

Bank Capital Regulation in a Zero Interest Environment

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Abstract

How does the zero lower bound on deposit rates (ZLB) affect (optimal) bank capital regulation and risk taking? I study these questions in a tractable dynamic equilibrium model, in which forward-looking banks compete imperfectly for deposit funding, and limited liability may induce excessive risk taking. If deposit rates are occasionally constrained by the ZLB, optimal capital requirements vary with the level of interest rates, where low rates motivate weaker requirements despite overall higher risk taking. The reason is that the ZLB makes capital regulation less effective in curbing risk shifting incentives, as tight capital requirements erode franchise value when banks cannot pass on the cost of capital to depositors. The model highlights a novel interaction between monetary and macroprudential policies, and shows that it may be desirable to complement existing regulation with policy tools that subsidize the funding cost of banks at the ZLB.

Keywords. Zero lower bound, search for yield, capital regulation, bank competition, risk shifting, franchise value

JEL classifications. G21, G28, E43

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1. Introduction

During the past decade, interest rates across advanced economies have been at historical lows, where they are likely to remain for a sustained period of time. Recent contributions show that low interest rates can induce investors to take more risk in a “search for yield” (e.g. [Rajan, 2005](#); [Martinez-Miera and Repullo, 2017](#)), and highlight their consequences for macroeconomic outcomes when monetary policy becomes constrained by the zero lower bound (ZLB) (e.g. [Eggertsson and Woodford, 2003](#); [Eggertsson and Krugman, 2012](#)). An open question remains how such a low-rate environment affects banking and financial regulation. In this paper, I tackle this question using a dynamic general equilibrium framework and analyze how the ZLB affects (optimal) bank capital regulation and risk taking.

The question addressed in this paper is important because the ZLB seems to be a particularly relevant constraint for commercial banks. For example, even with interbank rates below zero, retail deposits have been shielded from negative rates in the Eurozone ([Heider et al., 2016](#)).¹ In section 2 I present similar evidence for U.S. banks, and argue that fees do not overcome the problem either, as they are not a per-unit price and quantitatively extremely small relative to the growing deposit base of banks.² In sum, low interest rates undermine the profitability of a banks’ deposit franchise, particularly when the ZLB constrains banks from passing on low asset returns to depositors (see further evidence in section 2, as well as [Drechsler et al., 2016](#)).

How do banks react to this environment of near-zero interest rates and compressed margins, and what are the implications for the ongoing debate about the optimal level of bank capital requirements (e.g. [Van den Heuvel, 2008](#); [Begenau, 2016](#))? I study these questions in a tractable dynamic equilibrium model with endogenous deposit competition and bank failures, in which the risk taking incentives of forward-looking banks are determined by their franchise value ([Hellmann et al., 2000](#)). The model endogenizes several elements relevant to bank capital regulation, yet remains tractable and allows to pin down analytically how the level of interest rates affects risk taking incentives and their interplay with capital requirements. I also calibrate the model to U.S. data and quantify optimal (welfare-maximizing) capital requirements in the presence of an occasionally binding ZLB constraint.

The main take-away from the model is that low interest rates may not only increases bank

¹While there are some cases of banks charging negative rates, a majority seems hesitant to do so. This seems to be particularly true for retail deposits, which may more easily substitute towards cash. Perhaps behavioral biases play a role too, as retail customers may perceive negative rates as unfair.

²While banks have been increasing fees, low interest rates induce large deposit inflows. Therefore, fees *relative to deposits* have actually been falling.

risk taking per se, but that the ZLB can also make capital requirements less effective in curbing such risk taking incentives. The reason is that tight capital requirements erode franchise value when the ZLB constrains banks in passing on the cost of capital to depositors. As a result, optimal capital requirements vary with the level of interest rates, where low interest rates motivate weaker requirements despite overall higher risk taking. Intuitively, capital requirements are optimally lower when interest rates are near-zero and the ZLB renders them less effective. In contrast, when interest rates are high banks can better absorb tight capital requirements as their market power allows them to pass on the cost of capital to depositors.

In the model, firms produce output using capital as the only input and there are two investment technologies to produce new capital. Households can directly invest in creating new capital, which I interpret as investments in the financial market. Banks can also produce new capital, albeit at a higher cost (perhaps due to the cost of operating a branch network and complying with regulation). The bank's technology can be interpreted as loans to a bank-dependent sector.

Banks take the return on capital as given, but have market power on the funding side, where they set deposit rates under monopolistic competition, subject to a zero lower bound constraint.³ Households are willing to accept a lower return on deposits because deposits carry a liquidity service valued in their utility function.⁴

There is a moral hazard problem, because bank risk-taking is not contractible and shareholders enjoy limited liability. At the same time, banks stand to lose rents upon failure because they have market power. In balance, banks trade off the gains from shifting risk on depositors against the risk of loss of franchise value.

The representative household's discount factor moves around stochastically over time, generating variation in the level of interest rates.⁵ There is no other source of aggregate risk.

In a first step, I revisit the question whether low interest rates induce banks to take more risk - a concern that has first been articulated by [Rajan \(2005\)](#) during the run-up to the financial crisis of 2008. In contrast to other contributions in the search for yield literature (e.g. [Acharya and Plantin, 2016](#); [Martinez-Miera and Repullo, 2017](#)), a reduction in interest rates has little effect on bank risk taking, so long as deposit rates are not constrained by

³The ZLB constraint is assumed exogenously, but could easily be endogenized by introducing fiat money.

⁴Since equity carries no convenience yield and bank investments are costlier than in the financial market, bank capital is (socially) costly in the model.

⁵In particular, the discount factor alternates according to a two-state Markov process. A high-rate state represents "normal" times with interest rates well above zero, such as the period before the crisis in 2008. In the low-rate state deposit rates may be constrained by the ZLB, as from 2009-2015.

the ZLB. The reason is that market power allows banks to pass on reductions in interest rates to depositors and maintain relatively stable interest margins. That is, with a slack ZLB banks are not exposed to interest rate risk, in line with recent evidence (Drechsler et al., 2017a; Hoffmann et al., 2017). At the same time, lower discount rates boost franchise values, inducing banks to actually take *less* risk.

This result reverses when deposit rates are constrained by the ZLB, where any reduction in asset returns eats 1-1 into margins, eroding franchise value and hence increasing risk taking incentives. This effect is particularly strong if the yield curve flattens substantially and the ZLB is expected to bind for a long time. Moreover, even if the ZLB is slack in a given period, incentives are affected if it is possible that the economy transitions to a state with a binding ZLB in the future. This dynamic effect highlights that even after a rate “normalization” (e.g. the Fed started raising rates in 2015), the possibility of falling back to the ZLB in the future may still affect incentives.

As a next step, I examine how the ZLB affects (optimal) capital regulation. In the model, capital requirements limit the leverage banks can take, reducing risk taking incentives by increasing a banks’ “skin in the game” (Holmstrom and Tirole, 1997). However, at the ZLB a countervailing effect comes into play. When banks cannot pass on the cost of capital to depositors, tight capital requirements erode franchise value, with the perverse effect of increasing risk taking incentives. Via this negative franchise value effect, the ZLB reduces the overall effectiveness of capital requirements exactly during times when bank risk taking incentives are already heightened.

The franchise value effect has implications for optimal capital regulation, which trades off the gain from less bank risk taking against the loss of lower liquidity creation by banks. Calibrating the model to U.S. data and allowing for a state-dependent capital requirement, I find an optimal level around 7-8% if the ZLB is slack at all times. In contrast, if the ZLB binds occasionally, optimal capital requirements vary with the level of interest rates. Perhaps surprisingly, optimal requirements are *weaker* whenever the ZLB binds, even though risk taking incentives are already higher at the ZLB. The reason is that the franchise value effect makes capital regulation less effective at the ZLB, motivating a weaker requirement despite overall higher risk taking. At the same time, low *expected* profitability increase risk taking incentives, motivating tighter requirements when interest rates are high but may fall back to the ZLB again in the future.

These findings closely relate to the debate on counter-cyclical capital regulation, where capital requirements optimally vary with the business cycle.⁶ Here, optimal capital requirements

⁶The case for counter-cyclical requirements is often made in models with welfare-relevant pecuniary exter-

also vary with the state of the macro-economy, but they do so with the “interest rate cycle” rather than the business cycle.⁷ Because the model abstracts from business cycle dynamics, it thus delivers a novel rationale for cyclical capital regulation, distinct from the traditional view on counter-cyclical regulation.

The franchise value effect at the ZLB is also relevant for the debate on whether monetary policy should target financial stability. Some commentators argue that monetary policy should focus on targeting inflation, and let macro-prudential policies take care of financial stability (e.g. [Bernanke, 2015](#)). However, if very low interest rates undermine the effectiveness of prudential policies, the two cannot be set independently.

I consider as an alternative policy tool a subsidy per unit of deposits, paid to banks whenever the ZLB binds. Such a policy effectively supports interest margins, and restores prudence incentives as it stabilizes profitability.⁸ However, its overall effect on welfare is ambiguous because the taxes raised to fund the subsidy create an additional distortion.

1.1. Related Literature

This paper relates to several strands of the literature. First, it relates to recent contributions that study optimal capital regulation in dynamic general equilibrium models with banks ([Van den Heuvel, 2008](#); [Martinez-Miera and Suarez, 2014](#); [Begenau, 2016](#); [Davydiuk, 2017](#)). None of these papers addresses the main question in this paper, namely how the ZLB affects optimal capital requirements. Some distinct modeling features include bank market power and bank failures. Allowing for bank failure, risk taking is driven by franchise values, as banks stand to lose rents upon failure ([Hellmann et al., 2000](#)). Introducing market power ensures that banks have strictly positive margins and franchise values, and allows me to study the effect of weakened profitability at the ZLB.

The notion that franchise value affects risk taking is in line with several contributions in the banking literature (e.g. [Hellmann et al., 2000](#); [Perotti and Suarez, 2002](#); [Repullo, 2004](#); [Boyd and De Nicolò, 2005](#); [Martinez-Miera and Repullo, 2010](#)). To the best of my knowledge this paper is the first to incorporate this channel in a dynamic general equilibrium model.

nalities or aggregate demand externalities (e.g. [Lorenzoni, 2008](#); [Stein, 2012](#); [Korinek and Simsek, 2016](#)).

The argument in the policy debate is that buffers built up in good times should be available to be used in bad times (e.g. [Goodhart et al., 2008](#)), and relies on frictions to raising equity. In contrast, the rationale here is relevant even absent any frictions to raising equity and welfare-relevant pecuniary externalities.

⁷In fact, the model abstracts from business cycle dynamics, singling out the effect of the level of interest rate.

⁸One can think of this policy as broadly resembling policies that subsidize the funding cost of banks, such as the ECB’s targeted long-term refinancing operations or the Bank of England’s Funding for Lending and Term Funding schemes.

Closely related to this paper, [Hellmann et al. \(2000\)](#) argue that capital requirements should be complemented with interest rate ceilings, since otherwise capital requirements erode franchise value. Effectively, the ZLB has the opposite effect of an interest rate ceiling, imposing a minimum rate banks have to pay to depositors. In contrast to [Hellmann et al. \(2000\)](#), I find that capital requirements erode franchise value only if the ZLB binds, since otherwise market power allows banks to fully pass on the cost of capital.⁹

Also closely related, [Brunnermeier and Koby \(2016\)](#) introduce the concept of a “reversal rate”, below which monetary policy becomes ineffective. While the authors also highlight the negative effect of low interest rates on bank profitability, this paper has a distinct focus on risk taking and novel implications for bank capital regulation.

This paper also relates to the literature on “search for yield”, which argues that low interest rates result in an increase in risk taking ([Rajan, 2005](#); [Jiménez et al., 2014](#); [Dell Ariccia et al., 2014](#); [Martinez-Miera and Repullo, 2017](#); [Drechsler et al., 2017b](#); [Acharya and Plantin, 2016](#)). Closely related, [Heider et al. \(2016\)](#) show in a diff-in-diff setting that negative interest rates in the Eurozone have induced banks that rely relatively more on deposit funding to lend to relatively riskier borrowers.

Via the risk taking channel of monetary policy an increase in risk tolerance is an *intended* effect of low interest rates via portfolio rebalancing ([Borio and Zhu, 2012](#); [Choi et al., 2016](#)). This paper relates to this literature, but focuses on inefficient risk shifting as a result of agency problems.

Another recent related strand of literature analyzes how monetary policy affects the market power of banks ([Drechsler et al., 2016](#); [Scharfstein and Sunderam, 2015](#)) and shadow banks ([Xiao, 2017](#)). [Drechsler et al. \(2016\)](#) present a “Deposits Channel” of monetary policy, in which market power allows banks to pass on increases in the Fed Funds rate less than 1-1 to depositors. Relatedly, [Drechsler et al. \(2017a\)](#) and [Hoffmann et al. \(2017\)](#) show that market power in the deposit market also shields banks from interest rate risk, despite them engaging in maturity transformation. My model builds on these findings. As long as the ZLB is slack, banks can pass on changes in interest rates to depositors and maintain stable margins. The core results rely on the insight that this mechanism breaks down once the zero lower bound distorts deposit pricing. This notion is consistent with event studies around monetary policy announcements which find that falling interest rates negatively affect bank stock prices if and only if the ZLB binds ([Ampudia and Van den Heuvel, 2017](#); [English et al., 2012](#)).

