%Δ in volatility	−19.17	6.55	9.89	48.10	22.99

The level values are expressed in thousands of 2009 US dollars per capita. The percentage change from the old to the new level (or volatility) are indicated by %Δ. Bank fund. costs denote banks' cost of capital, that is, the weighted average of banks' equity financing costs and debt financing costs.

requirement because a lower leverage ratio reduces the benefits of the subsidy and therefore aligns banks' incentives with the incentives of a welfare-maximizing regulator. A higher monitoring intensity means that bank-dependent production becomes more productive (+27.42%) because it achieves a better risk-return trade-off. This increases banks' return on assets (ROA) by 13%.

Finally, a higher capital requirement reduces the countercyclicality of monitoring. Under the old capital requirement, the business-cycle correlation of monitoring is −0.41 (see Table 6). Under the new regime, it is around −0.3. This means that the quality of bank lending deteriorates less in the run-up of a boom, smoothing out business-cycle fluctuations in bank production and, consequently, consumption and output.

In general equilibrium, a higher capital requirement leads to lower funding costs, more credit provisions, and more monitoring and thus less excessive risk-taking by banks. Consumption increases because (1) output increases and (2) overinvestment in low-quality bank projects decreases.

5.3. Welfare gain

In the spirit of Lucas (2000), I compute the welfare cost of the benchmark capital requirement level as the percentage change in consumption needed to make households indifferent between the current regime and the optimal regime in case of an immediate implementation. That is, I find the scalar λ_0 that keeps households indifferent between

$$E_0 \left(\sum_{t=0}^{\infty} \beta^t U((c_t, s_t) | \xi = 9.25\%) \right) \\ = E_0 \left(\sum_{t=0}^{\infty} \beta^t U((\lambda_0 c_t, s_t) | \xi = 12.38\%) \right).$$

The LHS denotes household's welfare under the benchmark calibration, while the RHS denotes household's welfare under the optimal capital requirement. Both calculations started from the same initial conditions because the optimal capital requirement calculation takes into account the transition from the old to the new policy regime. This results in $\lambda_0 = 0.99955$. Households are indifferent if the new regime requires them to permanently give up 0.045% of their consumption. That is, the new regime represents a small welfare improvement commonly found in the literature (see, e.g., Lucas, 2000; Van Den Heuvel, 2008).

6. Sensitivity analysis of welfare results

This section discusses the sensitivity of the welfare results. I study the role of government debt, the liquidity preference curvature, and the alternative subsidy parameterizations.

6.1. The role of government debt

Government debt does not enter households' utility function, so households do not demand government debt. However, government debt allows banks to provide liquidity (issue deposits) without having to hold equity capital against it.

As a consequence, a higher level of government debt allows banks to provide more liquidity services.

How would a different level of B affect the welfare results? Table 8 presents the results of the model for two different levels of government debt: $B = 25.13$ and $B = 8$. The benchmark calibration obtains $B = 16.75$. This table presents the optimal level of ξ under these alternative calibrations of B in column 1 and the percentage change from the average level of selected variables under $\xi = 9.25\%$ to the new average level under the new optimal capital requirement in columns 2–7. A higher B means that the level

Table 8Result sensitivity to B .This table shows the sensitivity of the welfare results to different levels of government debt B .

	% Change in variable from $\xi = 9.25\%$ to ξ^{optimal}						
	Optimal ξ 1	Output 2	C 3	RA 4	D 5	r 6	M 7
$B^{\text{BM}} = 16.75$	12.38%	0.02	0.33	2.35	−0.86	−84.55	6.57
$B = 8.00$	12.00%	0.03	0.28	2.66	−1.01	−81.98	5.91
$B = 25.13$	12.75%	0.04	0.38	1.49	−0.74	−86.30	7.05

BM denotes the benchmark calibration. C denotes consumption; RA denotes risky assets; D denotes bank deposits; r denotes the deposit rate; and M denotes monitoring intensity. The first column shows the optimal capital requirement result under different values of B . Columns 2–7 list the percentage change for the selected variable when moving from the benchmark capital requirement to the optimal capital requirement economy. For example, a value of 0.33 in column 4 for $B = 16.75$ means consumption increases by 0.33% under the new capital requirement regime.

Table 9Result sensitivity to η .This table shows the sensitivity of the welfare results to different levels of η .

	% Change in variable from $\xi = 9.25\%$ to ξ^{optimal}							
	Vol(s/c) 1	Optimal ξ 2	Output 3	C 4	RA 5	D 6	r 7	M 8
BM $\eta = 1.4$	1.61	12.38%	0.02	0.33	2.35	−0.86	−84.55	6.57
$\eta = 1.10$	1.80	12.75%	0.10	0.41	−0.66	−1.15	−78.75	7.65
$\eta = 1.75$	1.48	12.00%	0.02	0.27	2.49	−0.52	−83.35	8.65
$\eta = 2.00$	1.40	11.90%	0.01	0.25	2.78	−0.29	−86.19	12.39
$\eta = 3.00$	1.16	11.25%	0.01	0.15	3.21	−0.12	−75.95	10.18
$\eta = 4.00$	0.85	10.88%	0.00	0.10	3.16	−0.09	−68.86	7.17
$\eta = 5.00$	0.51	10.50%	0.00	0.07	2.90	0.05	−70.65	3.28

BM denotes the benchmark calibration. RA refers to banks' risky assets. r refers to the deposit rate. D refers to bank deposits. M refers to banks' monitoring intensity. The first column presents the volatility of deposits relative to consumption, which is the target moment for η . In the data, this number is 1.61. The higher η , the lower the relative volatility. The second column presents the optimal welfare result under the different values of η . Columns 3–8 present the percentage change in the selected variable when moving from the benchmark capital requirement to the optimal capital requirement economy. For example, a value of 0.33 in column 4 for $\eta = 1.4$ means that consumption increased by 0.33% under the new capital requirement.

of liquidity provision is higher, and a larger fraction of it is not affected by the capital requirement because banks can issue deposits against B without a capital charge. As a consequence, the regulator can set a higher capital requirement (12.75% versus 12.38%) because the fraction of liquidity provision affected by the capital requirement is smaller. The reverse logic holds for low levels of government debt.

