

# Bank Capital Regulation in a Zero Interest Environment

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## Abstract

How do near-zero interest rates affect bank competition, risk taking and regulation? I study these questions in a tractable dynamic general equilibrium model, in which forward-looking banks compete imperfectly for deposit funding, and deposit insurance may induce excessive risk taking. The zero lower bound on deposit rates (ZLB) distorts bank competition and boosts risk shifting incentives, particularly if rates are expected to remain near-zero for long. At the ZLB, capital regulation becomes a less effective tool to curb risk shifting incentives. When banks cannot pass on the cost of capital to depositors, tight capital requirements erode franchise value, countervailing the usual “skin in the game” effect. Optimal capital requirements vary with the interest rate cycle, highlighting a novel interaction between monetary and macro-prudential policies. Complementing existing regulation with policy tools that subsidize the funding cost of banks may improve welfare at the ZLB.

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

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# 1. Introduction

Since the financial crisis in 2008 interest rates across advanced economies have been at historical lows, where they are likely to remain for a sustained period of time. A vast literature studies the implications of low interest rates for macroeconomic outcomes, in particular when monetary policy is constrained by the zero lower bound (ZLB). An open question remains how such a low-rate environment affects banking and financial regulation. The goal of this paper is to fill this gap, and its key contribution is to show that the zero lower bound on deposit rates may undermine the effectiveness of prudential regulation.

The question addressed in this paper is important because the ZLB seems to be a particularly relevant constraint for commercial banks, which are hesitant to set negative deposit rates. For example, [Heider et al. \(2016\)](#) find that in the Eurozone retail deposits tend to be shielded from negative rates even as interbank rates fall below zero.<sup>1</sup> In section 2, I present similar evidence for U.S. banks, and show that fees do not overcome the problem either, as they are quantitatively extremely small relative to the growing deposit base of banks.<sup>2</sup>

This zero lower bound on deposit rates is a challenge for the business model of banks, which earn a margin by investing in relatively safe, long-term assets, that are overwhelmingly funded with short-term, liquid liabilities ([Hanson et al., 2015](#)).<sup>3</sup> This intermediation margin may shrink when banks are constrained in passing on falling interest rates to depositors, as further evidence in section 2 confirms.

How do banks react to this environment of near-zero interest rates and compressed margins? Does it induce a reach for yield, and how should financial regulation react? I study these questions in a tractable dynamic general 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 is tractable and al-

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<sup>1</sup>While 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.

<sup>2</sup>The problem is that unlike interest rates, fees are not proportional to an account's balance. While banks have been increasing fees, deposits were flowing into the banking sector at the same time. Therefore, fees *relative to deposits* have actually been falling.

<sup>3</sup>Over the period 1996-2013, the median U.S. bank in the Call Reports data funds 85% of its assets with deposits. While larger banks have better access to wholesale funding, the median deposit funding is still 76% among banks with a balance sheet size greater than \$1 billion.

lows to pin down analytically how the level of interest rates affects risk shifting incentives and their interplay with bank capital regulation. I also calibrate the model to U.S. data to derive optimal capital requirements in the presence of an occasionally binding ZLB constraint, and derive novel implications for the interplay between monetary and macro-prudential policies.

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 and set deposit rates under monopolistic competition. Households are willing to accept a lower return on deposits because they carry a liquidity service valued in their utility function.<sup>4</sup>

There is a moral hazard problem, as deposits are insured by the government and shareholders have 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 the deposit insurance against the risk of loss of franchise value.

To generate variation in the level of interest rates, the representative household's 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 1996-2008 in figure 2. In the low-rate state deposit rates may be constrained by the ZLB, as from 2009-2015.<sup>5</sup>

In a first step, I use the model to study 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](#)), I find that a reduction in interest rates has little effect on bank risk taking, so long as deposit rates are not constrained

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

<sup>5</sup>Since the only source of aggregate variation is in discount factors, the model abstracts from business cycle dynamics. While interest rates and business cycles are arguably correlated, the goal of this paper is to understand how bank competition, regulation and risk taking are affected by a stochastic process that moves interest rates exogenously.

by 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 into margins and erodes profitability. As a consequence of lower franchise values, banks shift more risk on the deposit insurance, particularly if the yield curve flattens substantially and the ZLB is expected to bind for a long time. Moreover, even in the high-rate state banks take more risk if it is likely that the economy transitions to the low-rate 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.

Crucially, the ZLB not only increases a banks’ incentives to take risk, but may also make capital regulation less effective in curbing such risk shifting incentives. In the model, capital regulation limits the leverage banks can take, reducing risk taking incentives by increasing a banks’ “skin in the game”. 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 regulation exactly during times when bank risk taking incentives are already heightened.

The franchise value effect has implications for optimal capital regulation. Calibrating the model to U.S. data and allowing for a state-dependent capital requirement, I find an optimal level around 7-8% in both the high-rate and low-rate state when the ZLB remains slack. In contrast, if the ZLB occasionally binds in the low-rate state, the optimal capital requirement varies with the interest rate cycle. The reason is that the franchise value effect makes capital regulation less effective in the low-rate state, motivating a weaker requirement despite overall higher risk taking. At the same time, low *expected* profitability increases risk taking incentives in the high-rate state, motivating a tighter requirement. Hence, optimal capital requirements are “macro-prudential”, in the sense that they optimally vary with the interest rate cycle. This point relates to the debate on counter-cyclical capital regulation, where people argue

that capital regulation should vary with the business cycle.<sup>6</sup>

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. 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 resembles funding schemes such as the ECB's targeted long-term refinancing operations or the Bank of England's Funding for Lending and Term Funding schemes.<sup>7</sup> This policy restores incentives as it stabilizes profitability. 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 a recent literature that studies 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. My 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](#)

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<sup>6</sup>The case for counter-cyclical requirements is often made in models with welfare-relevant pecuniary externalities 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.

<sup>7</sup>These policy schemes offer cheap funding to banks, conditional on making loans.

Van den Heuvel, 2017; English et al., 2012).

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, my paper has a distinct focus on risk taking and novel implications for bank capital regulation.

My 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; DellAriccia 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). My paper relates to this literature, but focuses on inefficient risk shifting as a result of agency problems.

A priori it is not clear why the *level* of an equilibrium price (the interest rate) should affect the incentives to take excessive risk. Consequently, most contributions identify mechanisms that explain how the level of interest rates affects the margin between asset returns and cost of liabilities. Relative to the literature, I have a distinct focus on deposit competition in the presence of a zero lower bound on deposit rates. In normal times, interest margins are determined by market power and hence not affected by the level of interest rates. Since additionally lower discount rates boost franchise values, I find that low interest rates may actually decrease risk taking incentives.<sup>8</sup>

My modeling approach is related to recent contributions by Begenau (2016) and Davydiuk (2017), who study optimal capital regulation in quantitative DSGE models with banks. Relative to these papers, a distinct feature of my model is that I allow for market power and bank failure.<sup>9</sup> Because I allow for bank failure, risk taking is driven by franchise value, as banks stand to lose rents upon failure (Hellmann et al., 2000). Introducing market power is

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<sup>8</sup>DellAriccia et al. (2014) also show that lower rates may decrease risk taking. If bank leverage is fixed, the overall cost of liabilities of highly levered banks may decrease relative to the return on loans as rates fall.

<sup>9</sup>In Begenau (2016) banks have unlimited liability, and in Davydiuk (2017) they are bailed out with probability one

necessary for banks to have strictly positive franchise values.

For the franchise value effect to be operative I need to explicitly solve the forward-looking problem of banks in the presence of occasionally binding constraints. To simplify this problem, I minimize the number of state variables, implying that I leave out several elements present for example in [Begenau \(2016\)](#), that would be desirable to include for a quantitative assessment. Therefore, all quantitative results of my paper should be seen as suggestive, although I am still able to meaningfully calibrate the model.