Finally, this paper is related to the macroeconomic literature on the zero lower bound and

⁹Section 6.1 discusses the differences to [Hellmann et al. \(2000\)](#) in more detail.

liquidity traps (e.g. Keynes, 1936; Krugman, 1998; Eggertsson and Woodford, 2003; Eggertsson and Krugman, 2012; Guerrieri and Lorenzoni, 2017). While this literature focuses on monetary and fiscal policy, this paper shows that the ZLB may also constrain the effectiveness of prudential regulation. In fact, I study the implications of the ZLB in a real model, in which interest rates clear the savings-investment market. The economy here can therefore be interpreted as one in which the price level and inflation expectations are fixed.

The rest of the paper is organized as follows. Section 2 presents motivating evidence. Section 3 describes the model setup, equilibrium and calibration. Section 4 discusses the framework's assumptions and inefficiencies, and section 5 studies the determinants of bank risk taking in the model. Section 6 derives optimal capital regulation, shows how it is affected by the ZLB, and discusses alternative policy options. Finally, section 7 concludes.

2. Motivating Evidence

This section summarizes three motivating empirical facts: (i) banks are hesitant to pass on negative interest rates to depositors; (ii) fees are too small relative to the deposit base of banks to overcome the problem, and falling; (iii) since the ZLB started binding in 2009, interest margins and bank profitability have shrunk, in particular for banks with a lot of deposit funding.

For selected years, figure 1 plots the cross-sectional distribution of U.S. banks' deposit interest expense per unit of deposit funding.¹⁰ Before 2009, the mean shifts around with the level of interest rates, but the shape of the distribution changes little (see appendix B for additional years). As the ZLB starts binding in 2009 the distribution becomes increasingly right-skewed, suggesting a distortion in deposit pricing as interest rates bunch near zero. This notion is confirmed by FDIC data showing that the average rate on savings accounts has been near zero since 2009 (not reported here, see the FDIC website). Heider et al. (2016) find similar evidence for the Eurozone, suggesting that many banks are unable or unwilling to lower deposit rates into negative territory, even when interbank rates fall below zero.¹¹

When banks cannot pass on falling interest rates to depositors, their margin between asset returns and cost of funding shrinks. This is illustrated in the right panel of figure 2, which plots

¹⁰Following Drechsler et al. (2016), the interest expense ratio is calculated using Call Reports data (series riad4170 divided by rcon2200). Due to the short maturity of deposits it is a good approximation for the current interest rate a bank offers on deposits.

¹¹Anecdotal evidence suggests that the reason banks are hesitant to set negative interest rates on retail deposits is that they are concerned about triggering a bank run.

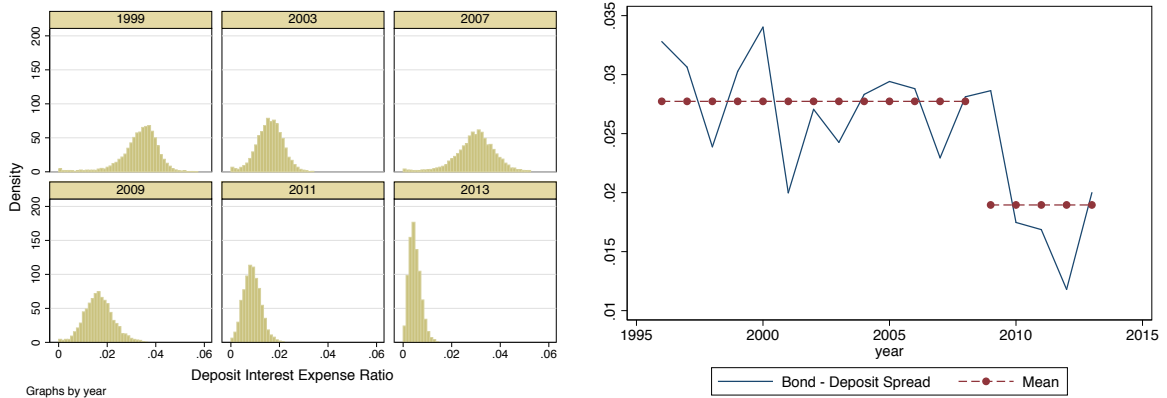


Figure 1: For selected years from 1999-2013, the left panel plots the cross-sectional distribution of deposit interest expense per unit of deposit funding across U.S. banks in the Call Reports data. The deposit interest expense ratio is defined as interest expenses per unit of deposits. The right panel plots the spread between the BofA Merrill Lynch US Corporate AAA Effective Yield (retrieved from FRED) and the interest expense per unit of deposit funding of the median U.S. bank.

the spread of corporate bond yields over median deposit interest expense.¹² Notwithstanding swings in the level of interest rates, the spread averages around 2.75% until 2008. Thereafter, a clear compression in the spread is visible, as the ZLB starts binding in 2009.

This comparison shows that for investments in an asset class with a given level of risk, deposit-funded banks earn relatively less at the ZLB. Relative to bank-level measures of interest income, this measure has the advantage that it is not confound with endogenous higher risk taking by banks. Still, appendix B shows that the spread between bank-level interest income and deposit interest expense follows a similar pattern, dropping around 2007 (though to a lesser extent).

Even if banks are unable to set negative interest rates on deposits, they may be able to do so effectively by increasing fees. By revealed preference, if the two were equivalent banks should have charged fees rather than interest rates also away from the ZLB. Arguably, the problem is that unlike interest rates, fees are not proportional to an account's balance. Already on a low level, service charges on deposits earn a small number of around 0.37% relative to deposits before 2008. Perhaps surprisingly, this number has actually been coming down in recent years, dropping below 0.25% (figure 2). While banks have been increasing fees (Azar et al., 2016), more deposits have been flowing into the banking system at the same time. Intuitively, in a low interest environment households gain little from hunting yield in

¹²The interest expense ratio is calculated using Call Reports data (series riad4170 divided by rcon2200). Due to the short maturity of deposits it is a good approximation for the current interest rate offered on deposits. The bond yield is the BofA Merrill Lynch US Corporate AAA Effective Yield, retrieved from FRED.

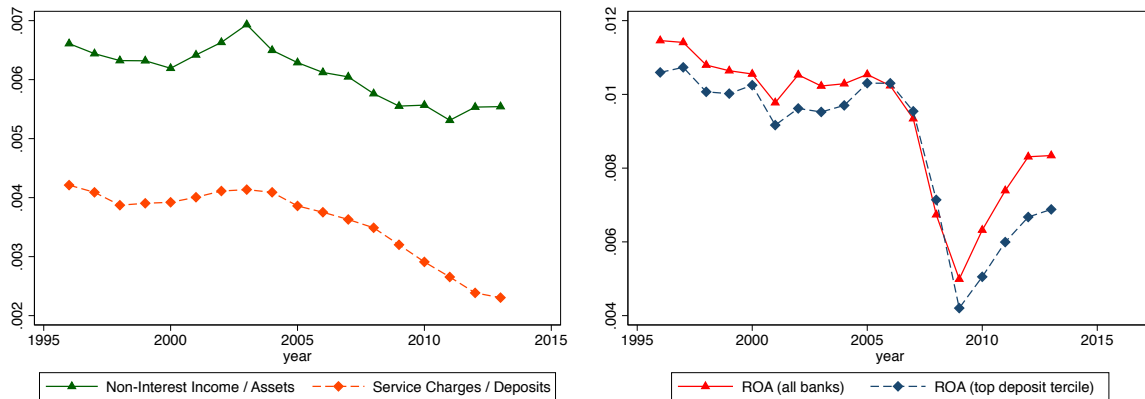


Figure 2: The left panel plots non-interest income per unit of assets, as well as service charges per unit of deposits for the median U.S. bank in the Call Reports data. Figure 10 in the appendix reports histograms for additional years. The right panel plots the median ROA (defined as net income over assets), separately across all banks and across banks in the top tercile of deposits /assets.

other investment opportunities, and might as well store their savings in deposit accounts that guarantee absolute safety.

Fees and other forms of non-interest income are therefore small and falling, especially relative to the net interest income of banks, which averages around 3.9% over the period 1984-2013. As a consequence, the overall ROA (net income over assets, including all income and expense) of the median U.S. bank has been significantly lower since the ZLB started binding in 2009, see the right panel of figure 2. The figure also shows that the drop in ROA is concentrated among those banks that rely most heavily on deposits funding, which arguably are most exposed to the ZLB constraint.

Overall, the evidence suggests that the zero lower bound on deposit rates binds, and that it has a negative effect on interest margins and bank profitability. Motivated by this evidence, the rest of this paper develops a model to understand how the zero lower bound affects bank risk taking incentives and capital regulation.

3. Model Setup

In the model, time runs discretely from $t = 0, \dots, \infty$. A representative household invests in bank deposits and the financial market, where deposits generate additional utility because they provide liquidity services.

Firms produce output using capital as the only input. There are two technologies to produce new capital, one operated by households, and the other by banks. The former

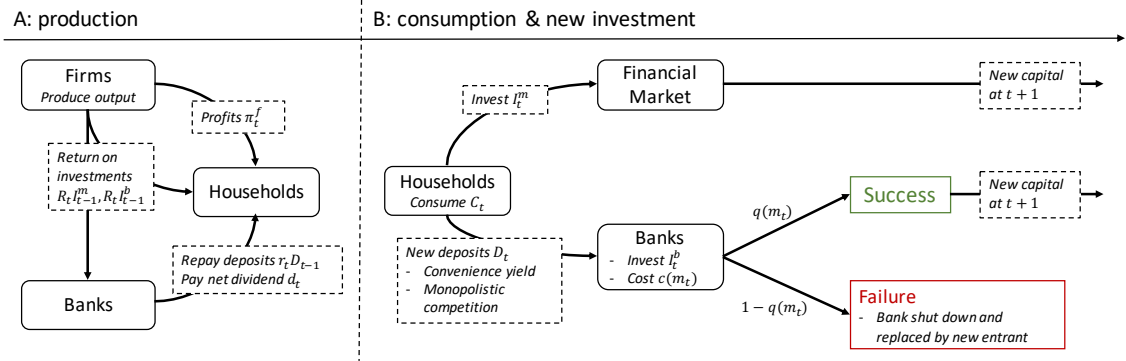


Figure 3: Flow diagram summarizing the within-period timing.

technology represents bank-independent finance, where households directly fund investments through the financial market. Capital produced by banks can be interpreted as bank loans that fund the investment of bank-dependent firms or mortgages. In the remainder I adopt these interpretations, and refer to the technologies as the financial market and bank loans, respectively.¹³

Banks compete monopolistically for deposit funding, subject to a zero lower bound on deposit rates.¹⁴ Banks affect the riskiness of their portfolio by choosing the (non-contractible) monitoring intensity, and are subject to a capital requirement that limits the leverage they can take.

The main focus of the paper is on how the level of interest rates affects risk taking and optimal capital regulation, in particular when the ZLB binds. To generate stochastic variation in interest rates, the household's discount factor varies according to a 2-state Markov process.

The flow diagram in figure 3 summarizes the timing within a period t . In the beginning of period t (stage A) firms produce output and pay households and banks a return on their investments made at $t - 1$. Banks use the proceeds to repay depositors and pay a dividend, and firms return their profits to households. Afterwards (stage B), households consume and new investments are made.

In the following I describe the individual elements of the model in more detail, solve the problem of firms, households, and banks, define the equilibrium and describe how I calibrate the model.

¹³In the real world, banks lend to firms which in turn make physical investments. Leaving out this extra layer of capital producing firms is equivalent to assuming that there are no frictions between them and banks.

¹⁴Here, the ZLB is exogenously assumed, but it can be motivated by the option to hoard cash with a net return of zero. In this paper, the ZLB plays the role as an off-equilibrium outside option, and its exact motivation is irrelevant.

3.1. Firms

A representative firm operates a production technology and produce output using capital K_t as the only input,

$$F(K_t) = K_t^\alpha,$$

where $\alpha < 1$. Capital is owned by firms, which start with an initial capital stock K_0 . In subsequent periods, capital depreciates with a rate δ and firms buy new capital K_t^{new} from households and banks, such that the capital stock evolves according to

$$K_t = (1 - \delta)K_{t-1} + K_t^{new}.$$

Denoting by R_t the return on newly produced capital, firm profits in period t can be written as

$$\pi_t^f = F(K_t) - R_t K_t^{new}.$$

The firm problem is to maximize expected profits, discounted by the household's stochastic discount factor β_t :

$$\max_{K_t} \mathbb{E}_0 \sum_{t=0}^{\infty} \left(\prod_{\tau=0}^{t-1} \beta_\tau \right) \pi_t^f. \quad (1)$$

The first order condition relates the return on capital to its marginal productivity:

$$R_t[1 - \beta_t(1 - \delta)] = F_K(K_t). \quad (2)$$

3.2. Household Problem and Liquidity Demand

An infinitely-lived, representative household maximizes her lifetime utility over consumption C_t and liquidity services from deposits D_t . Households have a preference for different varieties of bank deposits indexed by $i \in [0, 1]$. Different varieties could represent a bank specializing in online banking, a big international bank with a prestigious brand, or a local bank with personal relations between clients and advisors. Alternatively, varieties can represent different locations and banks differentiate spatially. Following [Dixit and Stiglitz \(1977\)](#) I model this preference by expressing D_t as a CES composite of varieties $D_{t,i}$,

$$D_t = \left[\int_0^1 D_{t,i}^{\frac{\eta-1}{\eta}} di \right]^{\frac{\eta}{\eta-1}}.$$

Product differentiation gives banks some market power, the degree of which is governed by the elasticity of substitution η .¹⁵ Higher values of η indicate greater ease of substitutability

¹⁵Arguably, bank market power is not only driven by product differentiation, and for example customer "stickiness" is likely another important determinant. The advantage of the Dixit-Stiglitz model of monopolistic competition is that it is quite tractable in general equilibrium. It is commonly used in the macro literature, and has recently gained popularity in the banking literature (e.g. [Drechsler et al., 2016](#)).

between varieties, implying lower market power. I assume that $\eta > 1$, such that deposits of different banks are substitutes.