6.2. Variations in the liquidity preference curvature parameter η

Table 9 shows the sensitivity of the welfare results for different levels of η . The parameter η is a key variable in households' utility function; see Eq. (8). The higher η , the more concave are households' preferences for liquidity and the less households like variations in the deposit-consumption ratio. The first column presents the volatility of the deposit-consumption ratio, which is the target moment for η . In the data, this number is 1.61. The higher η , the lower this volatility, as households dislike movements in that ratio. The second column presents the optimal capital requirement results implied by the different values of η . Columns 3–8 present the percentage change in the selected variable when moving from the benchmark capital

requirement to the optimal capital requirement economy. For example, a value of 0.33 in column 4 for $\eta = 1.4$ means that consumption increased by 0.33% under the new capital requirement regime.

A higher η is associated with a lower optimal capital requirement level because households are more sensitive to reductions in the supply of deposits. Hence, the deposit rate is also more sensitive to changes in the supply of deposits. Consequently, bank funding costs fall more with an increase in the capital requirement. This leads to a stronger lending and monitoring response.

6.3. Variation in the subsidy function parameters

Banks are regulated because they benefit from direct and indirect government support, for example, discount window lending, deposit insurance, capital injections, and discretionary crisis interventions, to support the markets in which banks operate. For the quantitative exercise in this paper, the key question considers to what degree these subsidies influence banks' loan supply and monitoring decisions. As I capture these benefits in reduced form with a subsidy function, one might be reasonably worried about how this function drives the welfare results.

Table 10

Result sensitivity to changes in the subsidy calibration.

This table shows the sensitivity of the welfare results for different levels of the targeted subsidy used to infer ω_2 and different values of ω_1 and ω_2 .

		% Change in variable from $\xi = 9.25\%$ to ξ^{optimal}						
		Optimal ξ 1	Output 2	C 3	RA 4	D 5	r 6	M 7
1	BM subsidy	12.38%	0.02	0.33	2.35	−0.86	−84.55	6.57
2	$\frac{1}{2} \times$ BM subsidy	10.88%	0.00	0.14	1.15	−0.01	−47.01	1.27
3	$2 \times$ BM subsidy	14.82%	0.07	0.54	2.89	−1.15	−93.66	10.30
4	$\omega_1 = \omega_1^{\text{BM}} \times \frac{1}{2}$	9.01%	0.01	0.00	0.14	0.06	5.05	−0.74
5	$\omega_1 = \omega_1^{\text{BM}} \times \frac{1}{2}$	13.33%	0.09	0.47	2.51	−0.91	−113.09	8.18
6	$\omega_2 = \omega_2^{\text{BM}} \times \frac{1}{2}$	11.08%	0.01	0.27	2.73	−0.52	−79.77	2.65
7	$\omega_2 = \omega_2^{\text{BM}} \times \frac{1}{2}$	14.42%	0.05	0.51	0.85	−1.00	−86.89	9.01

BM denotes the benchmark calibration. C denotes consumption. RA refers to the risky assets of banks. r refers to the deposit rate. D refers to bank deposits and M to banks' monitoring intensity. The first column presents the optimal welfare result under this calibration. Columns 2 and 7 present the percentage change in the selected variable when moving from the benchmark capital requirement to the optimal capital requirement economy. For example, a value of 0.33 for consumption in row 1 means that consumption increased by 0.33% under the new capital requirement regime.

In my benchmark calibration, I parameterize the subsidy function using banks' first-order condition for lending and monitoring and the implicit bank subsidy estimate provided by [Gandhi and Lustig \(2015\)](#). [Table 10](#) summarizes the results from changing this baseline calibration.

The first row presents the benchmark calibration result. The second row shows the result for a calibration that uses only a half of the estimated subsidy value by [Gandhi and Lustig \(2015\)](#). The third row doubles this subsidy value. The fourth and fifth row and the sixth and seventh row use a quarter and 1.5 times the benchmark value of ω_1 and a half and 1.5 times the benchmark value of ω_2 , respectively.

If banks receive larger subsidies (row 3), the capital requirement is optimally higher. Banks overinvest more in low-quality projects compared with the benchmark calibration because the government offers banks a higher insurance value against bad realizations of the shock ε^B . A higher capital requirement level better aligns banks' monitoring efforts with the socially optimal level of monitoring. Bank monitoring substantially increases by 10.30%, therefore reducing inefficient bank production. The reduction in overinvestment (i.e., the main difference from the benchmark calibration) and the increase in production boosts consumption by 0.54%. This logic is reversed when I calibrate the model to only half the estimated value of the implicit subsidy (row 2). Relative to the benchmark calibration, the capital requirement needs to "correct" less distortions.

Rows 4 and 5 show the welfare results under two extreme calibrations for ω_1 . When ω_1 is a quarter of its benchmark value, the optimal capital requirement is lower. Intuitively, such low levels of the sensitivity of the subsidy to the size of banks imply that banks have much less incentives to overinvest and to take on too much risk (see the second to last equation in [Appendix Section A.2](#)). Reducing the capital requirement to 9% leads to more efficient lending and liquidity provision.

In contrast, row 5 is akin to row 3. A scaled-up version of the subsidy implies higher distortions in the economy, and thus a higher capital requirement is needed to correct

these distortions. Under the new requirement, banks reduce excessive risk-taking (increase monitoring and reduce lending) and liquidity provision.

Rows 6 and 7 show how changes in ω_2 affect the model's results. Because the subsidy is decreasing in profits and the capitalization of banks, banks have incentives to monitor less compared to a world without subsidies. Moreover, similar to the case with ω_1 , a higher ω_2 encourages banks to overinvest in risky assets. When ω_2 is low, fewer distortions need to be corrected, and bank monitoring increases less compared to the benchmark calibration. When ω_2 is high, the risky assets response is lower because the level of overinvestment in low-quality projects was higher during the $\xi = 9.25\%$ regime. The higher degree of distortion ex ante is met by a stronger increase in monitoring activity ex post (under ξ^{optimal}).