That franchise value affects risk taking has been shown in the banking literature (e.g. [Hellmann et al., 2000](#); [Perotti and Suarez, 2002](#); [Repullo, 2004](#); [Martinez-Miera and Repullo, 2010](#)). To the best of my knowledge I am the first to incorporate it in a dynamic general equilibrium model.

Closely related to my paper, [Hellmann et al. \(2000\)](#) argue that capital requirements should be complemented with interest rate ceilings, since otherwise capital requirements erode franchise value. 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.<sup>10</sup> Effectively, the ZLB has the opposite effect of an interest rate ceiling, imposing a minimum rate banks have to pay to depositors.

Finally, this paper is related to the macroeconomic literature on the zero lower bound and 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, I show 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 in my model 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 and contrasts the competitive equilibrium to the first best allocation, and section 5 studies the determinants of bank risk taking in the model. Section 6 derives optimal capital

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<sup>10</sup>This difference is the result of different modeling choices. The analysis in [Hellmann et al. \(2000\)](#) is based on a Monti-Klein type model of competition. My paper takes a general equilibrium approach, in which all returns are priced by households, and the demand for deposits is endogenously derived from household optimization.

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.

For selected years, figure 1 plots the cross-sectional distribution of U.S. banks' deposit interest expense per unit of deposit funding.<sup>11</sup> 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.<sup>12</sup>

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 left panel of figure 2, which plots the spread of corporate bond yields over median deposit interest expense.<sup>13</sup> 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. While bank-level measures of interest

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<sup>11</sup>Following 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.

<sup>12</sup>Anecdotal 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.

<sup>13</sup>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 offered on deposits. The bond yield is the BofA Merrill Lynch US Corporate AAA Effective Yield, retrieved from FRED.



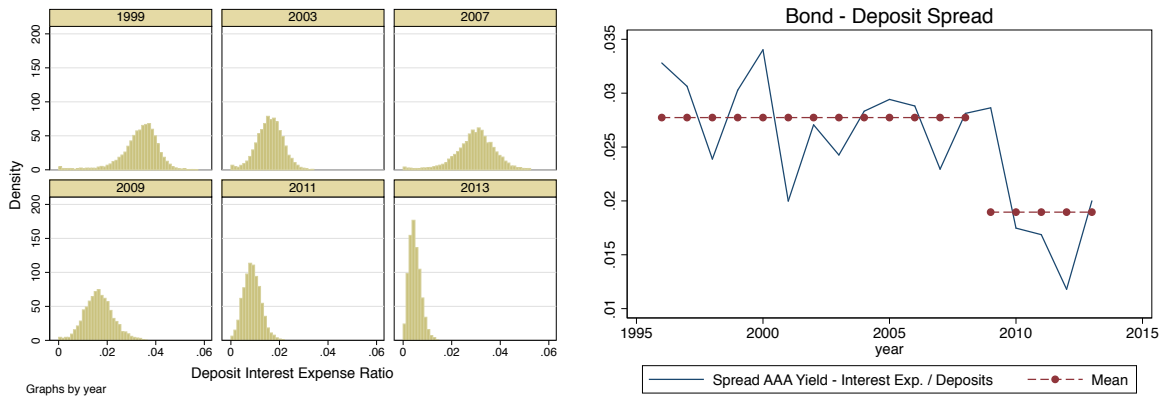


Figure 1: For selected years from 1999-2013, the left panel plots the cross-sectional distribution of deposit interest expense per unit of deposit funding across U.S. banks in the Call Reports data. The deposit interest expense ratio is defined as interest expenses per unit of deposits. The right panel 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.

income may be confound with higher risk taking, appendix B shows that the spread between the interest income ratio and deposit interest expense ratio 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. 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 1). While banks have been increasing fees (Azar et al., 2016), at the same time more deposits have been flowing into the banking system. Intuitively, in a low interest environment households gain little from hunting yield in 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 a 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 net income (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.

Overall, the evidence suggests that the zero lower bound on deposit rates binds, and that it

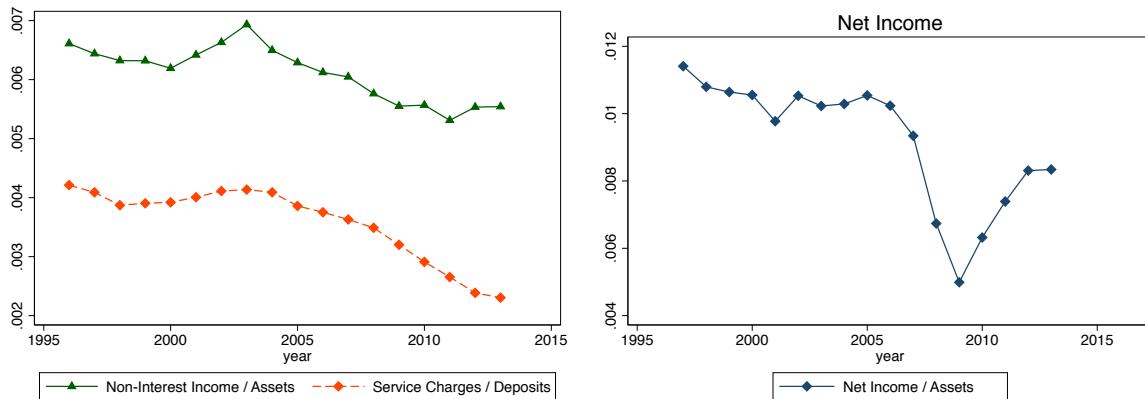


Figure 2: The left panel plots non-interest income per unit of assets, as well as service charges per unit of deposits for the median U.S. bank in the Call Reports data. Figure 10 in the appendix reports histograms for additional years. The right panel plots the median net income over assets.

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, competition 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 as 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 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.<sup>14</sup>

Banks compete monopolistically for deposit funding, subject to a zero lower bound on deposit rates.<sup>15</sup> Deposits are insured by the government, which funds the insurance through

<sup>14</sup>In 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.

<sup>15</sup>Here, the ZLB is exogenously assumed, but it can be motivated by the option to hoard cash with a net

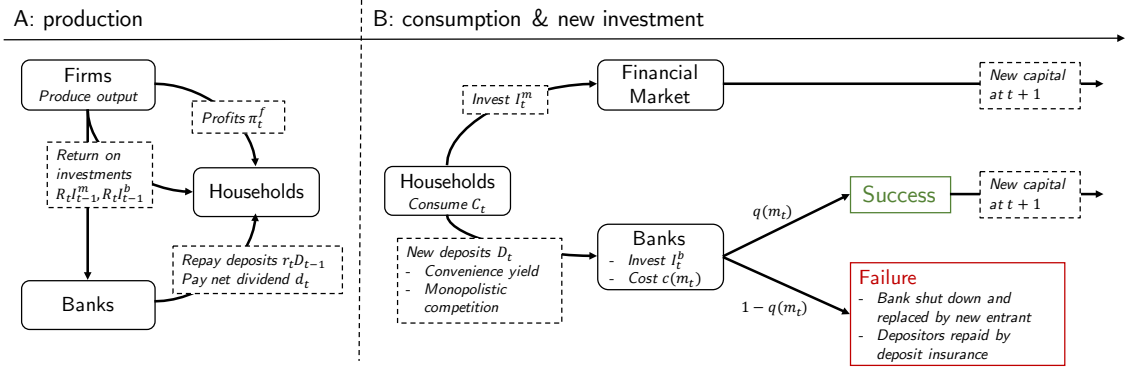


Figure 3: Flow diagram summarizing the within-period timing.

taxes running a balanced budget.<sup>16</sup> Moreover, banks choose the riskiness of their loans 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 I allow the household's discount factor to vary 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.

return of zero. In this paper, the ZLB plays the role as an off-equilibrium outside option, and its exact motivation is irrelevant.

<sup>16</sup>Deposit insurance is taken as a given institutional feature, rather than an active policy tool. Indeed, in the U.S. nation-wide deposit insurance has been in place since the Banking Act in 1933. It can be motivated in an environment with inefficient bank runs (Diamond and Dybvig, 1983), which are not the focus of this paper.