Next to deposits, households can invest in the financial market I_t^m , to produce capital goods that are sold to firms in the following period. Households are also the owners of firms and banks. Firms rebate their profits π_t^f , and banks make a net dividend payment d_t^b , which may take negative values when raising new equity.

The household's discount factor β_t evolves according to a two-state Markov process. At the beginning of each period, households learn whether $\beta_t = \beta_H$, resulting in high interest rates (state $s = H$), or $\beta_t = \beta_L > \beta_H$, resulting in low interest rates (state $s = L$). The probability of transitioning from state s to s' is denoted $P_{ss'}$.

Utility is linear in consumption C_t and concave in deposits D_t ,¹⁶ and the problem of the representative household is given by

$$\begin{aligned} \max_{C_t, I_t^m, D_{t,i}} \quad & \mathbb{E}_0 \sum_{t=0}^{\infty} \left(\prod_{\tau=0}^{t-1} \beta_{\tau} \right) [C_t + \gamma v(D_t)] \\ \text{with} \quad & D_t = \left[\int_0^1 D_{t,i}^{\frac{\eta-1}{\eta}} di \right]^{\frac{\eta}{\eta-1}}, \\ \text{s.t.} \quad & C_t + I_t^m + \int_0^1 D_{t,i} di = R_t I_{t-1}^m + \int_0^1 r_{t,i} D_{t-1,i} di + d_t^b + \pi_t^f, \\ & D_{t,i} \geq 0, \forall i. \end{aligned} \tag{3}$$

Here, $\gamma \geq 0$ measures the household's preference for liquidity services, and $v(D_t) = \log(D_t)$ is the "convenience" utility households derive from holding deposits. The deposit rate offered by bank i is denoted $r_{t,i}$. The first constraint is the household's budget constraint, and the second a non-negativity constraint on deposits.¹⁷ The first-order condition with respect to I_t^m yields the household's Euler equation

$$R_{t+1} \beta_t = 1. \tag{4}$$

Since β_t can only take two values, this condition implies that the economy is either in a high-rate environment with $R_{t+1} = 1/\beta_H \equiv R_H$, or a low-rate environment with $R_{t+1} = 1/\beta_L \equiv$

¹⁶The quasi-linear, separable preferences can easily be generalized to a general utility function $U(C_t, D_t)$. This formulation simplifies solving the model, as it implies that the return on capital R_t only depends on the current state.

¹⁷Note that due to log-utility the solution is always interior. I_t^m and C_t can take negative values (as in Brunnermeier and Sannikov, 2014). When $I_t^m < 0$, firms disinvest and return cash to investors. Negative consumption can be interpreted as working.

R_L . This property highlights the analytical attractiveness of the chosen utility function, namely that the return on capital is a function of the current state only.¹⁸

Next to the financial market, households invest in bank deposits. The demand for deposits of bank i is given by the first-order condition with respect to $D_{t,i}$:

$$D_{t,i}(r_{t+1,i}) = \left[\frac{1 - r_{t+1,i}/R_{t+1}}{\gamma v'(D_t)} \right]^{-\eta} D_t, \quad (5)$$

where I use that $\beta_t = 1/R_{t+1}$ by (4). Banks can attract more funding, the higher the deposit rate $r_{t+1,i}$ they offer, i.e. the lower the interest margin $R_{t+1}/r_{t+1,i}$. The elasticity of substitution η governs how elastic demand is with respect to deposit rates, as greater substitutability makes it easier for households to switch to competitors. Finally, the demand for deposits increases in the preference for liquidity services γ .

3.3. The Bank's Problem

In each period t , bank i sets its gross deposit rate $r_{t+1,i}$, and decides how much equity to contribute per unit of deposit, denoted $e_{t,i}$. Setting deposit rates, banks are subject to a zero lower bound constraint that requires $r_{t+1,i} \geq 1$. Moreover, there is an exogenous capital requirement \bar{e}_t , and regulation requires $e_{t,i} \geq \bar{e}_t$.

Each bank has access to a single project of variable scale I_t^b , that I interpret as bank loans. Note that since $e_{t,i}$ is expressed as capital *per unit of deposit*, the total investment scale of the project is $I_t^b = (1 + e_{t,i})D_{t,i}(r_{t+1,i})$. With probability $q(m_t)$, the project succeeds and produces one unit of capital per unit of investment, which can be sold to the representative firm in the following period. Success probabilities are i.i.d. across banks, such that there is no aggregate risk.

In case of failure, the project produces nothing and the bank fails. Shareholders enjoy limited liability, but failing banks cannot continue operating as they are shut down by the regulator. To keep the total number of banks constant, I assume that each failing bank may be replaced by a new entrant, but that the total number of bank licenses is limited by mass 1.¹⁹

¹⁸Arguably, variations in discount factors are not the main driver behind movements in interest rates. However, the goal here is not to explain why interest rates are low, and this formulation allows to study the implications of low interest rates while preserving tractability.

¹⁹Note that it is optimal for new banks to enter, since banks have market power and earn monopolistic rents.

Banks that do not fail in a given period pay a net dividend

$$d_t^b = \underbrace{[R_t(1 + e_{t-1}) - r_t]D_{t-1,i}(r_{t,i})}_{\text{net interest income}} - \underbrace{[e_t + (1 + e_t)c(m_t)]D_{t,i}(r_{t+1,i})}_{\text{cost of new loans}}, \quad (6)$$

which consists of the bank's net interest income (define as the net return on loans, after repaying depositors), net of the monitoring cost and equity it contributes to new loans. Newly created banks $d_t^b < 0$, because these banks have no interest income from previous loans and must therefore raise equity externally. Failing banks pay zero dividends as they are shut down.

The project's success probability increases in the monitoring intensity $m_t \geq 0$ chosen by the bank. In principle, $q(m_t)$ can be any function with $q'(m_t) \geq 0$, that is bounded by $\lim_{m_t \rightarrow \infty} q(m_t) \leq 1$, and $\lim_{m_t \rightarrow 0} q(m_t) \geq 0$. For concreteness I use as a functional form the CDF of the Standard Gaussian distribution, $q(m_t) = \Phi(m_t)$.²⁰ Banks incur a cost

$$c(m_t) = \psi_1 + \frac{\psi_2}{2}m_t^2$$

per unit of investment, which consists of two components. The parameter ψ_1 governs the overall cost of operating a bank, such as maintaining a branch network and costs of complying with regulation. The second term depends on the bank's monitoring intensity m_t , and creates a trade-off between risk and return.

The bank's monitoring intensity is not contractible. After raising deposit funding and choosing their leverage, banks hence set the level of m_t that maximizes their equity value, which generally does not align with the socially optimal level of m_t because shareholders enjoy limited liability.

A central element in the further analysis is the bank's franchise value V_t^b , which generally takes strictly positive values due to the market power of banks.²¹ To define the franchise value, it is useful to write the problem of a bank that did not fail in a given period recursively as:

$$V_t^b = \max_{r_{t+1,i}, m_t, e_t} d_t^b + q(m_t)\beta_t \mathbb{E}_t V_{t+1}^b \quad (7)$$

²⁰The advantage is that this function is well behaved and bounded between 0 and 1.

²¹When deposit rates are constrained by the ZLB, it may potentially be that the bank's franchise value turns negative. I do not study this case and focus on equilibria with $V_t^b \geq 0$

where dividends d_t^b are defined in (6), and subject to the following constraints:

$$m_t = \arg \max_{m_t} d_t^b + q(m_t)\beta_t \mathbb{E}_t V_{t+1}^b, \quad (8)$$

$$D_{t,i}(r_{t+1,i}) = \left[\frac{1 - r_{t+1,i}/R_{t+1}}{\gamma v'(D_t)} \right]^{-\eta} D_t, \quad (9)$$

$$e_t \geq \bar{e}_t, \quad (10)$$

$$r_{t+1,i} \geq 1. \quad (11)$$

Here, (9) is the demand for deposit variety i derived from the household problem, (10) is the regulatory capital requirement, and (11) is the ZLB constraint. Eq. (8) is an incentive-compatibility constraint characterizing the bank's non-contractible monitoring decision.

The bank's problem is solved "backwards", starting with the optimal monitoring choice for a given level of $r_{t+1,i}$ and e_t . The incentive-compatible m_t is characterized by the first order condition from (8):

$$c'(m_t)(1 + e_t)D_t = q'(m_t)\beta_t \mathbb{E}_t V_{t+1}^b. \quad (12)$$

Intuitively, the bank equates the marginal cost of monitoring on the left-hand side to the marginal benefit on the right-hand side. The higher the bank's expected franchise value $\mathbb{E}_t V_{t+1}^b$, the more intensely it monitors.

Note that the remaining FOC's w.r.t. e_t and $r_{t+1,i}$ may ignore their partial effect on m_t by the Envelop Theorem. Using the Envelope Theorem, the FOC w.r.t. e_t shows that banks always choose the minimum amount of equity consistent with the capital requirement, $e_t = \bar{e}_t$:

$$\frac{\partial V_t^b}{\partial e_t} = q(m_t)\beta_t R_{t+1} - (1 + c(m_t)) \leq 0. \quad (13)$$

The inequality follows from using that $\beta_t R_{t+1} = 1$, by the household's Euler equation (4). Banks choose the minimum level of capital because bank equity is privately and socially costly. As an alternative to bank equity, households can invest in the financial market, producing one unit of capital for one unit of investment. In contrast, a unit of bank loans has a higher cost ($1 + c(m_t)$). Hence, investments in bank equity are dominated, making it costly to put equity into banks.²² Note that this does not hold for deposits, as they carry a convenience yield.

The first-order conditions with respect to the deposit rate determines r_{t+1} :

$$r_{t+1} = \max \left\{ R_{t+1} \left[\frac{\eta - 1/q(m_t)}{\eta - 1} - \frac{\eta}{\eta - 1} \frac{(1 - q(m_t))e_t + (1 + e_t)c(m_t)}{q(m_t)} \right], 1 \right\}. \quad (14)$$

²²Note, however, that this does *not* imply that households are unwilling to hold bank stock. If bank stocks were traded, they would in fact do so at strictly positive values, reflecting the monopolistic rents banks earn. The subtle difference here is between raising new equity and the value of outstanding equity. While outstanding stocks are valuable, bank management would never voluntarily raise new equity funding.

In the first case in (14), banks set the deposit rate at an interior solution, proportional to the return on capital. Deposit rates are below R_{t+1} , as banks pass on their costs and charge a mark-up that depends on the elasticity of substitution between deposits η (a higher level of η implies less market power and hence higher deposit rates). If this interior solution is smaller than 1, the ZLB binds and the second case in the max-function applies.

Note that I dropped all i subscripts because in the remainder I focus on symmetric equilibria.

3.4. Equilibrium

The only state variables of the model are the capital stock K_t and the realization of the discount factor β_t . Both are known at the beginning of the period, and decisions are made subsequently. In the following equilibrium definition I focus on symmetric equilibria, in which all banks choose the same deposit rate and monitoring intensity.

Definition. *Given government policies $\{T_t, \bar{e}_t\}_{t=0}^{t=\infty}$, transition probabilities $P_{ss'}$, an initial state $s_0 \in \{H, L\}$, and an initial capital stock K_0 , a symmetric competitive equilibrium is a set of prices $\{R_t, W_t, r_t\}_{t=0}^{t=\infty}$ and allocations $\{K_{t+1}, I_t^m, I_t^b, C_t, D_t, e_t, m_t\}_{t=0}^{t=\infty}$, such that*

- (a) *Given an initial capital stock K_0 and prices $\{R_t, W_t\}_{t=0}^{t=\infty}$, firms maximize profits (1).*
- (b) *Given prices $\{R_t, W_t, r_t\}_{t=0}^{t=\infty}$, households maximize lifetime utility solving (3).*
- (c) *Given prices $\{R_t\}_{t=0}^{t=\infty}$, banks maximize net dividends solving (7).*
- (d) *Market clearing is satisfied at any time $t \geq 0$*

- *aggregate resource constraint:*

$$C_t + I_t^m + I_t^b(1 + c(m_t)) = F(K_t),$$

- *capital:*

$$K_t = (1 - \delta)K_{t-1} + K_t^{new},$$

with

$$K_t^{new} = I_{t-1}^m + q(m_t) \underbrace{(1 + e_{t-1})D_{t-1}}_{=I_{t-1}^b}.$$

The set of equations describing the equilibrium is summarized in Appendix A.1. The forward-looking nature of the bank's problem and the occasionally binding ZLB constraint potentially complicate solving the model. However, owing to the simple stochastic structure and linear utility function, the equilibrium values of all variables relevant for the bank's

forward-looking problem (R_t, e_t and D_t) depend on the current state only, i.e. they are memory-less and independent of the time period t .²³ This property simplifies solving the forward-looking bank problem, as it allows to express the expected franchise value as

$$\mathbb{E}_s V_{t+1} = P_{ss'} V_s + (1 - P_{ss'}) V_{s'}.$$

Thereby, one can find the bank's value function by simply solving a system of non-linear equations. For ease of notation I denote the value of a memory-less variable x_t in state s simply as x_s , and the expectations given state s as $\mathbb{E}_s x_{t+1} \equiv \mathbb{E}_t[x_{t+1}|s]$.²⁴

3.5. Calibration

I derive as many results as possible analytically, but also rely on a numerical solution when analytics are ambiguous, as well as for the quantification of optimal capital requirements in Section 6. For this purpose, I calibrate the model to U.S. data. The calibration also allows me to get a sense for the magnitude of the effects.