These results show that the key dynamics of the model are not affected by the subsidy. The precise level of the optimal capital requirement does change, however, with a different parameterization of the subsidy. The higher the subsidy level, or the more sensitive it is to leverage or bank size, the more distorted bank decisions will be. Hence, not surprisingly, the optimal capital requirement level is increasing in the level of distortions.

Across all experiments, the level of the optimal capital requirement ranges between 9% and 15%. This is still a fairly small range, implying that the key trade-offs from a higher capital requirement in the model, namely, the reduction in liquidity provision and the increase in consumption, are not materially affected by different assumptions about the reduced-form subsidy function, the deposit demand elasticity, and the supply of government debt.

7. Conclusion

Common intuition about how tighter bank capital rules affect banks' cost of capital, and therefore their credit supply can be misleading when general equilibrium effects are ignored. When households value liquidity provision by

banks via deposits, a reduction in the supply of deposits caused by a tighter capital requirement can make deposits more valuable to households, meaning they are willing to hold deposits at a lower equilibrium interest rate. If this effect is large enough, banks' cost of capital—the weighted average of debt and equity financing—can, in fact, fall and make lending more attractive to banks. Overall, my results stress the importance of analyzing and quantifying financial regulation proposals in general equilibrium.

The model used here encompasses central features of banks that policy makers consider important. Banks provide liquidity by issuing deposits, and they decide how much to lend. They also have incentives to make riskier loans than what is socially optimal because of a government subsidy that captures implicit and explicit government support. Modeling the subsidy in reduced-form makes my model tractable and has only a modest effect on the key trade-off between deposits and consumption in the welfare calculation. However, this assumption also has important drawbacks. The nature and strength of government support to financial institutions is complex, stochastic, and time variant, and, most importantly, it may interact with banks' expectations in nontrivial ways. Thus, microfounding this feature in my model will likely affect how and to what extent banks change their risk-taking behavior in anticipation of a subsidy and therefore the optimal capital requirement level. For example, the optimal level could be higher if banks expect an even higher willingness to provide government support to banks in a crisis. Banks might also act strategically to elicit greater government support as discussed by Farhi and Tirole (2012). Endogenizing and quantifying the bailout process alongside other relevant features of the banking system is an important avenue for future research.

Appendix A. Additional model details

A1. Discussion of assumptions

A1.1. Household's demand for safe and liquid assets in the form of deposits

In my model, households derive utility from deposits because banks liabilities are safe and liquid. Gorton and Pennacchi (1990) first interpreted bank debt, in particular deposits, as such. Evidence for a demand for safe and liquid assets is often expressed with a convenience yield, which is the yield investors forgo because the asset delivers liquidity services. The more investors desire liquidity, the higher should be the convenience yield or liquidity premium. A growing body of empirical work (Gorton et al., 2012; Krishnamurthy and Vissing-Jorgensen, 2012; Hanson et al., 2015; Nagel, 2016) show that the convenience yield decreases with the quantity of safe and liquid assets.

Fig. A.1 shows that bank debt is priced as if it also carries a convenience yield. Moreover, this convenience yield is decreasing in the supply of bank debt. The figure plots the interest rate spread between Aaa-rated corporate bonds and the interest rate on bank debt against the ratio of bank debt to GDP. The interest rate on bank debt is measured by the ratio of total interest expenses to total debt using data from the FDIC. Fig. A.1 shows that a lower bank-debt-to-GDP ratio is associated with a higher convenience yield. This pattern is similar to the evidence in other money-like assets (such as Fig. 1 in Krishnamurthy and Vissing-Jorgensen, 2012 for Treasuries).

Fig. A.1 supports my assumption that households derive liquidity services from holding any type of bank liabilities (e.g., deposits and other bank debt). In addition, the work by Gandhi and Lustig (2015) and Kelly et al. (2016) shows that nondeposit bank debt also benefits from

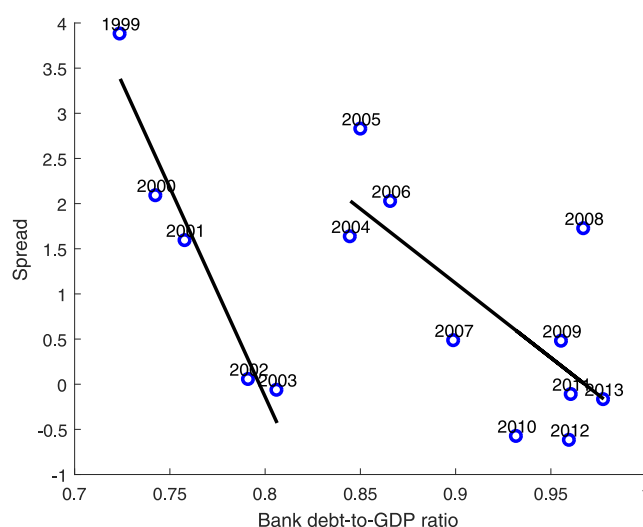


Fig. A.1. Evidence of a convenience yield on bank debt.

The figure plots the spread between the Aaa corporate bond rate and the implied interest rate on aggregate bank debt adjusted for the term spread between a 20- and 1-year zero-coupon Treasury bond (y axis) against the bank debt-to-GDP ratio (x axis) based on annual observations from 1999 to 2013 (blue circles). The black lines represent the fitted regression lines based on an ordinary least squares (OLS) regression for two different subsamples, a pre-2004 monetary policy tightening sample, and a post-2004 monetary policy tightening sample. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

implicit government guarantees. Extending the definition of liquidity-providing bank liabilities beyond deposits is also important because large banks rely much more on nondeposit credit market borrowings.

The reduced-form modeling of a demand for bank debt in Eq. (8) is akin to that in [Poterba and Rotemberg \(1986\)](#) and [Christiano et al. \(2010\)](#). [Sidrauski \(1967\)](#) money-in-the-utility specifications have been used to capture the benefits from money-like-assets for households in macroeconomic models.⁸ [Feenstra \(1986\)](#) shows the functional equivalence of models with money-in-the-utility and models with transaction costs.