### 3.1. Firms

Firms operate a production technology and produce output using capital  $K_t$  as the only input,

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

where  $\alpha < 1$ . Firms start with an initial capital stock  $K_0$ . In subsequent periods, capital depreciates with a rate  $\delta$  and firms buy new capital from households and banks, such that the capital stock evolves according to

$$K_t = (1 - \delta)K_{t-1} + I_{t-1}^m + \tilde{I}_{t-1}^b.$$

Here,  $I_{t-1}^m$  denotes newly produced capital by households investing in the financial market, and  $\tilde{I}_{t-1}^b$  new capital created through bank loans. Denoting by  $R_t$  the return on newly produced capital, firm profits in period  $t$  can be written as

$$\pi_t^f = F(K_t) - R_t(K_t - (1 - \delta)K_{t-1}).$$

The firm problem is to maximize expected profits, discounted by the household's stochastic discount factor  $\beta_t$ ,

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

### 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. Following [Dixit and Stiglitz \(1977\)](#) I model this preference by expressing  $D_t$  as a CES composite of varieties  $D_{t,i}$ ,

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

In this model of monopolistic competition product differentiation gives banks some market power, the degree of which is governed by the elasticity of substitution  $\eta$ .<sup>17</sup> Higher values of

<sup>17</sup>Arguably, 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](#)).

$\eta$  indicate greater ease of substitutability 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  $\pi_t^f$  and banks make a net dividend payment  $d_t^b$ , which may take negative values when raising new equity.

The household's discount factor  $\beta_t$  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  $D_t$ , and the problem of the representative household is given by

$$\begin{aligned} \max_{C_t, I_t^m, D_{t,i}} \quad & \mathbb{E}_0 \sum_{t=0}^{\infty} \left( \prod_{\tau=0}^{t-1} \beta_{\tau} \right) [C_t + \gamma v(D_t)] \\ \text{with} \quad & D_t = \left[ \int_0^1 D_{t,i}^{\frac{\eta-1}{\eta}} di \right]^{\frac{\eta}{\eta-1}}, \\ \text{s.t.} \quad & C_t + I_t^m + \int_0^1 D_{t,i} di = R_t I_{t-1}^m + \int_0^1 r_{t,i} D_{t-1,i} di + d_t^b + \pi_t^f - T_t, \\ & C_t, I_t^m, D_{t,i} \geq 0. \end{aligned} \tag{2}$$

Here,  $\gamma \geq 0$  measures the household's preference for liquidity services, and  $v(D_t)$  is a CRRA utility function with relative risk aversion  $\theta$ . The deposit rate offered by bank  $i$  is denoted  $r_{t,i}$ , and  $T_t$  are taxes raised by the government to fund the deposit insurance. The first constraint is the household's budget constraint, and the second a non-negativity constraint for consumption, deposits and investments in the financial market.

The first-order condition with respect to  $I_t^m$  yields the household's Euler equation

$$R_{t+1} \beta_t = 1. \tag{3}$$

Since  $\beta_t$  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  $R_{t+1} = 1/\beta_L \equiv R_L$ . 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.<sup>18</sup>

<sup>18</sup>Arguably, variations in discount factors are not the main driver behind movements in interest rates. The

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  $D_{t,i}$ :

$$D_{t,i}(r_{t+1,i}) = \left[ \frac{1 - r_{t+1,i}/R_{t+1}}{\gamma v'(D_t)} \right]^{-\eta} D_t, \quad (4)$$

where I use that  $\beta_t = 1/R_{t+1}$  by (3). 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  $\eta$  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  $\gamma$ .

### 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, capital regulation requires that  $e_{t,i} \geq \bar{e}_t$ .

Each bank has access to a single project that I refer to as bank loans. Since  $e_{t,i}$  is expressed 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, that is sold to firms in the following period. The success probabilities across banks are i.i.d., such that there is no aggregate risk.

In case of failure, the project produces nothing and the bank fails. Depositors of failing institutions are repaid by the deposit insurance fund, but failing banks are not bailed out and cannot continue operating. To keep the total number of banks constant, I assume that each failing bank can be replaced by a new entrant, but that the total number of bank licenses is fixed as mass 1.<sup>19</sup>

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

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goal here is not to explain why interest rates are low, and this simple formulation allows to study the implications of low interest rates while preserving tractability.

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

of the standard Gaussian distribution,  $q(m_t) = \Phi(m_t)$ .<sup>20</sup> 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  $\psi_1$  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.

Crucially, the bank's monitoring intensity is not observable and can therefore not directly be constrained by financial regulation. Instead, the choice of  $m_t$  must be incentive compatible, implying that banks generally do not choose the socially optimal level of risk taking.

A crucial element in the analysis will be the value of the bank's franchise  $V_t$ , which generally takes strictly positive values due to the market power of banks.<sup>21</sup> To define the franchise value, it is useful to write the bank's problem recursively as

$$\begin{aligned} V_t &= \max_{m_{t,i}, e_{t,i}, r_{t+1,i}} \pi_{t,t+1}^b D_{t,i}(r_{t+1,i}) + q(m_{t,i}) \beta_t \mathbb{E}_t V_{t+1}, \\ \text{with} \quad \pi_{t,t+1}^b &= (q(m_{t,i}) \beta_t [R_{t+1}(1 + e_{t,i}) - r_{t+1,i}] - [e_{t,i} + (1 + e_{t,i})c(m_{t,i})]), \\ \text{s.t.} \quad D_{t,i}(r_{t+1,i}) &= \left[ \frac{1 - r_{t+1,i}/R_{t+1}}{\gamma v'(D_t)} \right]^{-\eta} D_t, \\ e_{t,i} &\geq \bar{e}_t, \\ r_{t+1,i} &\geq 1. \end{aligned} \tag{5}$$

Here,  $\pi_{t,t+1}^b$  are discounted expected profits per unit of deposits raised at period  $t$ .<sup>22</sup>

The FOC w.r.t.  $e_{t,i}$  shows that banks always choose the minimum amount of equity consistent with the capital requirement,  $e_{t,i} = \bar{e}_t$ :

$$\frac{\partial V_t}{\partial e_{t,i}} = q(m_t) \beta_t R_{t+1} - (1 + c(m_t)) \leq 0. \tag{6}$$

The inequality follows from using that  $\beta_t R_{t+1} = 1$ , by the household's Euler equation (3). Banks choose the minimum level of capital because bank equity is privately and socially costly.

<sup>20</sup>The advantage is that this function is well behaved and bounded between 0 and 1.

<sup>21</sup>When 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  $V_t \geq 0$ .

<sup>22</sup>Hence,  $V_t$  is defined as the value of a bank after paying out its entire earnings as dividends. Net dividends transferred to households at time  $t$  are  $d_t^b = [R_t(1 + e_{t-1,i}) - r_{t,i}] D_{t-1}(r_{t,i}) - [e_{t,i} + (1 + e_{t,i})c(m_{t,i})] D_t(r_{t+1,i})$ , with negative values indicating net equity raised. Note that only the net payout matters, since there are no costs to adjusting dividends (in contrast to, e.g. [Begenau \(2016\)](#)).

Households can always invest in the financial market, producing one unit of capital per unit of investment. In contrast, a unit of bank loans has the cost  $(1 + c(m_t))$ . Hence, investments in the bank's technology are dominated, making it costly to put equity into banks.<sup>23</sup>

The first-order conditions with respect to the deposit rate and monitoring intensity jointly determine  $r_{t+1}$  and  $m_t$ :

$$r_{t+1} = \max \left\{ R_{t+1} \left[ 1 - \frac{\eta}{\eta - 1} \frac{(1 - q(m_t))e_t + (1 + e_t)c(m_t)}{q(m_t)} \right], 1 \right\}, \quad (7)$$

$$c'(m_t)(1 + e_t)D_t = q'(m_t)\beta_t [(1 + e_t)R_{t+1} - r_{t+1}]D_t + \mathbb{E}_t V_{t+1}. \quad (8)$$

In the first case in (7), 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 the cost of equity and charge a mark-up that depends on the elasticity of substitution between deposits  $\eta$  (a higher level of  $\eta$  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.