I think of the high-rate state as “normal times”, with safe, short term rates away from the ZLB, such as the period from the 1990s until the financial crisis in 2008. Accordingly, I set $\beta_H = 0.95$ to generate a return on capital of around 5.5%, which is equal to the average yield on AAA corporate bonds over the period 1996-2008, as reported in FRED.²⁵ The level of rates in the low-rate state is one of the main comparative statics of interest. In the baseline calibration, I set $\beta_L = 0.975$ to target the average AAA corporate bond yield over 2009-2013 at around 2.5%.

Regarding aggregate Macro moments, I set $\delta = 0.065$, equal to the average depreciation rate of the U.S. capital stock from 1970-2016, computed using the BEA's Fixed Assets Tables 1.1 and 1.3. Using the same data and period, I compute an average capital-output ratio of 3.25. Accordingly, I set $\alpha = 0.38$, such that $K_H/Y_H = 3.25$ in the high-rate state.

Next, I set the capital requirement s.t. $\bar{e}_t/(1 + \bar{e}_t) = 0.085$, equal to the minimum requirement for the Tier 1 capital ratio in the Basel III framework.

To calibrate the cost function parameters I first set $\psi_1 = 0.018$. This is equal to the median bank's ratio of non-interest expenses to assets, calculated using Call Reports data over the

²³In fact, the equilibrium values of all variables except for I_t^m and C_t are memory-less.

²⁴With non-linear utility, the model can be solved globally by value function iteration. This would require iterating back and forth between the household problem and the bank problem, taking into account equilibrium conditions.

²⁵BofA Merrill Lynch US Corporate AAA Effective Yield© [BAMLC0A1CAAAY], retrieved from FRED, Federal Reserve Bank of St. Louis; <https://fred.stlouisfed.org/series/BAMLC0A1CAAAY>.

period 1984-2013. The parameter ψ_2 is the cost of monitoring. Hence, it governs bank risk taking, and I set it to get an equilibrium $q(m_H)$ of roughly 0.9924 in the high-rate state. This way, the success probability is in line with the average annual proportion of banks failing in the U.S., computed to be 0.76% by Davydiuk (2017) using the Failed Bank List issued by the FDIC.

The elasticity of substitution η affects bank market power and hence interest margin $R_H - r_H$. Following Drechsler et al. (2016) I use Call Reports data to proxy deposit rates as the deposit interest expense per unit of deposits. Similarly, I calculate the interest income rate as the ratio of interest income over total assets, and the interest margin as the difference between interest income and expense ratio. The average interest margin over the period 1996-2008 is 3.5%, consistent with a value of $\eta = 5$.

Given the calibration of the bank variables I set the parameters γ and θ governing the preference for liquidity. Doing so, I target the ratio of aggregate deposit liabilities of U.S. chartered institutions to the aggregate debt instruments of non-financial corporates using data from the Flow of Funds. This is only one moment to set two parameters. Accordingly, I first restrict $\theta = 1$, the log case, and then set $\gamma = 0.003$ to get a ratio ratio of $D_H / (D_H + K_H^m) = 0.2$, consistent with the Flow of Funds data.

Finally, in the baseline calibration I set the transition probabilities equal to $P_{HH} = 0.9$ and $P_{LL} = 0.8$. This implies an expected duration of 10 years spent in the high-rate state, and 5 years in the low-rate state. For comparison, the Federal Funds Rate target range was at 0% for seven years, from December 2008 to December 2015. All parameter values are summarized in table 1 in appendix A.2.

4. Discussion of the Framework and Inefficiencies

To preserve tractability I make several assumptions, and abstract from some realistic elements. I elaborate on these here, discuss the inefficiencies present in the model, and compare the competitive to the first best equilibrium.

4.1. Discussion of the Framework

Convenience yield. The money in the utility approach assumes a social value of bank debt. While a shortcut, the banking literature has identified several micro-foundations that motivate this assumption. Because bank debt is information-insensitive, it protects depositors from better informed traders (Gorton and Pennacchi, 1990; Dang et al., 2017). Its demandability

may incentivize monitoring (Diamond, 1984), and facilitates the transformation of risky long-term assets into liquid and safe claims (Diamond and Dybvig, 1983; Ahnert and Perotti, 2017). Moreover, banks invest into ATM networks and electronic payment infrastructure that make deposits a convenient medium of exchange.

Bank costlier than the financial market. It is costlier for banks to produce new capital goods than it is via the financial market. This assumption ensures that it is socially costly to provide equity to banks, as the financial market provides a superior outside option, i.e. that the banks' FOC w.r.t. equity (13) is negative. It ensures a meaningful trade-off between overcoming moral hazard and the cost of bank equity, and can be interpreted as operating costs such as the costs of operating a branch network and complying with regulation.

One might expect that the convenience yield of deposits already makes bank equity costly. This would only hold in a model in which the balance sheet size of a bank is fixed and the relevant opportunity cost is the interest paid on deposits. If instead banks can expand the size of their balance sheet, the relevant opportunity cost is the required return of shareholders, which in this model is given by the financial market.²⁶

Riskless financial market. Taken literally, in the model banks are riskier than the financial market. However, one could easily introduce risk in the financial market. In fact, because households are risk-neutral one may simply re-interpret the return in the financial market as a risky return that pays R_{t+1} *in expectation*. What matters is that there is some risk in the bank's investment, to open the possibility of bank failure and introduce the risk-shifting moral hazard I am interested in.

Market power on the lending side. While banks have market power in deposit markets, in the model they are price takers on the lending side. In the real world, banks have some market power over borrowers that cannot easily substitute bank funding for other sources of finance, such as small businesses and households. Market power on the lending side could potentially alleviate some of the pressure on profitability at the ZLB, and instead result in a misallocation of finance between bank-dependent and bank-independent borrowers. However, at the margin some borrowers can substitute to other sources of finance. While market power may support margins to some extent, it would thus not fully overcome the problem.

²⁶To see this, consider a version of the model in which the total investment size $I_t^b = (1 + e)D_t$ is fixed at $I_t^b = 1$, s.t. $D_t = \frac{1}{1+e_t}$. In this case, the banks' FOC w.r.t. e_t is negative if and only if $r_{t+1} < \frac{R_{t+1}}{q(m_t)}$. Given risk-neutrality, the required return on deposits would indeed less than $R_{t+1}/q(m_t)$ if there is a convenience yield.

4.2. First Best and Inefficiencies

Before analyzing how the ZLB affects risk taking and regulation, it is useful to understand what market failures lead to inefficiencies in this economy. The non-contractability of monitoring in combination with limited liability for shareholders imply that the incentives of bank shareholders may not be aligned with the social optimum. Moreover, households receive less than the competitive return on deposits because banks have market power.

To see how these market failures affect equilibrium outcomes, it is useful to characterize the first best allocation (FB) and contrast it to the competitive equilibrium (CE). The first best allocation is the solution to a planner's problem, who directly chooses risk taking, consumption and investment subject to aggregate resource constraints:

$$\begin{aligned}
 \max_{C_t, I_t^m, D_{t,i}, m_t, e_t} \quad & \mathbb{E}_0 \sum_{t=0}^{\infty} \left(\prod_{\tau=0}^{t-1} \beta_{\tau} \right) [C_t + \gamma v(D_t)] \\
 \text{with} \quad & D_t = \left[\int_0^1 D_{t,i}^{\frac{\eta-1}{\eta}} di \right]^{\frac{\eta}{\eta-1}}, \\
 \text{s.t.} \quad & C_t + I_t^m + \int_0^1 (1 + e_{t,i}) D_{t,i} (1 + c(m_{t,i})) = F(K_t), \\
 & K_t = (1 - \delta)K_{t-1} + I_{t-1}^m + q(m_t)(1 + e_t)D_t
 \end{aligned} \tag{15}$$

From the CES aggregator it follows immediately that the planner allocates the same amount of deposit funding to each bank, $D_{t,i} = D_t$. Moreover, since the bank's investment technology is dominated, investments into banks can only be socially useful if they are in the form of deposits, and hence $e_t = 0$. The remaining variables are chosen according to the first-order conditions w.r.t. I_t^m , m_t and D_t :

$$\beta_t R_{t+1} = 1 \tag{16}$$

$$c'(m_t) = q'(m_t) \tag{17}$$

$$D_t = \left(\frac{\gamma}{1 - q(m_t) + c(m_t)} \right)^{\theta} \tag{18}$$

These three conditions are readily compared to their counterparts in the competitive equilibrium. First, (16) is equivalent to the household's Euler equation (3), implying that the overall level of capital accumulation is not distorted.

In contrast, condition (17) differs from its counterparts in the CE. In the FB allocation, $\frac{c'(m_t)}{q'(m_t)} = 1$. This is not generally true in the CE, as revealed by the bank's FOC w.r.t monitoring (12).

Similarly, condition (18) can be compared to the demand for deposits by households (18), after rewriting it as

$$D_t = \left(\frac{\gamma}{1 - r_{t+1}/R_{t+1}} \right)^\theta. \quad (19)$$

Clearly, the quantity of deposits in the CE is only equal to its FB level if $\frac{r_{t+1}}{R_{t+1}} = c(m_t) - q(m_t)$. However, this is not generally true, see (14).

These two comparisons show that misallocations arise because banks do not choose the optimal amount of risk taking, and do not provide the optimal amount of liquidity via deposits. These inefficiencies are a result of the two frictions in the model. Limited liability gives bank shareholders an option-like payoff, as they do not fully internalize losses incurred in case of failure. This convex payoff structure induces excessive risk taking. On the other hand, monopolistic competition implies that banks may take *less* risk relative to the FB. The reason is that the bank's franchise value reflects rents due to market power, which are of private value to bank shareholders but do not add to welfare. Overall, bank shareholders trade off the gains from shifting risk on depositors against the risk of loss of franchise value. In the baseline calibration, banks take excessive risk relative to the first best (failure probability of 0.76% vs 0.17% in the first best).

While market power may reduce those excessive risk-taking incentives, it also reduces the liquidity provision by banks. Low deposit rates weaken the demand for deposits by households, resulting in an inefficiently low quantity of liquidity production in equilibrium.

5. Risk Taking off and at the Zero Lower Bound

This section shows how risk taking incentives are affected by the level of interest rates and other parameters in the model. Because the answer depends on whether the ZLB binds, a first step is to show under what conditions deposit rates become constrained.

5.1. Zero Lower Bound

Banks set their deposit rate according to the first-order condition (14). This may either be at an interior solution if the return on capital is sufficiently high, and at the corner solution $r_{t+1} = 1$ if the ZLB binds.

Lemma 1. *At any time t , in state s the ZLB is slack (i.e. banks set an interior deposit rate $r_s \geq 1$) if and only if*

$$\beta_s \leq \beta_s^{ZLB}, \quad (20)$$

where β_s^{ZLB} is implicitly defined by

$$\beta_s^{ZLB} = \frac{\eta - 1/q_s}{\eta - 1} - \frac{\eta}{\eta - 1} \frac{(1 - q(m_s^*))\bar{e}_s + (1 + \bar{e}_s)c(m_s^*)}{q(m_s^*)},$$

and m_s^* denotes the equilibrium level of monitoring as a function of β_s^{ZLB} , implicitly defined by (4), (5), (14) and (12).

Lemma 1 defines a threshold β_s^{ZLB} , below which the ZLB binds. In the baseline calibration, this threshold is around 0.965 in both the high-rate and low-rate state, such that deposit rates hit the ZLB when the return on capital drops below 3.5% ($= 1/\beta_s^{ZLB} - 1$). The return on capital is above this threshold in the high-rate state (5.5%), while in the low-rate state $R_L = 2.5\%$ and the ZLB binds.

5.2. Do Low Interest Rates Spur Risk Taking?

The following proposition answers this question, by examining the comparative statics of equilibrium monitoring with respect to a marginal change in the discount factor β_t .

Proposition 1. *Hold $\beta_{t+1}, \beta_{t+2}, \dots$ fixed. The comparative statics of monitoring m_t with respect to the discount factor β_t depend on whether the ZLB binds:*

- If $\beta_t \leq \beta_s^{ZLB}$ (slack ZLB) a marginal increase in β_t increases equilibrium monitoring:

$$\frac{dm_t}{d\beta_t} \geq 0$$

(i.e. lower rates induce less risk taking).

- If $\beta_t > \beta_s^{ZLB}$ (binding ZLB), a marginal increase in β_t (falling rates) unambiguously decreases equilibrium monitoring m_t :

$$\frac{dm_t}{d\beta_t} \leq 0$$

(i.e. lower rates induce more risk taking) .