A1.2. Banks monitoring and risk choice

Banks monitoring enhances the efficiency of the bank-dependent production sector. Since [Schumpeter \(1939\)](#), monitoring has been viewed as one of the key roles of banks in the economy. In a seminal paper, [Diamond \(1984\)](#) formalized this idea. In [Holmstrom and Tirole \(1997\)](#), firms and banks have incentives not to exert the optimal amount of effort. While lending to firms is subject to the standard moral hazard problem, the monitoring choice of banks may not be optimal when banks have private information. [Tirole \(2006, p. 360\)](#)⁹ shows that a simple way to introduce a variable monitoring intensity is by assuming convex monitoring costs.

In practice, bank monitoring most commonly occurs in the form of loan covenants (e.g., [Diamond, 1984](#)) that restrict how borrowers can operate ([Drucker and Puri, 2009](#)). Empirical evidence shows that loan covenants generally improve firms performance ([Demiroglu and James, 2010](#)).¹⁰

The stochastic productivity term, described in Eq. (4), depends on banks' monitoring choice, m^B . More precisely, the monitoring choice of banks in t inversely determines the banks exposure to the aggregate banking sector shock, ϵ_t^B . When banks choose to monitor more, they lower their risk exposure to aggregate risk. As a counter-example, in the run-up to the recent financial crisis, flawed lending standards led to more subprime mortgage originations and higher vulnerabilities to house price shocks. For example, [Dell Ariccia et al. \(2012\)](#) show how poor lending standards went hand in hand with a subprime mortgage expansion.

A1.3. Motivation for subsidy function

The government subsidy to banks in the model has the feature of a government put. The subsidy payments increase with (1) banks size, (2) banks' leverage, and (3), indirectly, with banks risk-taking. I parameterize the

subsidy function in the following way:

$$TR\left(k^B, \frac{\tilde{e}}{k^B}\right) = \omega_1 k^B \exp\left(-\omega_2 \frac{\tilde{e}}{k^B}\right),$$

where k^B represents banks' risky assets, and $\tilde{e} = e + \pi$ represents equity after profits. Profits are a function of banks' risk choices.

The main paper analyzes how capital requirements affect banks' choices of the quantity and quality (via monitoring) of the credit supply and liquidity provision. The reduced-form subsidy function allows me to carry out this exact analysis without explicitly modeling endogenous default. Doing so keeps the model tractable. Alternative quantitative general equilibrium frameworks with endogenous default require me to abstract either from aggregate risk (see [Nguyen, 2014](#) for an endogenous default model without aggregate risk) or from analyzing the efficient scale of bank lending jointly with banks' risk choice. The reason for the latter is that tractable models of endogenous default expose firms, banks, and agents to idiosyncratic valuation shocks that can push them to default if their leverage is too high.¹¹ Unless the problem is scale invariant, such that the investment choice can be separated from the leverage choice, one must keep track of the whole size distribution of firms, banks, and agents in general equilibrium. Doing so is highly intractable in a model with several state variables. Ultimately, the first-order reason for adding a subsidy to the model, whether in reduced form or endogenized, is to capture banks' incentives to engage in excessive risk-taking, either indirectly through leverage or directly through a higher exposure to the aggregate shock. This choice depends on the sensitivity of the subsidy to leverage.

In the data, banks have limited liability and benefit from explicit (FDIC insurance) or implicit government guarantees.¹² Without government protection, the risk of default is reflected in borrowing costs. Instead, if the government acts as a backstop to banks, creditors do not require compensation for default risk, lowering the cost of debt financing.¹³ My model takes the presence of government guarantees as given. In the literature, government subsidies are typically justified based on financial stability concerns and the protection of small and unsophisticated bank creditors.

In the model, banks have unlimited liability but receive a subsidy that depends on leverage after profits \tilde{e}/k^B . The

⁸ Another way of eliciting a liquidity demand from households includes a shopping time technology.

⁹ [Tirole \(2006\)](#) variable monitoring intensity model is based on the model of [Pagano and Röell \(1998\)](#).

¹⁰ Too much monitoring also can occur ([Burkart et al., 1997](#)). Too tight covenants (e.g., because of bank-specific default experience as in [Murfin, 2012](#)) can restrict borrowers' ability to undergo value-enhancing projects and restrict investment ([Chava and Roberts, 2008](#)). Empirically, too much monitoring does not seem to be a major concern in the banking sector. For this reason, the monitoring function $G(m^B)$ is strictly increasing in m^B . However, this is without loss of generality.

¹¹ Endogenous default can be modeled with a constant mass of ex ante identical banks that have a scale independent optimization problem and are hit with iid valuation shocks. This leads a fraction of banks to default. To introduce default, [Elenev et al. \(2016\)](#) and [Begenau and Landvoigt \(2018\)](#) use a similar trick with idiosyncratic shocks to agents' utility and banks payoff function, respectively.

¹² During the financial crisis, bank regulators extended guarantees on bank liabilities. For example, they increased the insured amount of deposits and guaranteed 100% of senior unsecured debt through the [Temporary Liquidity Guarantee Program](#).

¹³ In the model, I take the presence of government guarantees as given. If the government could credibly commit not to bail out banks, the incentives for excessive risk-taking would be void, and the model's optimal capital requirement would be zero. This paper is silent on why these government bailout guarantees exist. The literature makes the case for both inefficient and efficient bailouts ([Chari and Kehoe, 2016](#)).

subsidy in the form of the transfer function captures the effect of a banking system that is considered “too-big-to-fail”.¹⁴ This has two consequences. First, default does not occur in equilibrium. Second, government guarantees effectively act as subsidies by lowering the debt financing costs for banks because default risks are not priced into the claims that banks issue.

I assume that the subsidy function is increasing in risk-taking (less monitoring), leverage, and size of the banking sector. The functional form also captures a complementarity between leverage and risk-taking via less monitoring. Finally, it also can be interpreted as capturing the value of tax rules that benefit debt over equity financing.¹⁵ The next section shows how these properties can be derived from first principles.

A1.4. Transfer function derivation from first principles

This section demonstrates how a model with an explicit default choice for banks and a government bailout implies a subsidy function that has the same shape as the reduced-form subsidy function used here.