Condition (8) is the bank's incentive compatibility constraint governing its risk taking. It 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 continuation value  $\mathbb{E}_t V_{t+1}$  on the right hand side, the more intensely it monitors. That is, higher franchise value reduces bank risk taking.

Note that I dropped all  $i$  subscripts, since the solution to the bank's problem does not depend on any individual characteristics and hence the equilibrium is symmetric.

### 3.4. Government

To close the model, the government runs a balanced budget to finance the deposit insurance. In a symmetric equilibrium, each period a fraction  $(1 - q(m_{t-1}))$  of banks fail, such that the government needs to raise taxes of

$$T_t = (1 - q(m_{t-1}))r_t D_{t-1} \quad (9)$$

to repay depositors of failing banks. Finally, the government sets the capital requirement  $\bar{e}_t$ , which is taken as exogenously given for now (section 6 derives the welfare-maximizing level

<sup>23</sup>Note, 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.



of  $\bar{e}_t$ ).

### 3.5. Equilibrium

The only state variables of the model are the capital stock  $K_t$  and the realization of the discount factor  $\beta_t$ . Both are known at the beginning of the period, and decisions are made subsequently. In the following equilibrium definition I use the fact that the equilibrium is symmetric (since none of the bank's first-order conditions are bank-specific).

**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  $\{R_t, r_t\}_{t=0}^{t=\infty}$  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  $\{R_t\}_{t=0}^{t=\infty}$ , firms maximize profits (1).*
- (b) *Given prices  $\{R_t, r_t\}_{t=0}^{t=\infty}$  and government policies  $\{T_t, \bar{e}_t\}_{t=0}^{t=\infty}$ , households maximize lifetime utility solving (2).*
- (c) *Given prices  $\{R_t\}_{t=0}^{t=\infty}$  and government policies  $\{T_t, \bar{e}_t\}_{t=0}^{t=\infty}$ , banks maximize net dividends solving (5).*
- (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:*

$$K_t = (1 - \delta)K_{t-1} + I_{t-1}^m + q(m_t)I_{t-1}^b,$$

*with*

$$I_t^b = (1 + e_t)D_t.$$

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  $t$ .<sup>24</sup> This property simplifies solving the bank’s problem, since it allows to explicitly derive the expected franchise value as

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

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  $\mathbb{E}_s x_{t+1} \equiv \mathbb{E}_t[x_{t+1}|s]$ .

### 3.6. Calibration

I derive as many results as possible analytically, but also rely on a numerical solution of the model when analytics are ambiguous. 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 find, and allows me to solve for optimal capital requirements in section 6.

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.<sup>25</sup> 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 period 1984-2013. The parameter  $\psi_2$  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

<sup>24</sup>In fact, the equilibrium values of all variables except for  $I_t^m$  and  $C_t$  are memory-less.

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

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  $\eta$  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  $\gamma$  and  $\theta$  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 - 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 other elements. I will 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 an ATM network and electronic payment infrastructure that make deposits a convenient medium of exchange.

**Bank costlier than the financial market.** I assume that 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 (6) 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 think that deposit insurance and the liquidity service of deposits already make bank equity costly. However, this is only true in a model in which the balance sheet size of a bank is fixed, such that 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.<sup>26</sup>

It is less important that banks do not have access to the dominating “financial market” technology. In the Internet Appendix I derive an extension of the model, in which the market technology dominates yet banks choose to invest in their own “bank loan” technology. This can be ensured by controlling the overall cost  $\psi_1$  of operating a bank. Here I simply assume that banks only have access to their own technology, allowing for a streamlined solution of the model.<sup>27</sup>

**Riskless financial market.** While perhaps counter-intuitive, it is also not important that investments in the financial market are riskless. Since households are risk-neutral, one could

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<sup>26</sup>To 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 is indeed less than  $R_{t+1}/q(m_t)$  if there is either deposit insurance or deposits have a non-pecuniary convenience yield.

<sup>27</sup>In the extension, the market technology succeeds with probability  $\mu < 1$ , and one needs to check that in equilibrium banks prefer to invest in loans, implicitly defining cut-off values for the parameters  $\psi_1$  and  $\mu$  that need to be checked.

easily introduce risk in the financial market. What matters is that there is some risk at the bank level investment, to introduce the possibility of bank failure and moral hazard.

**No bailouts.** In the model banks are never bailed out upon failure, and bank failures impose no distress costs on the rest of the system. While in the real world regulators tend to take a tough no-bailout stance *ex ante*, the immense costs of the failure of large institutions often forces regulators to bail out banks *ex post* (e.g. [Acharya and Yorulmazer, 2007](#)). Both elements could easily be added to model. A (possibly endogenous) bailout probability would dampen the franchise value effect, as banks may be able to continue operating even after failure. This would increase the risk taking incentives of banks. A higher cost of bank failure would motivate tighter capital regulation in equilibrium.

**Entry.** In the model, the total number of bank licenses is limited to 1, ensuring that entry is always profitable since there are rents to be earned. Indeed, in the real world there are many regulatory barriers to entry in the banking industry. For 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.<sup>28</sup>

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 consistent with this notion. Since the ZLB started binding in 2008, the average number of banks per county has been dropping from around 14.5 to 13.5.

This effect is not present in my model, because entry is still profitable at the ZLB, as banks earn monopolistic profits.<sup>29</sup> 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

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<sup>28</sup>See for example the FAQ on “How can I start a bank?” on the website of the Board of Governors of the Federal Reserve System.

<sup>29</sup>Except 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.

of the degree of competition between banks.

**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 can alleviate some of the pressure on profitability, and result in a misallocation of finance between bank-dependent and bank-independent borrowers. However, banks are not monopolist and at the margin some borrowers can substitute to other sources of finance. While market power may support margins to some extent, it would still not fully overcome the problem.

#### 4.2. First Best and Inefficiencies

Before analyzing the model, 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:

$$\begin{aligned}
& \max_{C_t, I_t^m, D_{t,i}, m_t, e_t} && \mathbb{E}_0 \sum_{t=0}^{\infty} \left( \prod_{\tau=0}^{t-1} \beta_{\tau} \right) [C_t + \gamma v(D_t)] \\
& \text{with} && D_t = \left[ \int_0^1 D_{t,i}^{\frac{\eta-1}{\eta}} di \right]^{\frac{\eta}{\eta-1}}, \\
& \text{s.t.} && C_t + I_t^m + \int_0^1 (1 + e_{t,i}) D_{t,i} (1 + c(m_{t,i})) = F(K_t), \\
& && K_t = (1 - \delta) K_{t-1} + I_{t-1}^m + q(m_t) (1 + e_t) D_t \\
& && C_t, I_t^m, m_{t,i}, D_{t,i} \geq 0
\end{aligned} \tag{10}$$

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  $D_t$ :

$$\beta_t R_{t+1} = 1 \quad (11)$$

$$c'(m_t) = q'(m_t) \quad (12)$$

$$D_t = \left( \frac{\gamma}{1 - q(m_t) + c(m_t)} \right)^\theta \quad (13)$$

These three conditions are readily compared to their counterparts in the competitive equilibrium. First, (11) is equivalent to the household's Euler equation (2), implying that the overall level of capital accumulation is not distorted.

In contrast, condition (12) 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 (8).

Similarly, condition (13) can be compared to the demand for deposits by households (13), after rewriting it as

$$D_t = \left( \frac{\gamma}{1 - r_{t+1}/R_{t+1}} \right)^\theta. \quad (14)$$

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 (7).

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 frictions in the model that are (i) deposit insurance and limited liability, and (ii) monopolistic competition.