To see this result, iterate the bank's FOC w.r.t. monitoring (12) forward one period, and rewrite it as

$$\frac{c'(m_t)}{q'(m_t)} = 1 - \underbrace{\frac{1}{1 + e_t} \frac{r_{t+1}}{R_{t+1}}}_{\text{Margin on current loans}} + \underbrace{\frac{1}{I_t^b R_{t+1}} [\beta_{t+1} \mathbb{E}_{t+1} V_{t+2} - [e_{t+1} + (1 + e_t)c(m_t)] D_{t+1}]}_{\text{Discounted continuation value}}. \quad (21)$$

²⁷ The direct effect of an increase in β_t is to push down R_{t+1} (by the households Euler equation 4). The right-hand side reveals that lower R_{t+1} affects monitoring via a *margin channel* and a *discounting channel*. When R_{t+1} falls, banks discount their continuation value less, boosting overall franchise value. Via this discounting channel, lower interest rates induce banks to monitor more intensely, i.e. take less risk. On the other hand, a low investment return may harm interest margins and thereby induce higher risk taking. The overall effect on risk taking hence depends on the balance between the discounting and margin channel.

As long as banks set deposit rates according to the interior solution in (14), the relevant ratio $\frac{r_{t+1}}{R_{t+1}}$ on the right-hand side is not a function of β_t :

$$\frac{r_{t+1}}{R_{t+1}} = \frac{\eta - 1/q(m_t)}{\eta - 1} - \frac{\eta}{\eta - 1} \frac{(1 - q(m_t))\bar{e}_t + (1 + \bar{e}_t)c(m_t)}{q(m_t)}. \quad (22)$$

As a result, the discounting channel dominates when the ZLB is slack, and hence lower interest rates induce less risk taking.²⁸ Intuitively, market power allows banks to pass on a reduction in R_{t+1} to depositors, such that the relative interest margin $\frac{r_{t+1}}{R_{t+1}}$ remains stable. In contrast, when the ZLB binds,

$$\frac{r_{t+1}}{R_{t+1}} = \frac{1}{R_{t+1}}, \quad (23)$$

and any reduction in R_{t+1} eats 1-1 into interest margins, such that the margin effect dominates when the ZLB binds. This can be easily verified analytically by plugging $r_{t+1} = 1$ into (21) (also using (19)).

While the comparative statics in Proposition 1 refer to a marginal change in β_t , keeping $\beta_{t+1}, \beta_{t+2}, \dots$ fixed, Figure 4 uses the numerical solution to show that the same results obtain when changing β_L along the entire equilibrium path. The left panel of Figure 4 shows that as long as $\beta_L \leq \beta_L^{ZLB}$, banks can decrease deposit rates proportionately, guaranteeing a stable interest margin. In contrast, when $\beta_L > \beta_L^{ZLB}$ the ZLB binds and margins shrink.

The right panel of Figure 4 plots the equilibrium success probability $q(m_L)$ against the discount factor β_L . The discounting effect dominates as long as the ZLB is slack ($\beta_L \leq \beta_L^{ZLB}$), even though the magnitude of the effect is quite modest. Success probabilities rise by a few basis points as the return on capital falls from above 5% (at $\beta = 0.95$) to around 3.5% (at $\beta = \beta_L^{ZLB}$). In contrast, when the ZLB binds the margin channel dominates and falling interest rates result in a sizable increase in risk taking. The annual probability of failure more

²⁷Note that the left-hand side increases in m_t , and the partial derivative of the RHS w.r.t. m_t is negative.

Consequently, equilibrium m_t increases in β_t if and only if the RHS increases in the RHS. This is easy to verify because $c'(m_t) = \psi_2$ and $q'(m_t)$ is equal to the PDF of the Standard Gaussian Distribution and hence decreases for any $m_t \geq 0$. Hence, $c'(m_t)/q'(m_t)$ increases in m_t .

²⁸This can easily be verified by plugging the interior solution from (14) into (21), also using (19)

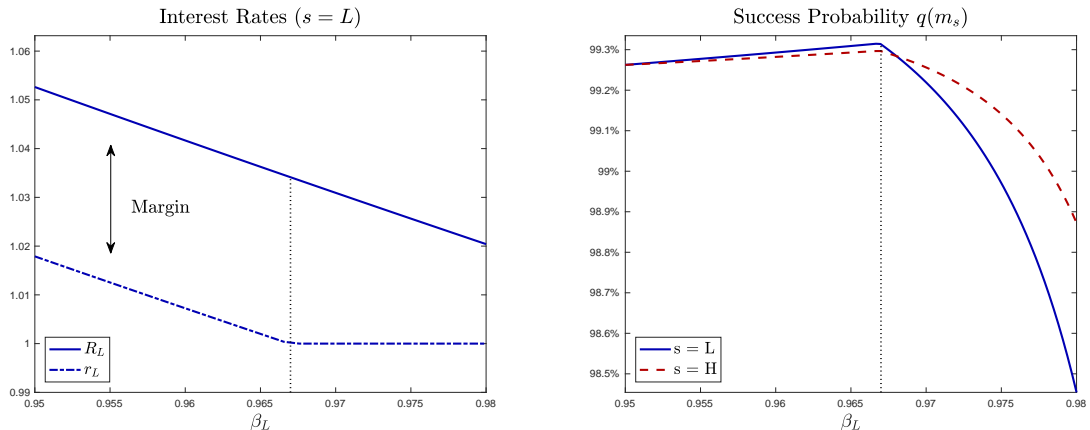


Figure 4: This figure plots equilibrium interest rates in the low-rate state ($s = L$), and equilibrium bank risk taking in both the low- and high-rate states, against the discount factor in the low-rate state β_L . The vertical dotted line indicates the threshold β_L^{ZLB} , beyond which the ZLB is binding. Parameters are calibrated as described in section 3.5.

than doubles from around 0.7% to above 1.5%, as the return on capital falls from 3.5% (at $\beta_L = \beta_L^{ZLB}$) to 2% (at $\beta_L = 0.98$).

Figure 4 also reveals that a binding ZLB in the low-rate state affects risk taking in the high-rate state, even though the ZLB is slack in the high-rate state ($s = H$, see the dashed red line). The reason is that the possibility of a binding ZLB in the future reduces expected future profitability, eroding franchise value. Risk taking incentives are not only affected by current profits, but also expected profitability going forward.

5.3. Expectations Matter

Because expected profitability affects franchise value, it matters for how long the economy is expected to remain at the ZLB:

Proposition 2. *Suppose that $\beta_H < \beta_H^{ZLB}$ and $\beta_L > \beta_L^{ZLB}$ (ZLB slack in the high-rate state, and binding in the low-rate state). There exists a threshold $\hat{\beta} \leq \beta_L^{ZLB}$, s.t. if*

$$\beta_L \geq \hat{\beta}, \quad (24)$$

then $V_H^b > V_L^b$. In this case, equilibrium monitoring in states $s = H, L$ decreases the more time the economy is expected to spend at the ZLB:

$$\frac{dm_s}{dP_{LL}} \leq 0, \quad \frac{dm_s}{dP_{HL}} \leq 0$$

When $\beta_L > \hat{\beta}$, the ZLB binds and intermediation margins are sufficiently compressed, such that the bank's franchise value in the high-rate state exceeds that in the low-rate state

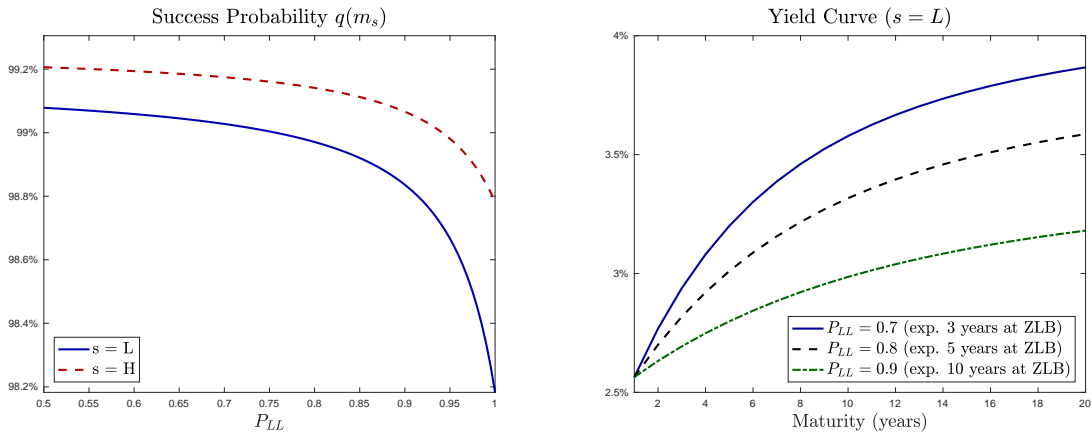


Figure 5: This figure plots bank risk taking in both the low- and high-rate states, against the probability of staying in the low-rate state (left panel). The right panel illustrates how an increase in the probability of remaining in the low-rate state P_{LL} translates into a flattening of the yield curve. Parameters are calibrated as described in section 3.5.

($V_H^b > V_L^b$). In this case, the overall value of banks is lower, the more time the economy spends in the low-rate state. Low expected profitability erodes franchise value and boosts risk taking incentives.

The left panel in Figure 5 illustrates the result of Proposition 2. It plots the equilibrium success probability $q(m_s)$ for $s = H, L$, against the likelihood of remaining in the low-rate state P_{LL} . In the baseline calibration indeed $V_H^b > V_L^b$, such that condition (24) is satisfied and an increase in P_{LL} results in more risk taking (lower success probability $q(m_s)$).

The right panel in Figure 5 connects this result to the yield curve, here calculated assuming that the expectations hypothesis holds.²⁹ A zero interest environment may be particularly problematic if the yield curve flattens substantially and rates are expected to be at the ZLB for long. The target range for the Fed Funds rate was lowered to 0% in December 2008, where it remained for seven years until the Fed started lifting rates in December 2015. An expected duration of seven years corresponds to a probability of staying in the low-rates state of around $P_{LL} \approx 0.85$. In the Eurozone rates are expected to remain near-zero for an even longer time. The ECB lowered its deposit facility rate close to zero by the beginning of 2009, and did not start the process of increasing rates by end 2018.

Even with rates in the U.S. rising, the overall level of interest rates is expected to remain low (perhaps due to demographic change and weak demand for finance by corporations). This increases the likelihood that upon the next major macroeconomic shock rates will hit the ZLB again. Proposition 2 shows that even when banks are not currently constrained by the ZLB,

²⁹I.e. the forward rate from date t to $t + \tau$ is calculated as $R_{t,t+\tau} = (R_{t+1} \times R_{t+2} \cdots \times R_{t+\tau})^{1/\tau}$.

the prospect of a binding ZLB in the future affects incentives. The more likely the economy transitions from the high-rate to the low-rate state (higher P_{HL}), the greater the chance that banks face weak profitability in the future, and hence the more risk they take.

5.4. Discussion of the Mechanism

In the model, risk taking is driven by bank franchise value, consistent with previous literature and several empirical studies. For example, [Jiang et al. \(2017\)](#) exploit the differential process of bank deregulation across U.S. states to show that a deregulation-induced increase in competition increases risk taking through reduced profits and bank franchise values. Similarly, [Beck et al. \(2013\)](#) find support for a positive relation between bank competition and fragility across a large set of countries, while [Craig and Dinger \(2013\)](#) find a positive relation between bank risk taking and deposit market competition.

Franchise value, in turn, is driven by interest margins and bank competition. As long as the ZLB is slack, interest margins are determined by market power. At the ZLB, bank competition is distorted, as depositors are unwilling to accept negative interest rates.³⁰

This approach highlights the distinct effect of the ZLB on bank profitability and franchise values and is consistent with high-frequency studies of bank stock price reactions to monetary policy announcements. [English et al. \(2012\)](#) and [Ampudia and Van den Heuvel \(2017\)](#) find that interest rate decreases boost bank stock prices when the ZLB is slack. [Ampudia and Van den Heuvel \(2017\)](#) also show that the effect reverses during the recent period with near-zero interest rates.

The overall mechanism closely mirrors the evidence in [Heider et al. \(2016\)](#). In a diff-in-diff setting, the authors show that negative policy rates in the Eurozone have eaten relatively more into the interest margin of banks with more deposit relative to wholesale funding. Consistent with the notion that tight margins spur risk taking, these banks are shown to increase their lending to riskier borrowers as interbank rates fall below zero.

Competition-stability framework? Contrary to this paper, other contributions in the literature show that higher competition may actually decrease risk taking incentives. For example,

³⁰[Drechsler et al. \(2016\)](#) argue more generally that the closer interest rates are to zero, the more bank deposits compete with cash. If I introduced a more general substitutability between cash and deposits, a reduction in interest rates would undermine bank market power even further away from zero. Consequently, the margin channel described in proposition 1 might already be at play with a slack ZLB, and a reduction in interest rates might increase risk taking incentives even when the ZLB is slack. Still, incentives would be affected disproportionately once the ZLB binds.

Boyd and De Nicolo (2005) place the risk shifting problem at the firm rather than the bank level. By charging lower lending rates, a more competitive banking sector then increases the “margin” of firms (between asset returns and borrowing rates), thereby increasing firm franchise value and hence lowering risk taking. Interestingly, the result that the ZLB enhances risk taking incentives is robust to whether the moral hazard problem is placed with banks or with firms.

To see this, consider a variation of the model, in which the risk taking decision is done by firms, which earn a margin between final asset returns and lending rates, which in turn depend on the competitiveness of the banking sector. When the ZLB constrains deposit rates, falling returns inevitably reduce the margin between final asset returns and deposit rates. Some of that squeeze in margins would have to be born by firms, inducing them to take more risk.