Consider a two-period bank optimization problem that features the same technology used in the main model. In addition, banks have the option to default (limited liability), and the government bails out defaulting banks. Banks choose risk via their monitoring intensity m^B , given the value of equity e and assets k^B . From the balance sheet identity $e + s = k^B$, profits $\Pi(m^B, \epsilon) = Z^B(k^B)^v - \delta k^B - rs$ are only a function of the shocks and the monitoring choice through Z^B . The technology variable Z^B depends on banks' monitoring intensity m^B and the shock in the following way: $Z^B(m^B) = m^B Z^{B, \text{good}} + (1 - m^B) Z^{B, \text{bad}}$, where $Z^{B, \text{good}}$ and $Z^{B, \text{bad}}$ are defined as in the paper. The government pursues the following bailout policy:

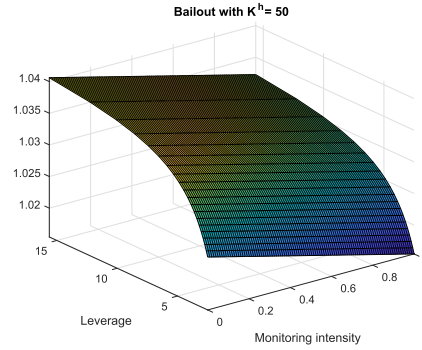
$$\text{Bailout} = \max\{0, -(e + \Pi)\}.$$

That is, it steps in as soon as banks realize losses that would have wiped out shareholders.¹⁶ As a result, banks have the following objective:

$$\max_{m^B} \mathbf{E}[(e + \Pi(m^B, \epsilon) + \text{Bailout})].$$

Thus, this objective is the expectation of the sum of the banks business part $e + \Pi(m^B, \epsilon)$ and the *Bailout* part. The value of the expected *Bailout* depends on m^B , k^B , and e .

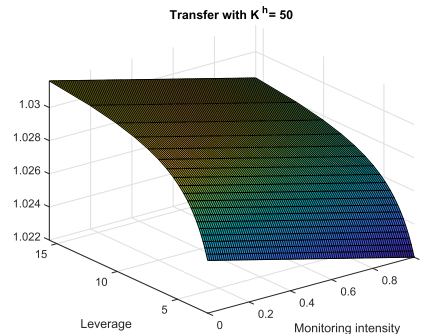
The following plot shows the value of the three-dimensional expected bailout function over different values of leverage k^B/e and m^B , holding the size of the bank k^B constant. The value of the expected bailout increases in leverage and m^B . Given the size of the bank and that leverage is given by the regulator through a binding capital constraint, the expected bailout only depends on risk-taking. If banks could freely choose leverage, they would maximize the value from the expected bailout by being highly levered and by taking on a lot of risk (i.e., they would monitor less).



This graph shows that the bailout is an increasing function of leverage, risk-taking, and assets with complementarities in leverage and risk-taking. In a model with limited liability of banks and government bailout, higher levels of leverage increase the probability of default and thus the likelihood that the government would need to step in and bailout the bank. Likewise, higher risk-taking by banks increases the probability of a default. And, finally, the absolute amounts of transfers, as measured by assets, are greater for larger banks. The payments by the government occurring in the future also can be expressed as a constant stream of subsidies that depends on equity after the realization of profits, risky assets, and risk-taking by banks. These variables would otherwise affect the probability of a default. The subsidy function thus becomes

$$TR\left(k^B, \frac{\tilde{e}}{k^B}\right) = \omega_1 k^B \exp\left(-\omega_1 \left(\frac{\tilde{e}}{k^B}\right)\right).$$

I find the ω parameters by minimizing the difference between the expected subsidy function and the expected bailout. With parameter values that are fairly close to the calibrated values, that is, $\omega_1 = 0.0140$ and $\omega_2 = 18.59$, the transfer function takes the following shape.



¹⁴ Bank owners have incentives to accept excessive risks when they have limited liability. In fact, equity claims are call options on bank assets, an analogy first discussed by Black and Scholes (1973). More risk increases the value of the call option. Gollier et al. (1997) show that the risk exposure of firms with limited liability is always larger than that of firms with unlimited liability. Pennacchi (2006) presents a model in which deposit insurance subsidizes banks, and banks can increase the subsidy by concentrating their loan portfolio on aggregate risk. Begenau et al. (2015) empirically demonstrate that commercial banks' use of derivatives increases the risk exposure of banks' balance sheet instead of hedging that exposure. Schneider and Tornell (2004) is one of the first papers to model the effect of bailout guarantees over the business cycle.

¹⁵ All firms in the United States can benefit from the tax subsidy on debt. But the tax advantage particularly matters for the financial sector who competes on small interest margins (Hanson et al., 2010).

¹⁶ Note that, in the data, the government tends to step in sooner (e.g., Wachovia was acquired by Wells Fargo in an FDIC-assisted process before it had even defaulted on its creditors).

In sum, the reduced-form subsidy function captures the shape of the bailout function that was derived from the first principles.

A2. Equilibrium conditions

This section presents the equilibrium conditions for the detrended model. The original variables, that is, Y_t , are decomposed into one part that is purely driven by the deterministic balanced growth path trend Γ and into another part that is the stochastic variation around that trend. That is, one can write $Y_t = \bar{Y}X_t \exp(\hat{y}_t)$, where \hat{y}_t is the log deviation from that trend. Eventually, I want to express the model in terms of the log deviation from its steady state. As a first step, I need to transform the original model by taking out the trend X_t . Also, I want to express the model in per capita terms by dividing all variables by N_t total economy hours. Because labor is measured in efficiency units, N_k generally represents effective hours per worker of nonbankers and bankers, respectively. The lowercase y denotes the trend stationary equivalent of Y (except for T , which denotes taxes).