Limited liability and deposit insurance give banks an option-like payoff as they do not internalize the losses incurred in case of failure. This convex payoff structure induces excessive risk taking. On the other hand, (ii) 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. These rents are of private value to banks but do not add to welfare. Generally, banks trade off the gains from shifting risk on the deposit insurance against the risk of loss of franchise value. In the baseline calibration, banks take excessive risk relative to the first best.

## 5. Risk Taking off and at the Zero Lower Bound

Given that banks do not take the optimal level of risk, the goal of this section is to study how risk taking incentives are affected by the level of interest rates and other parameters in the model. It turns out that the answer crucially depends on whether the ZLB binds. For that reason, I start by showing under what conditions banks indeed do become constrained in setting their deposit rate.

### 5.1. Zero Lower Bound

Banks set their deposit rate according to the first-order condition (7). This may either be at an interior solution if the return of 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*

$$\beta_s \leq \beta_s^{ZLB}, \quad (15)$$

where  $\beta_s^{ZLB}$  is implicitly defined by

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

and  $m_s^*$  denotes the equilibrium level of monitoring as a function of  $\beta_s^{ZLB}$ , implicitly defined by (3), (4), (7) and (8).

Lemma 1 defines a threshold  $\beta_s^{ZLB}$ , 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  $\beta_t$ .

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



- If  $\beta_t \leq \beta_s^{ZLB}$  (slack ZLB) a marginal increase in  $\beta_t$  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  $\beta_t$  (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, rewrite the bank's FOC w.r.t. monitoring (8) as

$$\frac{c'(m_t)}{q'(m_t)} = 1 - \underbrace{\frac{1}{(1+e_t)} \frac{r_{t+1}}{R_{t+1}}}_{\text{Margin on current loans}} + \underbrace{\beta_t \frac{\mathbb{E}_t V_{t+1}}{(1+e_t)D_t}}_{\text{Discounted franchise value}}. \quad (16)$$

The left-hand side increases in monitoring  $m_t$ .<sup>30</sup> The right-hand side reveals that the level of interest rates affects monitoring via a *margin channel* and a *discounting channel*. A higher level of  $\beta_t$  implies that banks discount their continuation value  $\mathbb{E}_t V_{t+1}$  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, an increase in  $\beta_t$  directly pushes down  $R_{t+1}$  (by the households Euler equation 3). A low return on capital may harm interest margins and thereby induce higher risk taking. However, as long as banks set deposit rates according to the interior solution in (7), the relevant ratio  $\frac{r_{t+1}}{R_{t+1}}$  on the right-hand side is not a function of  $\beta_t$ :

$$\frac{r_{t+1}}{R_{t+1}} = 1 - \frac{\eta}{\eta - 1} \frac{(1 - q(m_t))\bar{e}_t + (1 + \bar{e}_t)c(m_t)}{q(m_t)}. \quad (17)$$

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,

$$\frac{r_{t+1}}{R_{t+1}} = \frac{1}{R_{t+1}}, \quad (18)$$

and any reduction in  $R_{t+1}$  directly eats into interest margins. This effect is illustrated in the left panel of figure 4, which plots the return on capital  $R_L$  and equilibrium deposit rate  $r_L$

<sup>30</sup>To be precise, the left-hand side increases in  $m_t$ , as long as  $m_t \geq \frac{1}{2}$ . In equilibrium, always  $m_t \geq \frac{1}{2}$  because the Gaussian distribution is symmetric, and .

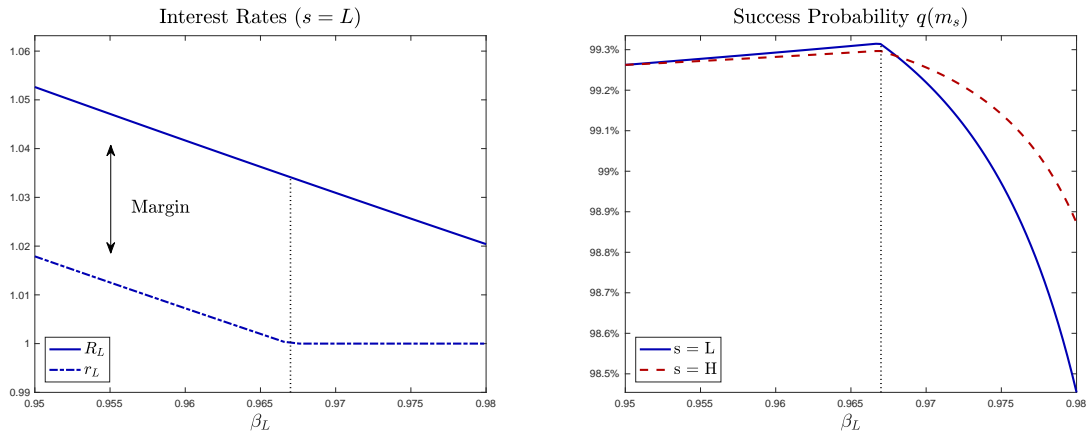


Figure 4: This figure plots equilibrium interest rates in the low-rate state ( $s = L$ ), and equilibrium bank risk taking in both the low- and high-rate states, against the discount factor in the low-rate state  $\beta_L$ . The vertical dotted line indicates the threshold  $\beta_L^{ZLB}$ , beyond which the ZLB is binding. Parameters are calibrated as described in section 3.6.

in the low-rate state, against the level of the discount factor  $\beta_L$ .<sup>31</sup> 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 overall effect on risk taking depends on the balance between the discounting and margin channel. The right panel of figure 4 plots the equilibrium success probability  $q(m_L)$  against the discount factor  $\beta_L$ . The discounting effect dominates as long as the ZLB is slack ( $\beta_L \leq \beta_L^{ZLB}$ ), as margins are stable.<sup>32</sup> The effect on risk taking is rather 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, the margin effect dominates when the ZLB binds. This can be shown analytically (proposition 1), by plugging  $r_{t+1} = 1$  into (16) (also using 14). Figure 4 suggests that the magnitude of the effect is sizable, more than doubling the annual probability of failure, 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  $\beta_L = 0.98$ ).

<sup>31</sup>Note that the comparative statics in proposition 1 regard a marginal change in  $\beta_t$ , keeping  $\beta_{t+1}, \beta_{t+2}, \dots$  constant. Figure 4 complements this result, varying the level  $\beta_L$  that applies whenever the low-rate state obtains.

<sup>32</sup>Analytically, this can be shown by plugging the interior solution from (7) into (16), also using (14). Doing so, the right hand side of (7) only depends on  $\beta_t$  via the discounting effect.

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

### 5.3. Expectations Matter

Because expected future 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*

$$\beta_L \geq \hat{\beta}, \tag{19}$$

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

$$\frac{dm_s}{dP_{LL}} < 0, \frac{dm_s}{dP_{HH}} > 0$$

When  $\beta_L > \hat{\beta}$ , the ZLB binds and intermediation margins are sufficiently compressed, such that  $V_H > V_L$ . 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  $q(m_s)$  against the likelihood of remaining in the low-rate state  $P_{LL}$ . In the baseline calibration indeed  $V_H > V_L$ , such that condition (19) is satisfied and an increase in  $P_{LL}$  results in more risk taking (lower  $q(m_s)$ ).

The right panel in figure 5 connects this result to the yield curve, here calculated assuming that the expectations hypothesis holds.<sup>33</sup> This calculation shows that 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

<sup>33</sup>I.e. the forward rate from date  $t$  to  $t + \tau$  is calculated as  $R_{t,t+\tau} = (R_{t+1} \times R_{t+2} \cdots \times R_{t+\tau})^{1/\tau}$ .