Industry consolidation? In the model, entry is always profitable since the total number of bank licenses is limited to 1 and there are rents to be earned. This is in line with the real world observation that there are many regulatory barriers to entry in the banking industry.³¹ Nevertheless, one may expect some consolidation after a prolonged period of near-zero interest rates. This notion is supported by evidence in appendix B.2, on the evolution of concentration in the banking industry. Since the ZLB started binding in 2008, the average number of banks operating in a given county has been dropping from around 14.5 to 13.5.

This effect is not present in the model, because entry is still profitable at the ZLB, as banks earn monopolistic profits.³² While consolidation may lighten the negative effect of the zero lower bound on franchise values to some extent, it is unlikely that it would alleviate the problem substantially. After all, the problem at the ZLB is not that banks compete too fiercely with each other, but that banks face competition from cash as an alternative source of liquidity. At the ZLB, deposit rates are fixed at the corner solution $r_t = 1$, independently of the degree of competition between banks.

³¹For example, the process of obtaining a bank charter is relatively long and complicated, and requires approval from the Office of the Comptroller of the Currency the FDIC, and in some cases the Federal Reserve. See the FAQ on “How can I start a bank?” on the website of the Board of Governors of the Federal Reserve System.

³²Except when rates are so low that $V_t < 0$. At this point banks scale down until the return on capital recovers sufficiently. Weak investment then pushes output below potential, and the economy ends up in a classic liquidity trap. I study this case in a previous version of the paper, available upon request.

6. Capital Regulation

In the model, the main policy tool to curb moral hazard is capital regulation. Given that the zero lower bound on deposit rates induces banks to take more risk, one might expect that the optimal reaction to near-zero interest rates is to tighten capital requirements. I find exactly the opposite. The reason is that at the zero lower bound capital requirements are a less effective tool to curb risk taking incentives, as shown in this section.

6.1. The Effectiveness of Capital Requirements at the ZLB

Generally, higher capital requirements curb a bank's incentives to take excessive risk:

Proposition 3. *An increase in the capital requirement induces banks to monitor more intensely in equilibrium:*

$$\frac{dm_s}{d\bar{e}_s} \geq 0.$$

Intuitively, higher capital increase a bank's "skin in the game" effect. As shareholders put more of their own funds at stake, their payoff becomes less convex, inducing a more prudent investment strategy (Holmstrom and Tirole, 1997). However, at the ZLB a countervailing effect comes into play. When banks are unable to pass on the cost of capital to depositors, tight capital requirements eat into bank profitability and erode franchise value:

Lemma 2 (Franchise Value Effect). *Define as*

$$\pi_{t,t+1}^b = q(m_{t,i})\beta_t [R_{t+1}(1 + e_{t,i}) - r_{t+1,i}] - [e_{t,i} + (1 + e_{t,i})c(m_{t,i})]$$

the net profits a bank earns from loans made at t . Taking into account how banks set deposit rates in (14), profits can be expressed, but keeping the level of monitoring m_t fixed, bank profits as a function of the capital requirement are given by

$$\pi_s^b(e_s; m_s) = \begin{cases} q \left[1 - \frac{\eta - 1/q(m_s)}{\eta - 1} \right] + \frac{1}{1-\eta} [(1 - q(m_s))e_s + (1 + e_s)c(m_s)], & \text{if } \beta_s \leq \beta_s^{ZLB} \\ q(m_s)(1 - \beta_s) - c(m_s) - e_s[1 + c(m_s) - q(m_s)], & \text{if } \beta_s > \beta_s^{ZLB} \end{cases}$$

Clearly,

- $\frac{\partial \pi_s^b(e_s; m_s)}{\partial e_s} \geq 0$ if $\beta_s \leq \beta_s^{ZLB}$ (ZLB slack)
- and $\frac{\partial \pi_s^b(e_s; m_s)}{\partial e_s} \leq 0$ otherwise.

Lemma 2 shows in partial equilibrium that bank profitability is only negatively affected by higher capital requirements if the ZLB binds. The reason is that with a slack ZLB, banks

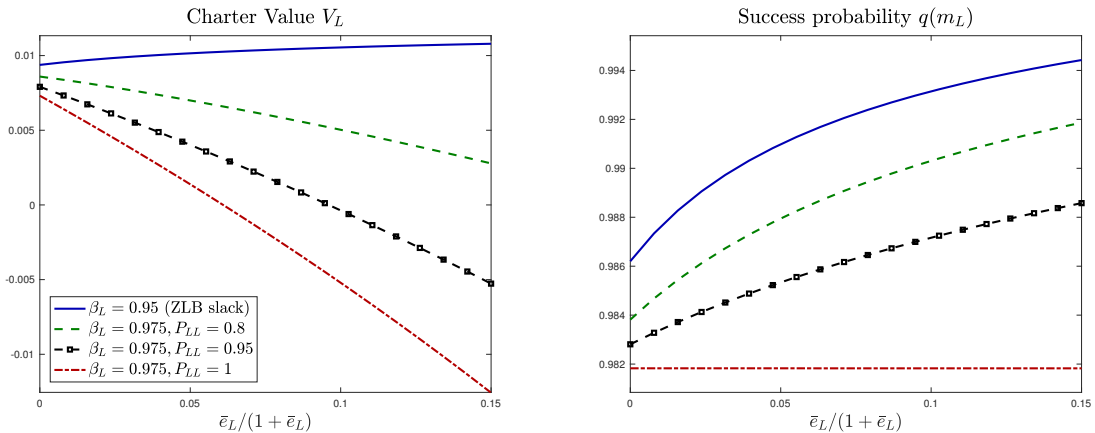


Figure 6: This figure plots franchise values (left panel) and risk taking (right panel) in the low-rate state, against the capital requirement \bar{e}_L . Different lines represent different levels of interest rates and probability of remaining in the low-rate state. Parameters are calibrated as described in section 3.5.

can pass on the cost of capital to depositors. This can be seen in the deposit rate setting in Eq. (14), reposted here for convenience:

$$r_{t+1} = \max \left\{ R_{t+1} \left[\frac{\eta - 1/q(m_t)}{\eta - 1} - \frac{\eta}{\eta - 1} \frac{(1 - q(m_t))e_t + (1 + e_t)c(m_t)}{q(m_t)} \right], 1 \right\}.$$

The cost of capital is the bank's operating cost $c(m_t)$, which households do not incur when investing in via the financial market instead of bank equity. Deposit rates decrease in $e_t c(m_t)$ as banks pass on this cost.

While Lemma 1 shows how profitability is affected in partial equilibrium (for a given level of monitoring), Figure 6 confirms the same effect along the entire equilibrium path (using the numerical solution based on the calibration in Section 3.5). The left panel plots the equilibrium franchise value in the low-rate state V_L against the capital requirement \bar{e}_L (keeping \bar{e}_H fixed), for different levels of β_L and likelihood of remaining in the low-rate state.

At $\beta_L = 0.95$ the ZLB is slack, and capital requirements have an overall positive effect on V_L , consistent with Lemma 1. In contrast, when the ZLB binds (at $\beta_L \geq 0.975$), higher capital requirements erode profitability. Intuitively, the figure also reveals that the adverse effect on franchise value is particularly strong the higher P_{LL} , i.e. the longer the economy remains at the ZLB in expectation.

The right panel of Figure 6 shows the implications for equilibrium monitoring. The more the capital requirement depresses franchise values, the less it curbs risk shifting incentives. For example, franchise values drop much more on the dashed black line with circle markers (representing $P_{LL} = 0.95$, or an expected duration of 20 years at the ZLB) than on the green, dashed line (representing $P_{LL} = 0.8$, or an expected duration of 5 years at the ZLB).

Accordingly, in the right panel the black line is flatter, i.e. a marginal increase in capital requirements reduces risk shifting incentives relatively less.

In fact, in the most extreme, limiting case $P_{LL} = 1$, the franchise value effect completely overrules the skin in the game effect, such that capital regulation no longer has any effect on risk taking incentives at all. This result can be shown analytically:³³

Proposition 4. *Suppose $\beta_L > \beta_L^{ZLB}$ (ZLB binds in the low-rate state). In the limiting case $P_{LL} = 1$ (the ZLB binds forever), equilibrium monitoring m_L is unaffected by the level of capital requirements,*

$$\frac{dm_L}{d\bar{e}_L} = 0.$$

Capital requirements and franchise value. Using a Monti-Klein model of bank competition, [Hellmann et al. \(2000\)](#) show that higher capital requirements may more generally undermine bank franchise value. Their result is in contrast to the monopolistic competition setup here, where banks can fully pass on the cost of capital to depositors as long as the ZLB remains slack.³⁴ Hence, whether capital requirements do or do not reduce franchise value away from the ZLB depends on modeling choices. However, this is besides the main point. The general result here is that at the ZLB higher capital requirements *disproportionately* affect franchise values. Clearly, the ZLB eliminates one margin of adjustment, such that higher capital requirements must inevitably have a more negative effect on bank profitability when the ZLB binds.

6.2. Optimal Capital Regulation

Section 5 shows that the ZLB may increase risk taking incentives, and the previous subsection shows that the ZLB can make capital requirements less effective. What does this mean for *optimal* capital regulation? To answer this question, I calculate the welfare-maximizing, state-dependent levels of the capital requirement $\{e_H^*, e_L^*\}$, that maximize the representative

³³To see that the capital requirement becomes ineffective, evaluate (21) at $s = L$ and $r_L = 1$, using D_L from (19) and V_L from (25). After some algebra, it can be seen that in the limiting case $P_{LL} = 1$ all \bar{e}_L drop out from the right hand side of (21), implying that m_L is unaffected by \bar{e}_L .

³⁴Another modeling difference to [Hellmann et al. \(2000\)](#) is the general equilibrium approach taken in this paper. In [Hellmann et al. \(2000\)](#) equity is priced by the opportunity cost of funds of bank owners, and banks face an exogenous demand for deposits as well as a choice between two investment opportunities with exogenously given returns. Here, households price the required return on equity and assets (via financial market investments), and the demand for deposits is also derived from household optimization. This equilibrium approach is useful when studying the effect of changing interest rates, as shifts in the household's discount factor affect the entire spectrum of required returns and interest rates.

household’s expected lifetime utility. For this purpose, I simulate the model for 300,000 random paths of length of 200 years, starting in the high-rate state ($s_0 = H$). I then pick the combination of capital requirements that maximizes the average lifetime utility across the 300,000 draws, and define the resulting allocation as the “second best”. This approach takes as given the level of competition, i.e. it is not part of the policy choice set.

The result of this exercise is presented in the top panel of figure 7, which plots optimal capital requirements for different levels of the household’s discount factor β_L . When $\beta_L < \beta_L^{ZLB}$ interest rates are high and the ZLB is slack. In this region, the optimal capital requirement lies between 7% and 8% in both the low-rate and high-rate state, somewhat above the level currently required according to the Basel III regulatory framework.³⁵ In contrast, when the ZLB binds ($\beta_L > \beta_L^{ZLB}$) in the low-rate state, the optimal capital requirement e_L^* drops significantly, while that in the high rate state, e_H^* increases. That is, if the ZLB binds occasionally in the low-rate state, optimal capital requirements are positively correlated with the level of interest rates.

What explains this pattern of optimal capital requirements? The two lower panels of figure 7 reveal that banks tend to take too much risk and provide too little liquidity relative to first best, as long as the ZLB is slack in both states ($\beta_L \leq \beta_L^{ZLB}$). In this region, optimal capital requirement trade off a reduction in risk taking against lower liquidity provision, resulting in an optimal level near 8%.³⁶

However, when the ZLB occasionally binds in the low-rate state ($\beta_L > \beta_L^{ZLB}$) two new effects come into play. First, the franchise value effect described in lemma 2 renders capital requirements less effective in curbing risk taking at the ZLB, motivating a weaker use in the low-rate state. This effect explains the drop in the optimal capital requirement e_L^* for $\beta_L > \beta_L^{ZLB}$ found in figure 7. Note that the drop in the optimal level occurs despite higher

³⁵In the model, the only assets of banks are risky loans and the requirement is expressed as a fraction of total non risk-weighted assets. Strictly speaking, the capital requirement therefore resembles more closely the leverage ratio requirement of Basel III, rather than capital requirements, which are risk-weighted. At the same time, in the model banks only invest in risky loans, which tend to carry relatively high regulatory risk-weights. The quantitative assessment of the optimal capital requirement can therefore be interpreted as a leverage requirement on risky loans, somewhere between the leverage and capital requirements of Basel III. According to Basel III capital regulation, banks are required to hold Tier 1 plus Additional Tier 1 capital of 6%, plus an additional 2.5% in the “Capital Conversation Buffer”, all as a fraction of risk-weighted assets (BIS, 2011). Moreover, Basel III requires a “leverage ratio” of at least 3% of Tier 1 capital over total (non risk-weighted) assets.

³⁶Recall from proposition 1 that lower discount rates induce banks to take less risk. This explains that for higher levels of β_L the optimal capital requirement decreases slightly, allowing for a higher level of liquidity provision while keeping the equilibrium success probability at a stable level.