The household utility is

$$U(c_t, s_t) = \log(c_t) + \theta \frac{(s_t/c_t)^{1-\eta}}{1-\eta},$$

and the resource constraint is

$$c_t + \Gamma k_t^f \left(1 + \varphi_f \left(\frac{i_t^f}{k_t^f} - \delta^*\right)^2\right) + \Gamma k_t^h \left(1 + \varphi_h \left(\frac{i_t^h}{k_t^h} - \delta^*\right)^2\right) = y_t^h + y_t^f + (1-\delta)k_{t-1}^f + (1-\delta)k_{t-1}^h - \frac{\kappa}{2}(d_t - \bar{d})^2,$$

where $\delta^* = (\Gamma - 1 + \delta)$. The equilibrium conditions are

$$M_{t+1} = \beta \Gamma^{-1} \left(\frac{\frac{1}{c_{t+1}} - \theta (s_{t+1})^{1-\eta} (c_{t+1})^{\eta-2}}{\frac{1}{c_t} - \theta (s_t)^{1-\eta} c_t^{\eta-2}} \right)$$

$$n_t = (1 + r_{t-1})s_{t-1} + (r_t^f + 1 - \delta)k_{t-1}^f - T_t$$

$$c_t + \Gamma s_t + \left(1 + \varphi_f \left(\frac{i_t^f}{k_t^f} - \delta^*\right)^2\right) \Gamma k_t^f + p_t \Theta_t$$

$$= n_t + (d_t + p_t) \Theta_{t-1} + w_t^f H^f$$

$$i_t^f = \Gamma k_t^f - (1 - \delta)k_{t-1}^f$$

$$E_t(M_{t+1})(1 + r_t) = \left(1 - \frac{\theta}{\Gamma} s_t^{-\eta} c_t^{\eta-1} \left(\frac{1}{\frac{1}{c_t} - \theta (s_t)^{1-\eta} c_t^{\eta-2}}\right)\right)$$

$$1 + \varphi_f \Gamma \left(\frac{i_t^f}{k_t^f} - \delta^*\right)^2 + 2\varphi_f \Gamma \left(\frac{i_t^f}{k_t^f} - \delta^*\right) (1 - \delta) \frac{k_{t-1}^f}{k_t^f} = E_t \left[M_{t+1} \left(r_{t+1}^f + \left(1 + 2\varphi_f \Gamma \left(\frac{i_{t+1}^f}{k_{t+1}^f} - \delta^*\right)\right) (1 - \delta) \right) \right]$$

$$1 = E_t \left[M_{t+1} \frac{(d_{t+1} + p_{t+1})}{p_t} \right]$$

$$w_t^f = (1 - \alpha) Z_t^f (k_{t-1}^f)^\alpha (H^f)^\alpha$$

$$r_t^f = \alpha Z_t^f (k_{t-1}^f)^{\alpha-1} (H^f)^{1-\alpha}$$

$$y_t^f = Z_t^f (k_{t-1}^f)^\alpha (H^f)^{1-\alpha}$$

$$y_t^B = \left(m_{t-1}^B Z_t^{B, \text{good}} + (1 - m_{t-1}^B) Z_t^{B, \text{bad}} \right) (k_{t-1}^B)^\nu$$

$$\log Z_t^f = \rho^f \log Z_{t-1}^f + \sigma^f \epsilon_t^f,$$

$$\log Z_t^{B,i} = \mu^{B,i} + \rho^{B,i} \log Z_{t-1}^{B,i} + \sigma^{B,i} \epsilon_t^{B,i} \quad \forall i \in \{\text{good}, \text{bad}\}$$

$$\pi_t = y_t^B - \delta k_{t-1}^B + r_{t-1}^{\text{gov}} b_{t-1} - r_{t-1} s_{t-1}$$

$$r_t^B = \nu \frac{y_t^B}{k_{t-1}^B}$$

$$e_t = \xi k_t^B$$

$$e_t = k_t^B + b_t - s_t$$

$$d_t = \tilde{e}_t - \frac{\kappa}{2} (d_t - \bar{d})^2 + TR \left(k_{t-1}^B, \frac{e_{t-1} + \pi_t}{k_{t-1}^B} \right) - \varphi_B \left(\frac{i_t^B}{k_t^B} - \delta \right) \Gamma k_t^B - \Gamma e_t - \frac{\phi_1}{2} (m_t^B)^2$$

$$\tilde{e}_t = \pi_t + e_{t-1}$$

$$\Lambda_t = s_t + e_t$$

$$TR \left(k_{t-1}^B, \frac{e_{t-1} + \pi_t}{k_{t-1}^B} \right) = \omega_1 k_{t-1}^B \exp \left(-\omega_2 \left(\frac{e_{t-1} + \pi_t}{k_{t-1}^B} \right) \right)$$

$$TR \left(k_{t-1}^B, \frac{e_{t-1} + \pi_t}{k_{t-1}^B} \right) + (1 + r_{t-1}^{\text{gov}}) b_{t-1} = \Gamma b_t + T_t$$

$$1 = \Lambda_t (1 + \kappa (d_t - \bar{d}))$$

$$i_t^B = \Gamma k_t^B - (1 - \delta) k_{t-1}^B$$

$$0 = \mathbf{E}_t [M_{t+1} \Lambda_{t+1} (r_{t+1}^{\text{gov}} - r_t)]$$

$$\mu_t = \Lambda_t \Gamma - \mathbf{E}_t \left[M_{t+1} \Lambda_{t+1} (1 + r_t) \left(1 - \omega_2 TR \left(1, \frac{\tilde{e}_t}{k_t^B} \right) \right) \right]$$

$$\mu_t \xi = -\Lambda_t \left(\varphi_B \Gamma \left(\frac{i_t^B}{k_t^B} - \delta^* \right)^2 + 2\varphi_B \left(\frac{i_t^B}{k_t^B} - \delta^* \right) \Gamma (1 - \delta) \frac{k_{t-1}^B}{k_t^B} \right)$$

$$+ \mathbf{E}_t \left\{ M_{t+1} \Lambda_{t+1} \left(\left(\nu \frac{y_{t+1}^B}{k_{t+1}^B} - r_t - \delta \right) \left(1 - \omega_2 TR \left(1, \frac{e_{t+1}}{k_{t+1}^B} \right) \right) \right. \right.$$

$$\left. \left. + 2\Gamma \varphi_B \left(\frac{i_{t+1}^B}{k_{t+1}^B} - \delta^* \right) (1 - \delta) + TR \left(1, \frac{e_{t+1}}{k_{t+1}^B} \right) \left(1 + \omega_2 \frac{e_{t+1}}{k_{t+1}^B} \right) \right) \right\}$$

$$\Lambda_t \phi m_t^B = \mathbf{E}_t \left[M_{t+1} \Lambda_{t+1} \left(Z_{t+1}^{B, \text{good}} - Z_{t+1}^{B, \text{bad}} \right) (k_{t+1}^B)^\nu \left(1 - \omega_2 TR \left(1, \frac{e_{t+1}}{k_{t+1}^B} \right) \right) \right]$$

Appendix B. Additional results

B1. Transition dynamics

Fig. B.1 shows how banks and consumption, output, and nonbank capital adjust from the old capital requirement equilibrium to the new capital requirement equilibrium over time. The y-axis refers to the percentage change from the equilibrium in the benchmark calibration.