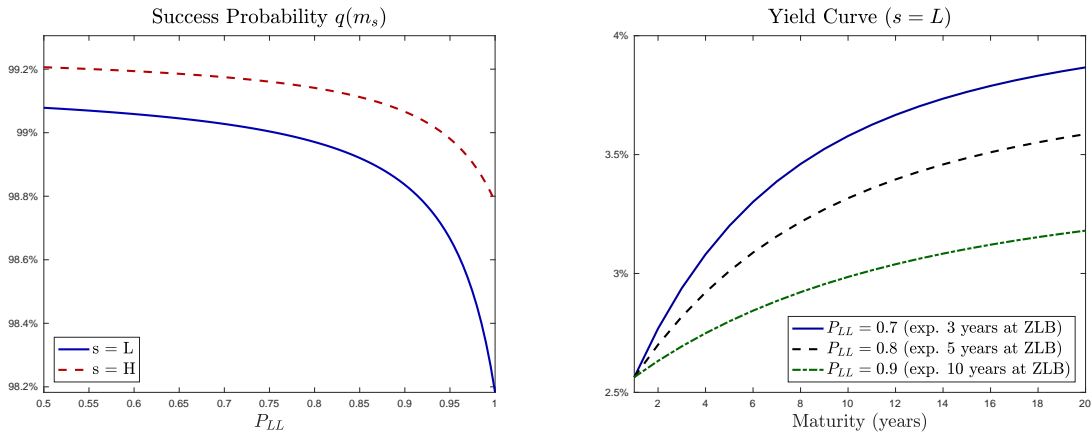


Figure 5: This figure plots bank risk taking in both the low- and high-rate states, against the probability of staying in the low-rate state (left panel). The right panel illustrates how an increase in the probability of remaining in the low-rate state  $P_{LL}$  translates into a flattening of the yield curve. Parameters are calibrated as described in section 3.6.

in the low-rates state of around  $P_{LL} = 0.85$ . 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 2017.

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 also shows that even when banks are not currently constrained by the ZLB, 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 (lower  $P_{HH}$ ), 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.<sup>34</sup>

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.

## 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 I illustrate after describing how I calibrate the model.

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<sup>34</sup>[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.

## 6.1. The Effectiveness of Capital Requirements

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:*

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

The intuition for this result is the typical “skin in the game” mechanism. 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. This is shown in the following lemma:

**Lemma 2** (Franchise Value Effect). *For a given level of monitoring  $m_s$ , bank profits as a function of the capital requirement are given by*

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

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.

Since weak profitability implies lower franchise value, capital regulation becomes a less effective tool to curb risk shifting incentives at the ZLB. This is shown in equilibrium in the numerical solution in figure 6, using the baseline calibration of section 3.6. 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  $\beta_L$  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  $V_L$ , in line with lemma 1. In contrast, when the ZLB binds (at  $\beta_L = 0.975$ ), higher capital requirements erode profitability. The figure also reveals that the adverse effect on franchise value is particularly strong, the longer the economy remains at the ZLB in expectation. Intuitively, the longer the ZLB binds, the lower is bank profitability *in expectation*.

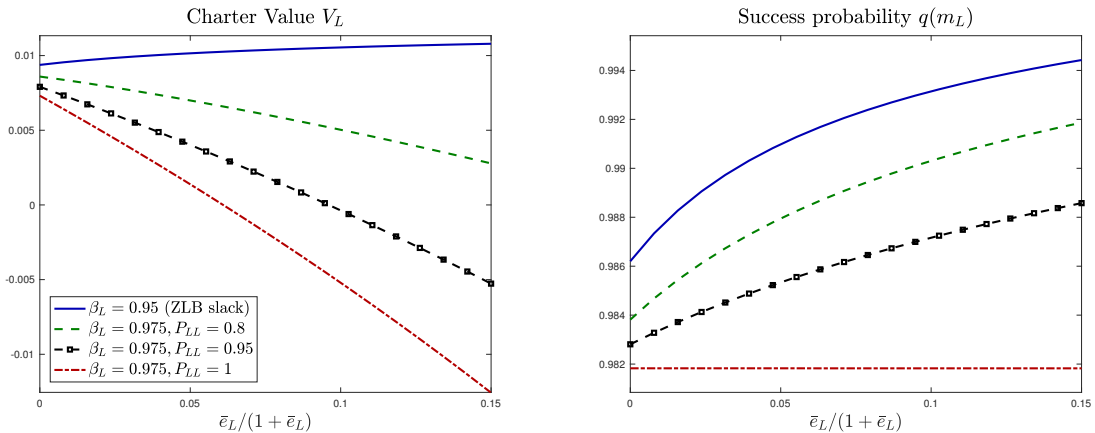


Figure 6: This figure plots franchise values (left panel) and risk taking (right panel) in the low-rate state, against the capital requirement  $\bar{e}_L$ . Different lines represent different levels of interest rates and probability of remaining in the low-rate state. Parameters are calibrated as described in section 3.6.

The right panel of figure 6 shows the implication for risk taking. The more the capital requirement depresses franchise values, the less it curbs risk shifting. 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 limiting case with  $P_{LL} = 1$ , the capital overhang effect completely overrules the skin in the game effect, such that capital regulation does not affect risk taking at all. This result can be shown analytically:<sup>35</sup>

**Proposition 4.** *Suppose  $\beta_L > \beta_L^{ZLB}$  (ZLB binds at 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,*

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

<sup>35</sup>To see that the capital requirement becomes ineffective, evaluate (16) at  $s = L$  and  $r_L = 1$ , using  $D_L$  from (14) and  $V_L$  from (20). After some algebra, it can be seen that with  $P_{LL} = 1$  all  $\bar{e}_L$  drop out from the right hand side of (16), implying that  $m_L$  is unaffected by  $\bar{e}_L$ .

## 6.2. Optimal Capital Regulation

Given that at the ZLB capital requirements may be less effective, what are the implications 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 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”. To be very clear, this means that I take deposit insurance and the level of competition as given, i.e. they are not part of the policy choice set.<sup>36</sup>

The result of this exercise is presented in the top panel of figure 7, for different levels of the household's discount factor  $\beta_L$ . When  $\beta_L < \beta_L^{ZLB}$  interest rates are high and the ZLB is slack. In this region, I find an optimal capital requirement 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.<sup>37</sup> In contrast, when the ZLB binds ( $\beta_L > \beta_L^{ZLB}$ ) the optimal capital requirement in the low-rate state,  $e_L^*$ , drops significantly and is U-shaped in  $\beta_L$ , while that in the high rate state,  $e_H^*$  increases.

To understand this pattern, note that in equilibrium banks take too much risk, i.e. the equilibrium level of monitoring  $m_L$  is below first best (bottom-left panel of figure 7).

While an increase in the capital requirement reduces risk taking, it also undermines the liquidity creation of banks. Focusing for now on the case of a slack ZLB ( $\beta_L \leq \beta_L^{ZLB}$ ),

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<sup>36</sup>Nation-wide deposit insurance is a long established institution that has been in place in the U.S. since the Banking Act in 1933.

<sup>37</sup>In 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.