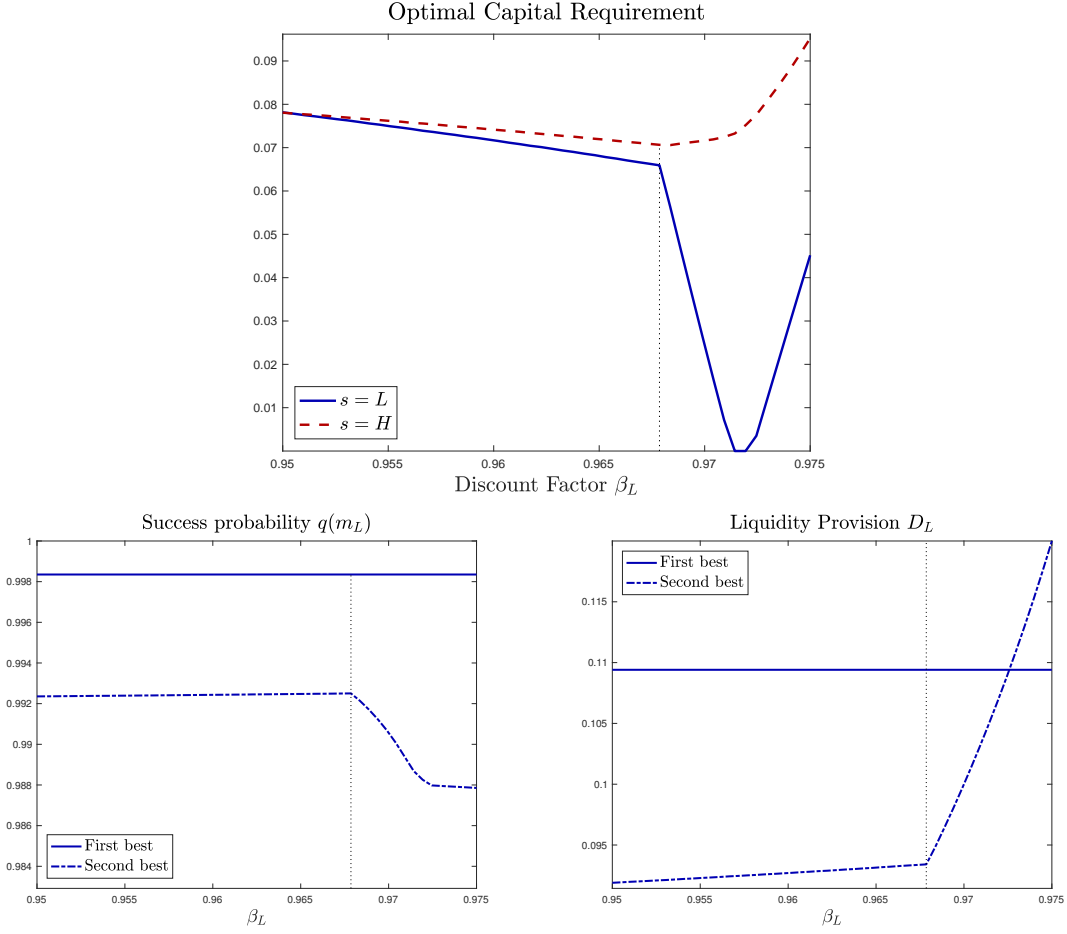


Figure 7: The top panel plots the optimal state-dependent capital requirement, for different levels of the discount factor in the low-rate state. The bottom panels plot for both the first best and second best the equilibrium success probabilities q_L and quantity of deposits D_L . The vertical dotted line marks the threshold β_L^{ZLB} , beyond which the ZLB binds in the low-rate state. Parameters are calibrated as described in section 3.5.

risk taking incentives (proposition 1). Hence, capital regulation optimally allows more risk taking at the ZLB (bottom left panel of figure 7).

In contrast, the binding ZLB in the low-rate state motivates a tighter level of capital requirements in the high-rate state, i.e. e_H^* increases. Because the ZLB is slack in the high-rate state, here the effectiveness of capital requirements is not undermined. Yet, risk taking incentives are heightened because banks have low expected profitability (upon falling back to the low-rate state) therefore unambiguously motivate a higher level of e_H^* .

Finally, to explain the U-shaped pattern of e_L^* , note that the marginal return to monitoring is higher at lower levels of m_t , i.e. $q(m_t) - c(m_t)$ is concave. When intermediation margins are still relatively high, the franchise value effect dominates, explaining the drop in e_L^* . At

some point, risk taking is so strong that the marginal return to monitoring is very high and it becomes optimal to again increase the capital requirement. However, in the baseline calibration with $\beta_L = 0.975$, the optimal capital requirement is still substantially lower than at $\beta_L = \beta_L^{ZLB}$ ($e_L^* \approx 4.5\%$, down from $e_L^* \approx 7\%$).³⁷

Discussion The finding that optimal capital requirements vary with the level of interest rates relates to the debate on counter-cyclical capital regulation. Recent contributions show that counter-cyclical leverage limits may be motivated in models with welfare-relevant pecuniary externalities (e.g. [Lorenzoni, 2008](#); [Stein, 2012](#); [Korinek and Simsek, 2016](#)). In the policy debate, a common rationale is that buffers built up in good times should be available to be used in bad times (e.g. [Goodhart et al., 2008](#)). In contrast, the argument here is based on the “interest rate cycle” and even applies in a setup without welfare-relevant pecuniary externalities. To the extent that interest rates are low in bad times, the model delivers a novel rationale for counter-cyclical regulation purely based on the inability of banks to absorb tight capital requirements at the ZLB.

Another implication of the franchise value effect is that monetary- and macro-prudential policy cannot be seen in isolation. In the policy debate it is sometimes argued that monetary policy should focus on inflation targeting, while macro-prudential policies should target financial stability (e.g. [Bernanke, 2015](#)). However, this argument sees monetary policy as an independent, alternative tool to macro-prudential regulation. If instead near-zero interest rates undermine the effectiveness of prudential policies, monetary- and macro-prudential policy cannot be set in isolation as their interdependencies need to be taken into account.

6.3. An Alternative Policy

Is there a better policy response than merely adjusting capital requirements at the ZLB? I consider as an alternative policy a subsidy τ_t per unit of deposits, paid to banks whenever the ZLB binds. The subsidy is set to replicates whatever negative rate banks want to set,

³⁷Note that for some values of β_L optimal capital requirement drop as low as zero at the ZLB. A 100% leverage prescription is certainly an over-statement of the quantitative magnitude of the effect, and reveals a weakness of the binary shock structure, namely that it ignores the “loss absorbing capacity” of bank capital. Under a more realistic distribution of returns the bank’s failure probability would rise exponentially as its equity tends to zero, resulting in a strictly positive optimal level of the capital requirement. Nevertheless, the more general point remains that the franchise value effect and its qualitative implications for optimal bank capital requirements identified in lemma 2 would still be present in this alternative version of the model. The binary shock structure puts the focus on moral hazard, remains tractability and still delivers a realistic quantitative assessment of the optimal capital requirement in the baseline calibration.

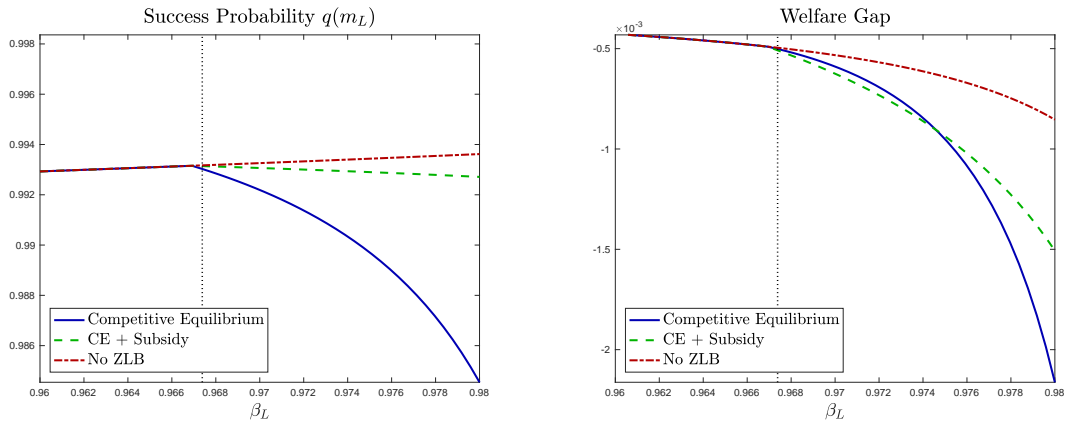


Figure 8: Risk taking (left panel) and welfare gap relative to the first best equilibrium (right panel), for different levels of β_L , under the competitive equilibrium, the equilibrium with a subsidy on deposits, and the equilibrium absent the ZLB friction. Parameters are calibrated as described in section 3.5.

effectively eliminating the ZLB. That is,

$$\tau_t = \min \{1 - r_{t+1}, 0\}.$$

To finance the subsidy, the government raises lump sum taxes of $\tau_t D_t$.

The subsidy broadly resembles cheap funding schemes such as the ECB’s Targeted Long Term Refinancing Operations (TLTRO), or the Bank of England’s Funding for Lending scheme. These policy schemes subsidize banks by providing cheap funding (often conditional on making loans). For example, the second round of TLTRO (TLTRO-II) enabled banks to borrow up to 30% of the amount of their existing stock of loans to non-financial corporations and households, at *negative* interest rates (ECB, 2017).

The subsidy effectively eliminates the ZLB constraint for banks. Accordingly, it restores bank profitability and hence incentives, as illustrated in the left panel of figure 8. This figure highlights the difference between the competitive equilibrium with and without the subsidy, and a counter-factual economy absent the ZLB friction. The left panel shows that under the subsidy the risk taking of banks is much lower than without it, close to the level of risk taking in an economy without the ZLB friction.

However, the overall effect of the subsidy on welfare is ambiguous. The right panel plots a welfare gap, defined as the percentage deviation of the representative household’s lifetime utility from the first best.³⁸ Only when rates are quite low (β_L high) does the subsidy result in a higher level of welfare. Intuitively, the taxes raised to fund the subsidy create an additional

³⁸As in the previous section, I simulate the model for 300,000 random paths of length of 200 years, and calculate the average lifetime utility across all draws.

distortion. From the view of depositors, investments in deposits are too attractive, such that the overall demand for liquidity is inefficiently high.

7. Conclusion

Since the 1980s real interest rates across advanced economies have followed a steady downward trend. While a “normalization” of interest rates is on its way, low rates are likely here to stay (Summers, 2014). This new environment of near-zero interest rates requires re-thinking some fundamental questions across macro- and financial economics. This paper is a step in this direction, highlighting potential consequences for banking and optimal capital regulation.

I find that the zero lower bound distorts bank competition, weakens profitability and induces higher risk taking. And even after monetary policy “normalization”, incentives are affected if the ZLB is expected to bind again in the future.

While the ZLB has often been discussed as a constraint to monetary policy, I show that it can also impede the effectiveness of bank capital regulation in curbing risk shifting incentives. As a result, optimal capital requirements vary with the level of interest rates and are optimally lower whenever the ZLB binds, even though risk taking incentives are already heightened.

An implication is that in an environment of structurally low interest rates, monetary and macro-prudential policies cannot be seen in isolation. Given that extremely low policy rates may undermine the effectiveness of prudential regulation, an interesting avenue for future research would be to study their joint determination.

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A. Paper Appendix

A.1. Equilibrium conditions

All equilibrium conditions can be summarized as follows:

- Firms

$$\begin{aligned} F(K_t) &= K_t^\alpha, \\ K_t &= (1 - \delta)K_{t-1} + I_{t-1}^m + q(m_t)I_{t-1}^b, \\ \alpha K_t^{(\alpha-1)} &= R_t - (1 - \delta). \end{aligned}$$

- Households

$$\begin{aligned} R_{t+1}\beta_t &= 1, \\ D_t &= \left(\frac{\gamma}{1 - r_{t+1}/R_{t+1}} \right)^\theta, \\ C_t &= F(K_t) - I_t^m - I_t^b(1 + c(m_t)). \end{aligned}$$

- Banks

$$\begin{aligned} \frac{c'(m_t)}{q'(m_t)} &= \frac{\beta_t \mathbb{E}_t V_{t+1}^b}{(1 + e_t)D_t} \\ V_t &= d_t^b + q(m_t)\beta_t \mathbb{E}_t V_{t+1}, \\ d_t^b &= [R_t(1 + e_{t-1}) - r_t]D_{t-1} - [e_t + (1 + e_t)c(m_t)]D_t(r_{t+1}), \\ r_{t+1} &= \max \left\{ R_{t+1} \left[\frac{\eta - 1/q_t}{\eta - 1} - \frac{\eta}{\eta - 1} \frac{(1 - q(m_t))e_t + (1 + e_t)c(m_t)}{q(m_t)} \right], 1 \right\}, \\ I_t^b &= (1 + e_t)D_t. \end{aligned}$$

A.2. Calibration

The following table summarizes the calibration of the model and data sources.

Table 1: Calibration

Parameter	Target Moment	Data Source
$\beta_H = 0.95$	Average corporate bond yield 1996 - 2008, $R_H = 1.055$	FRED
$\beta_L = 0.975$	Average corporate bond yield 2009 - 2013, $R_L = 1.025$	FRED
$\delta = 0.065$	Average depreciation rate of U.S. capital stock 1970 - 2016	BEA Fixed Assets Tables
$\alpha = 0.38$	Average U.S. capital-output ratio 1970-2016, $K_H/Y_H = 3.25$	BEA Fixed Assets Tables
$\bar{e}_s = 0.0929$	Basel III bank capital requirement, $\bar{e}_s/(1 + \bar{e}_s) = 0.085$	BIS
$\psi_1 = 0.018$	Median U.S. bank's non-interest expense / assets 1984 - 2013, $\psi_1 = 0.018$	Call Reports (obtained through WRDS)
$\psi_2 = 0.0018$	Average annual failure rate of U.S. banks, $q(m_H) \approx 0.9924$	Davydiuk (2017)
$\eta = 5$	Average interest margin of U.S. banks from 1996-2013 $R_H - r_H = 3.5\%$	Call Reports (obtained through WRDS)
$\gamma = 0.003$	Deposit liabilities of U.S. chartered institutions / debt instruments of non-financial corporates, $D_H/(D_H + I_H^m) = 0.2$	Flow of Funds
$P_H = 0.9$	Expected duration in high-rate state of 10 years	N/A
$P_L = 0.8$	Expected duration in low-rate state of 5 years	N/A

A.3. Proof of Proposition 2

This appendix shows (i) that $V_H > V_L$ when $\beta_L < \hat{\beta}$, and (ii) that in this case equilibrium monitoring increases in P_{HH} and decreases in P_{LL} .