B2. Additional welfare results

B2.1. Optimal capital requirement without transition dynamics

When transition dynamics are ignored, the optimal capital requirement is $\xi = 15\%$, as shown in Fig. B.2.

When transition dynamics are included, deposits fall by more than what is necessary to reach the new equilibrium. The reason is that capital accumulates slowly over time.

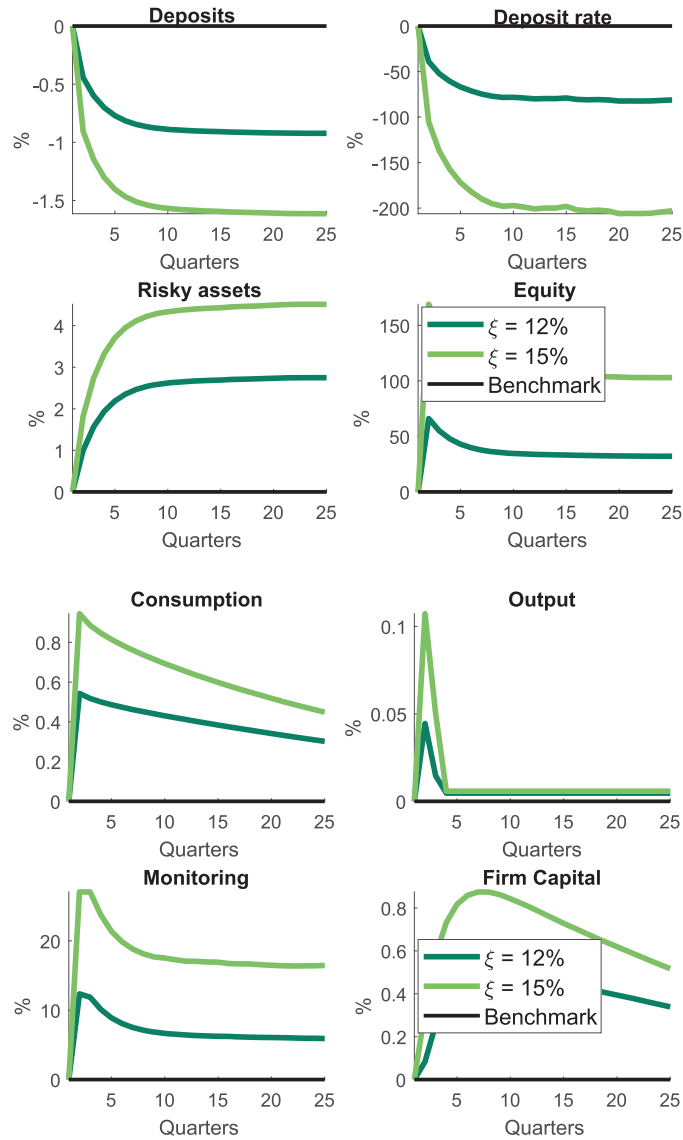


Fig. B.1. Transition dynamics.

This figure shows the transition dynamics (% deviation from the benchmark level over time) of the model following an increase in the capital requirement from the benchmark level to 12% or 15%.

When transition dynamics are not included, households do not suffer the initial reduction in deposits to reach the new steady state. This reduces the costs of an increase in the capital requirement, which results in a higher optimal level.

B2.2. Nonstochastic steady-state optimal capital requirement

Nonstochastic steady-state welfare depends on the capital requirement because ξ determines how much deposits and consumption are produced. The optimal amount of capital requirement in the steady state trades off the

increase (decrease) in consumption against the decrease (increase) in bank debt holdings from higher (lower) capital requirement. In the steady state, the optimal capital requirement is $\xi = 11\%$, which is lower than $\xi = 12.38\%$ because transition dynamics and aggregate shocks do not factor into the steady-state optimal capital requirement calculation. Welfare changes only modestly with ξ , so the reduction in volatility matters. Simply put, it is important to account for the effects of shocks and transition dynamics in the calculation of the optimal capital requirement level.

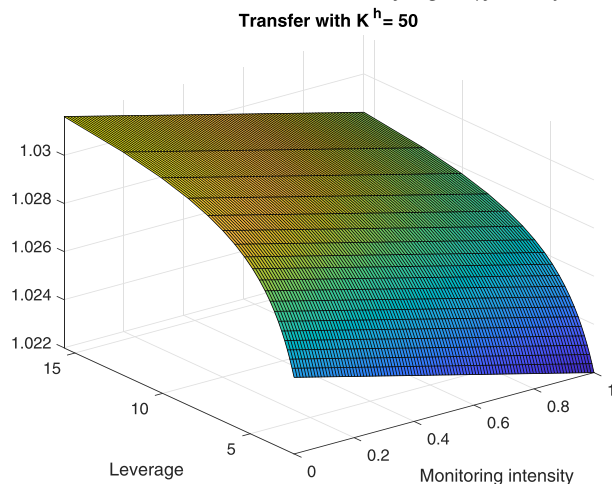


Fig. B.2. Optimal capital requirement without considering transition dynamics.

This figure shows household welfare in % consumption equivalent units as a function of the capital requirement.