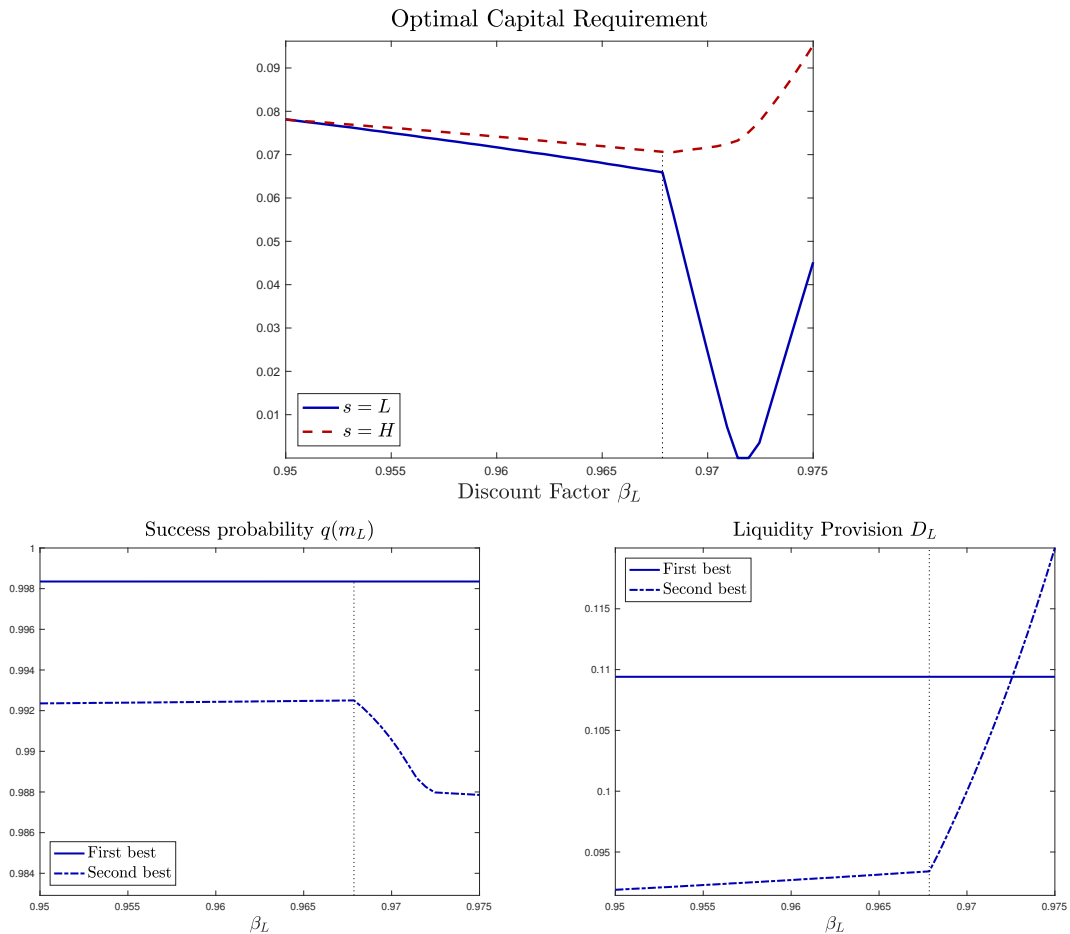


Figure 7: The top panel plots the optimal state-dependent capital requirement, for different levels of the discount factor in the low-rate state. The bottom panels plot for both the first best and second best the equilibrium success probabilities  $q_L$  and quantity of deposits  $D_L$ . The vertical dotted line marks the threshold  $\beta_L^{ZLB}$ , beyond which the ZLB binds in the low-rate state. Parameters are calibrated as described in section 3.6.

the bottom-right panel of figure 7 reveals that banks provide too little liquidity, i.e. the equilibrium level of  $D_L$  is below first best.

From equation (18), banks pass on the cost of capital in the form of a higher interest margin (for a given level of  $m_L$ ,  $r_L/R_L$  decreases in  $e_L$ ). The optimal level of the capital requirement trades off a reduction in risk taking against lower liquidity provision. These two countervailing forces are optimally traded off at a capital requirement near 8% when  $\beta_L = \beta_H = 0.95$  and the ZLB is slack. Recall from proposition 1 that lower discount rates induce banks to take less risk. This explains that for higher levels of  $\beta_L$  the optimal capital requirement decreases

slightly, allowing for a higher level of liquidity provision while keeping the equilibrium success probability at a stable level.

### 6.3. Regulation Over the Interest Rate Cycle

Optimal capital requirements change substantially when deposit rates are occasionally constrained by the ZLB ( $\beta_L > \beta_L^{ZLB}$ ). The franchise value effect renders capital requirements less effective in curbing moral hazard, motivating a weaker use at the ZLB. This effect explains the drop in the optimal capital requirement  $e_L^*$  for  $\beta_L > \beta_L^{ZLB}$  found in figure 7.<sup>38</sup> It also explains why capital regulation optimally allows more risk taking at the ZLB (bottom left panel of figure 7).

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, the optimal capital requirement at  $\beta_L = 0.975$  is still substantially lower than at  $\beta_L = \beta_L^{ZLB}$  ( $\approx 4.5\%$  vs  $7\%$ ).

At the same time, depressed franchise values in the low-rate state motivate a tighter level of capital requirement  $e_H^*$ . Because the ZLB is slack in the high-rate state, here the effectiveness of capital requirements is not undermined by the capital overhang effect. Heightened risk taking incentives induced by low expected profitability (upon falling back to the low-rate state) therefore unambiguously motivate a higher level of  $e_H^*$ .

Thus, optimal capital requirements vary with the interest rate cycle, relating 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.

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<sup>38</sup>The optimal level of the capital requirement drops 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 model. The binary shock structure ignores the “loss absorbing capacity” element 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 capital overhang effect would still be present in this alternative version of the model. The binary shock structure puts the focus on moral hazard and still delivers a realistic quantitative assessment of the optimal capital requirement away from the ZLB.

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 any costs to raising equity, and absent 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 because at the ZLB capital requirements may be a less effective tool to curb moral hazard.

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, there may be a case to jointly set the two policies.

#### 6.4. 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  $\tau_t$  per unit of deposits, paid to banks whenever the ZLB binds. The subsidy is set to replicates whatever negative rate banks want to set, 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 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 provide cheap funding to banks, conditional on making loans. For example, the second round of TLTRO (TLTRO-II) was announced in March 2016, and enabled banks to borrow up to 30% of the amount of their existing stock of loans to non-financial corporations and households. The maximum rate banks have to pay for TLTRO-II funding is zero (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

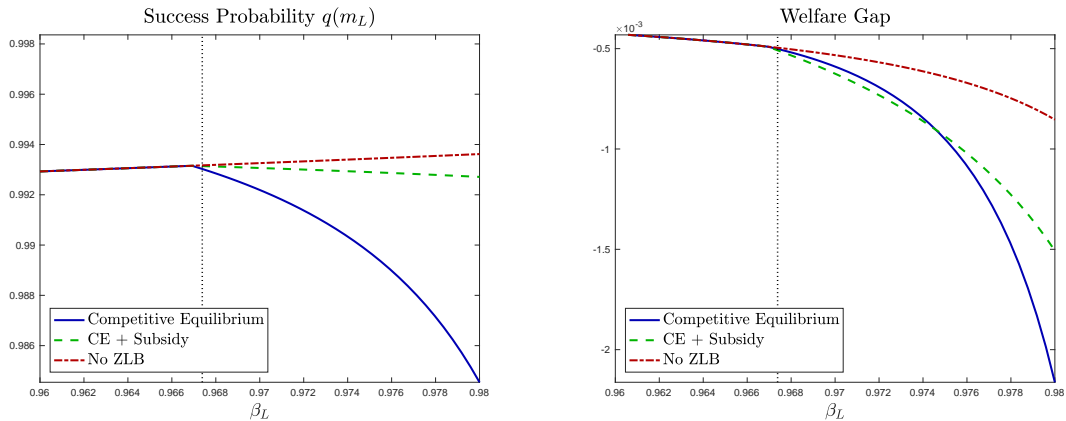


Figure 8: Risk taking (left panel) and welfare gap relative to the first best equilibrium (right panel), for different levels of  $\beta_L$ , under the competitive equilibrium, the equilibrium with a subsidy on deposits, and the equilibrium absent the ZLB friction. Parameters are calibrated as described in section 3.6.

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.<sup>39</sup> Only when rates are quite low ( $\beta_L$  high) does the subsidy result in a higher level of welfare. The taxes raised to fund the subsidy create an additional 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 many central banks are preparing for a “normalization” of interest rates, 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

<sup>39</sup>As 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.

financial regulation.

I show that the zero lower bound distorts bank competition, weakens profitability and induces higher risk taking. This effect is particularly strong if the yield curve flattens substantially and rates are expected to remain low for a long time. Moreover, 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 affect the effectiveness of bank capital regulation in curbing risk shifting incentives. At the ZLB, banks cannot pass on the cost of capital to depositors, such that tight capital requirements erode franchise value. This effect has the perverse effect of increasing risk taking incentives, undermining the usual “skin in the game” effect of capital requirements ([Holmstrom and Tirole, 1997](#)).