(i) Use the definition of V_t and $\pi_{t,t+1}$ from (7), and that $\mathbb{E}_s V_{t+1} = P_{ss} V_s + P_{ss'} V_{s'}$, to find the franchise value of the bank in state $s \in \{H, L\}$:

$$V_s = \frac{1}{\Lambda} [(1 - q(m_{s'}))\beta_{s'} P_{s's'} \pi_s D(r_s) + q(m_s)\beta_s P_{ss'} \pi_{s'} D(r_{s'})], \quad (25)$$

with

$$\Lambda \equiv (1 - q(m_H)\beta_H P_{HH})(1 - q(m_L)\beta_L P_{LL}) - (q(m_H)\beta_H P_{HL})(q(m_L)\beta_L P_{LH}),$$

and $D(r_s)$ is defined in (19). By lemma 1, if $\beta_L > \beta_L^{ZLB}$, the ZLB binds. In this case, one can write π_L as

$$\pi_L = q(m_L) \left[(1 + \bar{e}_L) - \frac{1}{R_L} \right] - [\bar{e}_L + (1 + \bar{e}_L)c(m_L)].$$

Moreover, with a binding ZLB at $r_L = 1$,

$$D(1) = \left(\frac{\gamma}{1 - 1/R_L} \right)^\theta.$$

Clearly, $\lim_{R_L \rightarrow 1} \pi_L < 0$, and $\lim_{R_L \rightarrow 1} D(1) = \infty$. Hence,

$$\lim_{R_L \rightarrow 1} \pi_L D(1) = -\infty.$$

Inspecting (25), it is clear that the term $\pi_L D(r_L)$ has a greater weight on V_L than V_H (since $(1 - q(m_H)\beta_H P_{HH}) > q(m_H)\beta_H P_{HL}$). Hence, V_L tends faster to $-\infty$ as β_L increases and there is a threshold $\hat{\beta} < 1$ s.t. for $\beta_L > \hat{\beta}$ it must be that $V_H > V_L$.

(ii) From (21), monitoring increases in $\mathbb{E}_t V_{t+1}$. With $V_H > V_L$ it follow immediately that $\mathbb{E}_s V_{t+1} = P_{ss} V_s + P_{ss'} V_{s'}$ increases in P_{HH} in the high state, and decreases in P_{LL} in the low state. Hence, monitoring increases in P_{HH} and decreases in P_{LL} . \square

B. Additional Evidence

B.1. Interest Margins and Deposit Rates at the ZLB

Figure 2 from the introduction shows that the spread between safe corporate bonds and the deposit expense ratio has declined since 2009. The left panel of figure 9 complements this data by showing the spread between interest income and deposit interest expense ratio of the median U.S. bank in the Call Reports data. Analogously to the interest expense ratio, the income ratio is defined as total interest income (riad4107) divided by total assets (rcfd2170).

As in figure 2, a compression in spreads is visible in these series too, though the magnitude of the drop is smaller and occurs slightly earlier - perhaps because non-performing loans started pushing down bank interest income already in 2007.

That interest income ratios are somewhat more stable than the return on safe bonds in figure 2 is consistent with the notion that banks start lending to riskier borrowers (since riskier borrowers pay higher interest rates). It is also driven by the fact that bank assets have relatively long maturity, so that margins only come under pressure once their long-term assets roll off. Drechsler et al. (2017a) show that banks in the U.S. lengthened the duration of their balance sheets during the zero-lower-bound period, which has limited the compression of their net interest margins.

In my model I cannot study these gradual effects as loans are re-priced every period. Nevertheless, the comparison to highly rated corporate bonds in figure 2 shows that for a given level of risk margins on new business are significantly compressed since 2009.

The right panel of figure 9 shows for a longer horizon the spread between the rate on 30 year mortgages (as reported in FRED), and the median deposit interest expense ratio. I calculate the mean of this spread for three phases: 1985 - 1995, 1996 - 2007, and 2007 - 2013.

In 1994 the Riegle-Neal Interstate Banking and Branching Efficiency Act removed several obstacles to banks opening branches in other states and provided a uniform set of rules regarding banking in each state. This act increased competition, with an evident negative effect on interest margins. In 2008 the ZLB starts binding, explaining the second drop in margins, analogous to the left panel and figure 2.

This pattern of interest margins is consistent with the model. Away from the ZLB, margins are determined by the level of competition (parameter η in the model). When the ZLB binds, the market power of banks breaks as depositors face cash as an attractive outside option. Accordingly, a further compression in margins occurs.

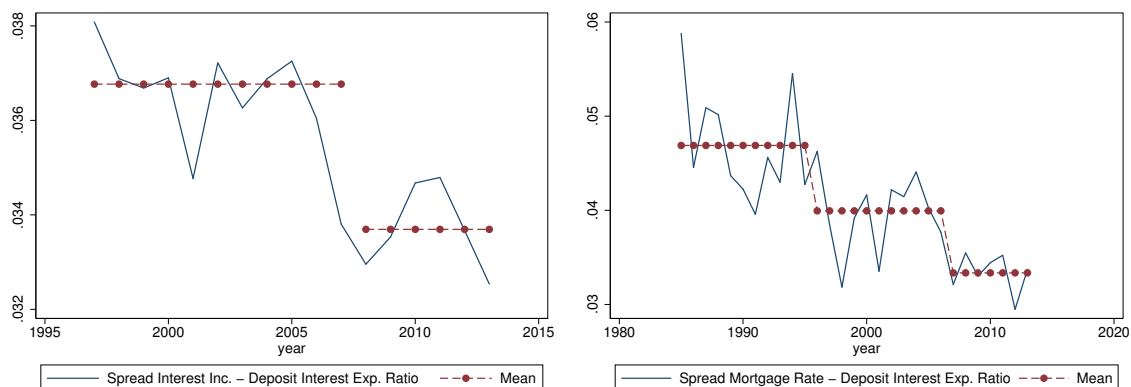


Figure 9: The left panel plots the median spread between interest income and deposit interest expense ratio, among all U.S. banks in the Call Reports data. The right panel plots the spread between the rate on 30 year mortgages and the median deposit expense ratio.

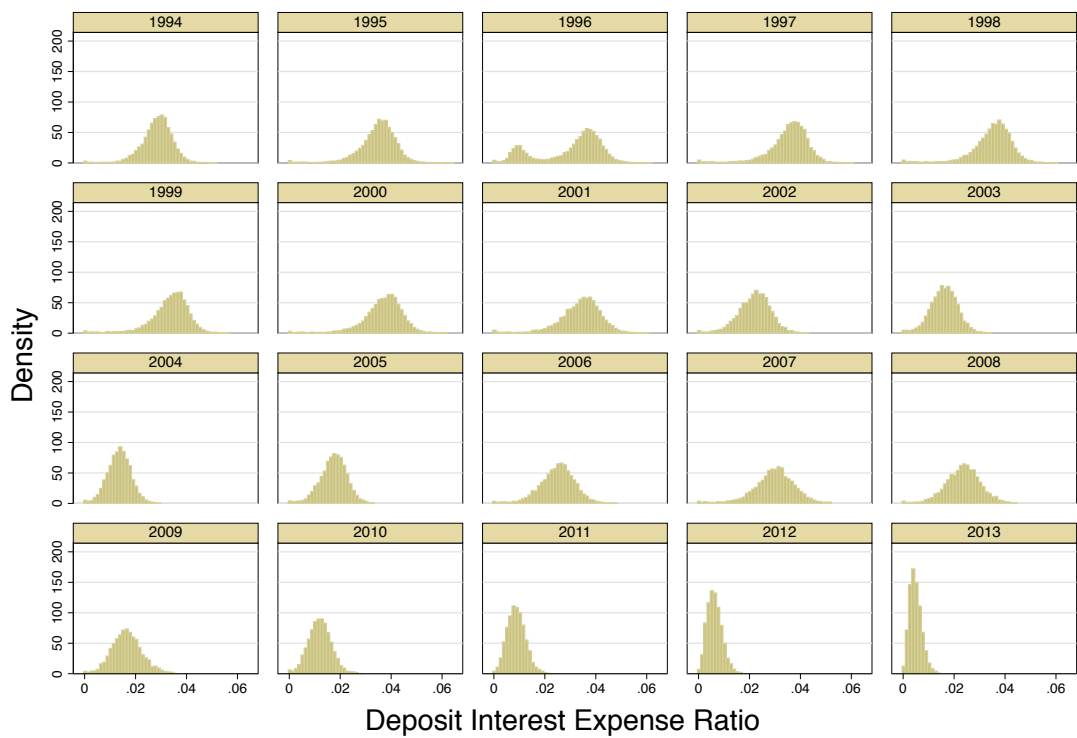
Deposit Rates Figure 10 expands on figure 1 in the introduction. This more comprehensive perspective shows that the skewness and concentration of the distribution is a phenomenon particular to the ZLB period after 2009. This is despite substantial swings in the Federal Funds rate over the relevant period.

B.2. Evolution of Bank Concentration

A central prediction of the model is that the ZLB distorts bank competition, as cash provides an attractive alternative source of liquidity for households. In the light of weakening profitability, one may expect the industry to consolidate.

Figure 11 presents evidence of the evolution of bank concentration since 1994, using branch-level data on deposit holdings from the FDIC. The left panel shows that the aggregate number of banks has been steadily decreasing since 1994. In contrast, the average number of banks per county increases from around 13 in 1994 to almost 14.5 in 2008. These trends are consistent with the interpretation that after 1994 competition *between* banks increased. In 1994 the Riegle-Neal Interstate Banking and Branching Efficiency Act removed several obstacles to interstate-banking. This allowed the most efficient banks to venture into other states, explaining the increase in the average number of banks per county. At the same time, less efficient banks leave the market, explaining the decrease in the number of banks on the national level.

As the ZLB starts binding in 2008, banks again face fiercer competition. However, this time tighter competition is not the result of fiercer competition with each other, but a result of the fact that depositors have cash as an alternative source of liquidity with zero net return. Accordingly, the growth in the number of banks per county reverses, falling in tandem with



Graphs by year

Figure 10: For the years 1994-2013, this figure plots the cross-sectional distribution of deposit interest expense ratios across U.S. banks in the Call Reports data. The deposit interest expense ratio is defined as interest expenses per unit of deposits.

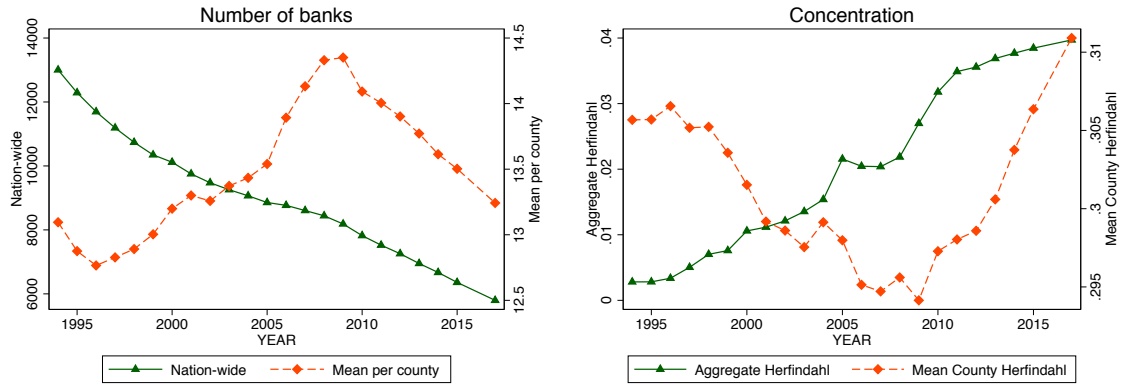


Figure 11: The left panel plots the number of banks on a nation-wide level (left axis), and the mean number of banks per county (right axis). Analogously, the right panel plots Herfindahl based on bank-level deposits on a nation-wide level, and per county.

the aggregate number of banks, and almost all the way back to its 1994 level. Likely other drivers behind the fall in the number of banks are the emergence of online banking and fintech, as well as bank failures triggered by the financial crisis.

The right panel of figure 11 further supports this interpretation by plotting deposit Herfindahls on a national and the country level. Following Drechsler et al. (2016), I calculate the county-level Herfindahl by summing the deposit holdings across all branches of a bank in a given county, and then calculating the Herfindahl as the sum of squared deposit market shares of all banks in a county. Analogously, I calculate the aggregate Herfindahl by summing the deposit holdings across all branches of a bank in the entire U.S.

Unsurprisingly, the Herfindahls have an inverse relationship to the number of banks, confirming that county-level concentration decreases from 1994-2008, but then starts increasing again as the ZLB binds from 2009 onwards. Interestingly, by 2015 the mean County Herfindahl surpasses its 1994 level.