Appendix C. Model dynamics

C1. Additional intuition for business-cycle facts

Table 6 contains business-cycle correlations for the model and compares them to the data. When η takes on a large value, households are less flexible about changes in the deposit-consumption ratio. When only the firm sector is hit by a positive shock, the marginal product of firm capital k^f is higher. This raises the opportunity costs for k^B and the rate at which shareholders want to be compensated. Without adjustment costs to capital or $\eta > 1$, the risky assets of banks immediately flow to firms at times when the productivity of capital in the firm sector is higher than in the banking sectors, producing a negative correlation between balance sheet variables and total GDP. Adjustment costs make it expensive to change the current stock of capital in either sector and therefore slow down the response of the model to shocks.

C2. Cross-correlations

In this section, I discuss additional implications of the dynamic model and the fit of the model with the data. The benchmark calibration sets the capital requirement to $\xi = 9.25\%$. I simulate the model 1000 times for 300 periods. Half of the observations are discarded. Then I apply the HP filter with a smoothing parameter of 1600 to the remaining simulated data points. I use these data to compute the correlations reported in Table C.2.

Table C.2 summarizes the cross-correlations of the model and compares them to the data. Overall, the model produces the correct signs of the correlations besides the following exceptions. Because banks are at the capital constraint, movements in bank capital stock, k^B , are perfectly correlated with movements in deposits, s . The correlations of equity with assets appear more procyclical in the model than in the data for the calibration sample (1999–2016). When computing the correlation between

Table C.2
Correlations, 1999 Q1–2016 Q4.

	y^B		Inv.		A		s		k^B		\tilde{e}		d		a		c		π		i^B	
	D	M	D	M	D	M	D	M	D	M	D	M	D	M	D	M	D	M	D	M	D	M
y^B	1																					
Inv.	0.54	0.46	1																			
A	0.33	0.81	0.25	0.20	1																	
s	0.28	0.81	0.20	0.20	0.99	1																
k^B	0.59	0.81	0.41	0.20	0.90	1																
\tilde{e}	0.32	0.99	0.27	0.42	-0.03*	0.86																
d	0.26	1	0.37	0.46	-0.23*	0.78																
i^B	0.91	0.76	0.62	0.55	0.37	0.81																
c	0.70	0.16	0.82	0.79	0.27	0.10																
π	0.30	0.96	0.36	0.45	-0.27	0.65																
i^B	0.30	0.79	0.43	0.36	0.20*	0.33																

This table displays the business-cycle correlations of model (M) objects and compares them to their data (D) counterparts. Variables: HP-cycle component of logged variable/GDP trend; HP smoothing = 1600. * $p < 0.05$; a Variables: HP-cycle component variable/GDP trend; y^B , bank-dependent sector output; A, assets; k^B , risky banking assets; \tilde{e} , equity; d, dividends; c, consumption; π , banks profits; i^B , bank investments.

Table C.3
Business-cycle correlations data, 1984 Q1–2013 Q4.

	GDP	Bank inc.	Inv	Assets	Deposits	Risky as	Tier1	Equity	Dividend	Deposit	Cons.	A/E	Income	Profit
GDP	1													
Bank inc.	0.62	1												
Investment	0.93	0.53	1											
Assets	0.46	0.39	0.34	1										
Deposits	0.44	0.29	0.29	0.99	1									
Risky assets	0.54	0.64	0.52	0.88	0.88	1								
Tier1	−0.04*	−0.12*	0.00*	−0.27	−0.31	−0.22	1							
Equity	0.28	0.12*	0.26	0.24	0.14*	0.19	0.40	1						
Dividend	0.33	0.25	0.34	−0.07*	0.04*	0.07*	−0.08*	0.11*	1					
Deposit rate ^a	0.55	0.94	0.50	0.23	0.24	0.55	−0.12*	−0.03*	0.22	1				
Cons	0.89	0.54	0.80	0.49	0.46	0.51	0.03*	0.36	0.35	0.43	1			
A/E	0.09*	0.18*	0.06	0.51	0.60	0.48	−0.55	−0.71	−0.05*	0.20	0.04*	1		
Income/risky A	0.53	0.65	0.53	−0.12*	−0.16*	0.08*	0.20	0.29	0.39	0.60	0.51	−0.34	1	
Profit	0.23	0.09*	0.23	−0.20	−0.25	−0.20	0.41	0.46	0.24*	−0.04*	0.30	−0.55	0.72	1
Bank inv.	0.33	0.07*	0.34	0.23	0.21	0.18*	−0.04*	0.23	0.01*	0.01*	0.36	−0.04*	0.20	0.26

This table displays the business-cycle correlations in the data. Variables: HP-filtered cycle component of logged variable relative to GDP trend; HP smoothing = 1,600. * $p < 0.05$; ^a Variables: HP-filtered cycle component variable relative to GDP trend. Bank inc., bank income; A/E, leverage as assets over equity; Cons, consumption, Tier1, Tier 1 equity; Bank inv., denotes bank investment.

equity and assets in the data for the longer period from 1984 to 2013 (see the Appendix Section C.3), the correlation is significantly positive. In the model, risky assets and book equity are strongly correlated because the capital requirement is binding. This finding is consistent with the data, where the ratio of equity to assets is acyclical, implying that equity expands along with assets during booms. The model fails to capture the negative correlation between profits and assets, as well as bank debt and risky assets because the model produces excessive comovement of profits with GDP. As assets and profits move together along the business cycle, they also exhibit a positive cross-correlation in the model.

C3. Correlations over a longer sample, 1984–2013

Table C.3 presents the business-cycle correlations for the longer sample from the first quarter in 1984 to the last quarter of 2013. The model follows the data less closely for the correlations of dividends, profits, return over risky assets, and equity with balance sheet variables. Interestingly, it is for those variables that the correlation behavior has changed the most in the data over the 1984–2013 period. For instance, book equity covaries more with GDP, bank income, and investment over the period 1999–2013 than compared to the longer horizon. Book equity appears to be uncorrelated with balance sheet variables over the shorter horizon. Over the long horizon, book equity positively covaries with balance sheet variables in a significant way. Return over risky assets (as measured by income relative to risky assets) is negatively correlated in the shorter sample with balance sheet variables but acyclical in the longer sample. Profits have a lower negative correlation with balance sheet variables in the longer sample. Dividends correlation coefficient becomes zero and insignificant. The correlation coefficients of those variables that are reasonably well matched by the model are also more stable across sample periods.

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