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, future research should study their joint determination.

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## A. Paper Appendix

### A.1. Equilibrium conditions

All equilibrium conditions can be summarized as follows:

- Firms

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

- 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

$$\begin{aligned}
 \frac{c'(m_t)}{q'(m_t)} &= \frac{[(1 + e_t)R_{t+1} - r_{t+1}]D_t + \mathbb{E}_t V_{t+1}}{(1 + e_t)D_t R_{t+1}} \\
 V_t &= \pi_{t,t+1}^b + q(m_t, i)\beta_t \mathbb{E}_t V_{t+1}, \\
 \pi_{t,t+1}^b &= (q(m_t)\beta_t [R_{t+1}(1 + e_t) - r_{t+1}] - [e_t + (1 + e_t)c(m_t)]) D_t, \\
 e_t &= \bar{e}_t, \\
 r_{t+1} &= \max \left\{ R_{t+1} \left[ 1 - \frac{\eta}{\eta - 1} \frac{(1 - q(m_t))e_t + (1 + e_t)c(m_t)}{q(m_t)} \right], 1 \right\}.
 \end{aligned}$$

## 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 (5), 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  $s \in \{H, L\}$ :

$$V_s = \frac{1}{\Lambda} [(1 - q(m_{s'}))\beta_{s'} P_{s's'} \pi_s D(r_s) + q(m_s)\beta_s P_{ss'} \pi_{s'} D(r_{s'})], \quad (20)$$

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 (14). By lemma 1, if  $\beta_L > \beta_L^{ZLB}$ , the ZLB binds. In this case, one can write  $\pi_L$  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 (20), 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  $\beta_L$  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 (16), 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  $\eta$  in the model). When the ZLB binds,

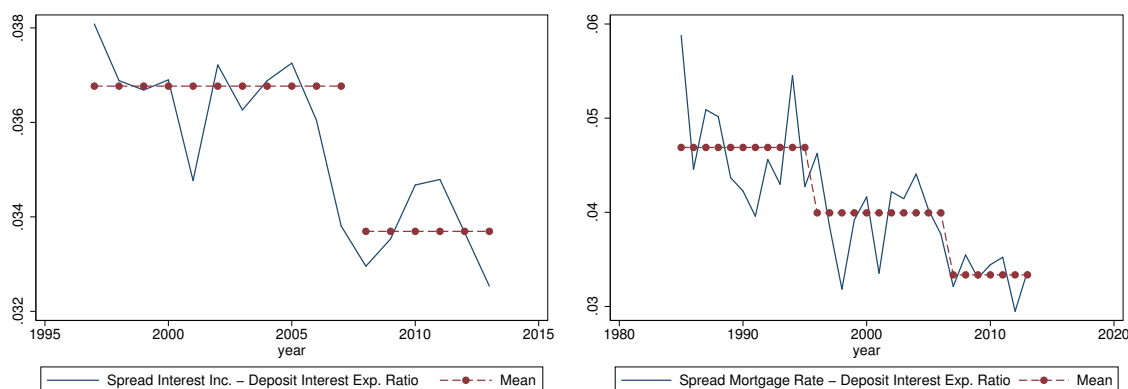


Figure 9: The left panel plots the median spread between interest income and deposit interest expense ratio, among all U.S. banks in the Call Reports data. The right panel plots the spread between the rate on 30 year mortgages and the median deposit expense ratio.

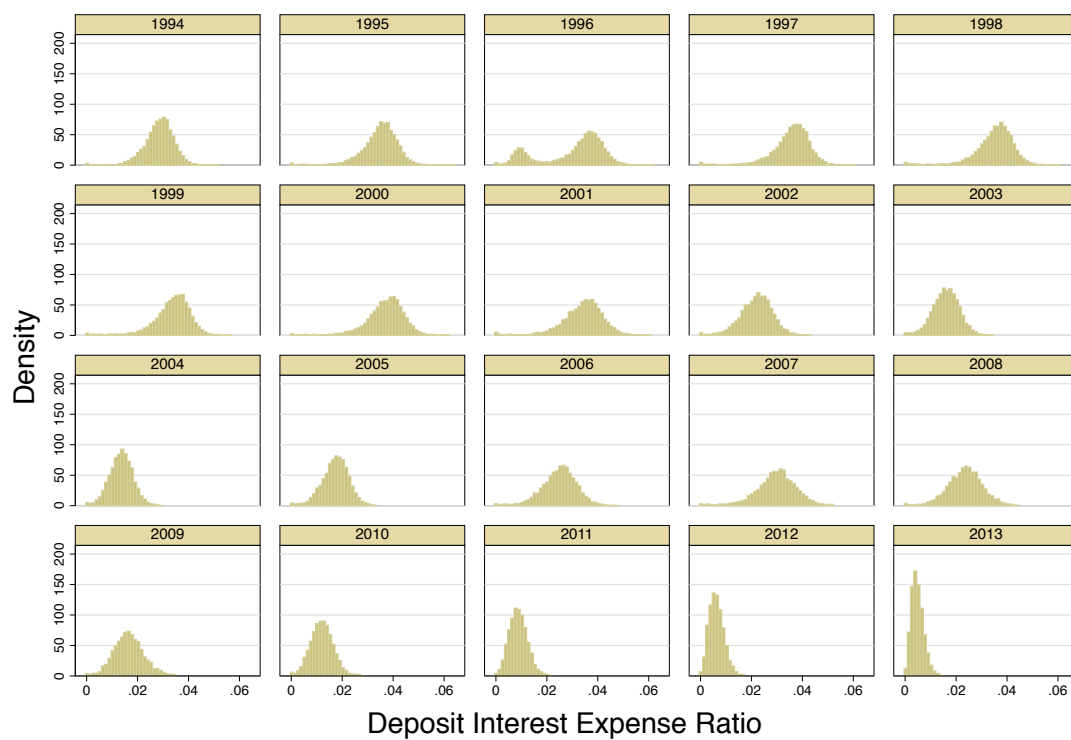
the market power of banks breaks as depositors face cash as an attractive outside option. Accordingly, a further compression in margins occurs.

**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



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.

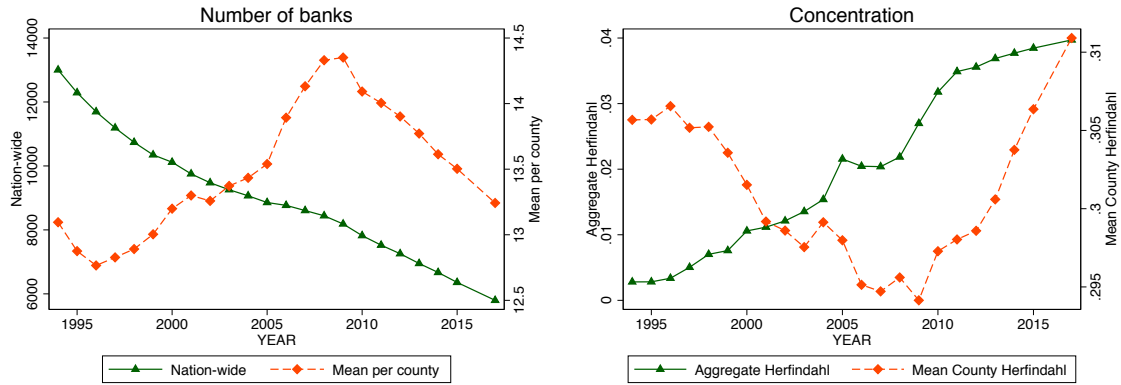


Figure 11: The left panel plots the number of banks on a nation-wide level (left axis), and the mean number of banks per county (right axis). Analogously, the right panel plots Herfindahl based on bank-level deposits on a nation-wide level, and per county.

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 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.