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# Bank Capital Regulation in a Zero Interest Environment

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## Abstract

How do near-zero deposit rates affect (optimal) bank capital regulation and risk taking? I study these questions in a tractable, dynamic equilibrium model, in which forward-looking banks compete imperfectly for deposit funding, subject to a (zero) lower bound constraint on deposit rates (ZLB). At the ZLB, capital requirements become less effective in curbing excessive risk-taking incentives, as they disproportionately hurt franchise values. As a consequence, optimal dynamic capital requirements vary with the level of interest rates if the ZLB binds occasionally. Subsidizing bank funding costs at the ZLB dampens risk-taking, but may reduce overall welfare.

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

**JEL classifications.** G21, G28, E43

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# 1. Introduction

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

This question is important because the ZLB seems to be a particularly relevant constraint for commercial banks. For example, even with interbank rates below zero, retail deposits have been largely shielded from negative rates in the Eurozone ([Heider et al., 2018](#)).<sup>1</sup> As a consequence, low interest rates can undermine the profitability of a banks’ deposit franchise, particularly when the ZLB constrains banks from passing on low asset returns to depositors (see further evidence in Section 2, as well as [Drechsler et al., 2017a](#)).<sup>2</sup>

How do banks react to this environment of near-zero interest rates and compressed margins, and what are the implications for (optimal) bank capital regulation? To tackle these questions, I propose a tractable, dynamic macro-banking model with imperfect deposit competition, endogenous risk taking, and bank failures. The model’s core builds on established mechanisms in the banking literature, that highlight the role of franchise value ([Hellmann et al., 2000](#)) and capital ([Holmstrom and Tirole, 1997](#)) for mitigating risk taking incentives. This core is embedded in a dynamic general equilibrium framework, in the spirit of a more recent literature that studies capital regulation in dynamic macro models with banks (e.g. [Van den Heuvel, 2008](#); [Martinez-Miera and Suarez, 2014](#);

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<sup>1</sup>While there are some cases of banks charging negative rates, a majority is 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>Section 2 presents U.S. evidence in line with this notion. It also shows that fees are unlikely to overcome the problem, as they are not a per-unit price and quantitatively extremely small relative to the growing deposit base of banks. While banks have been increasing fees, low interest rates induce large deposit inflows. Therefore, fees *relative to deposits* have actually been falling.

Begenau, 2016; Davydiuk, 2017). This approach allows to calibrate the model to U.S. data and quantify optimal capital requirements in the presence of an occasionally binding ZLB constraint. Yet, the model remains tractable and allows to derive analytically how the level of interest rates affects risk taking incentives and their interplay with capital requirements.

In the model, there are three agents who operate in a discrete-time, infinite horizon setting. Firms produce output, taking physical capital as the only input. Households consume and invest, either directly in firms through a financial market, or indirectly via bank equity and deposits. Deposits carry a convenience yield valued in the household's utility function, and banks set deposit rates under monopolistic competition (Dixit and Stiglitz, 1977).<sup>3</sup> On the asset side, banks make loans to firms, and choose the loan's monitoring intensity so as to maximize shareholder value. The only source of aggregate variation is in the households' discount factor, which moves stochastically over time and generates variation in the level of interest rates.

The model's key friction is that a bank's monitoring decision is not contractible. Since shareholders enjoy limited liability, this moral hazard problem induces more risk taking than is socially optimal. However, failing banks are shut down and therefore stand to lose rents upon failure. In balance, banks trade off the gains from shifting risk on depositors against the risk of loss of franchise value. The second key friction is that deposit rates are constrained by a zero lower bound. I introduce the ZLB as an exogenous contractual friction, and an extension in the appendix shows how it can arise endogenously in a model with cash or bank runs.<sup>4</sup>

In a first step, I revisit the question whether low interest rates induce banks to take more risk, a behavior that has been referred to as *reaching for yield* in the previous literature (e.g. Rajan, 2005; Jiménez et al., 2014; Dell Ariccia et al., 2014; Martinez-Miera and Repullo, 2017; Drechsler et al., 2017b; Acharya and Plantin, 2016). The model offers a nuanced answer. On the one hand, low interest rates can eat into interest margins, reducing franchise values and hence inducing more risk taking. On the other hand, lower

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<sup>3</sup>Market power derives from product differentiation, which could be interpreted in terms of a bank's branch locations or its brand.

<sup>4</sup>For the results in this paper, it does not matter whether the lower bound is really at zero, or at  $-x\%$ , as long as there is some lower bound.

discounting of future profits boosts franchise values, thus inducing *less* risk-taking. While the overall effect is ambiguous, I show analytically that under relatively mild conditions the former *margin channel* dominates whenever the ZLB binds. Intuitively, when banks are constrained in lowering deposit rates, any drop in asset returns eats one-for-one into margins. Moreover, even if the ZLB is slack in a given period, incentives are affected if with some probability the economy transitions to a state with a binding ZLB in the future. This dynamic effect highlights that even after a rate “normalization” (e.g. the Fed started raising rates in 2015), the possibility of falling back to the ZLB in the future may affect incentives today. Overall, these results are in line with empirical findings in [Heider et al. \(2018\)](#), who 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.

In the model, capital requirements are the main policy tool to curb risk taking incentives, via a “skin in the game” effect ([Holmstrom and Tirole, 1997](#)). On the other hand, to the extent that equity is relatively costly, higher capital requirements may reduce a bank’s franchise value and thereby increase risk taking ([Hellmann et al., 2000](#)). I show that this negative franchise value effect becomes disproportionately stronger when the ZLB binds. As long as the ZLB is slack, banks can react to tighter capital requirements by reducing deposit rates, dampening the negative impact on franchise values (especially if banks have a lot of market power). When the ZLB binds, this margin of adjustment vanishes, such that tighter capital requirements disproportionately reduce franchise values. Hence, the ZLB not only increases risk taking incentives per se, but it also makes capital requirements less effective in curbing such risk taking incentives.

What are the implications of these positive results for optimal, welfare-maximizing capital regulation? To answer this question, I quantify optimal regulation using a calibration of the model to U.S. data, and allowing optimal requirements to depend on the current aggregate state (i.e. on the level of the household’s discount factor and hence interest rates). If the ZLB is slack at all times, I find optimal capital requirements around 10%-11%. In contrast, if the ZLB binds occasionally, optimal requirements vary with the level of interest rates. Perhaps surprisingly, they are lower whenever the ZLB binds, even though there is already more risk taking at the ZLB. The reason is that the franchise value effect makes capital requirements less effective, motivating a weaker use when the

ZLB binds. In contrast, if the ZLB is slack today, but there is a chance for it to bind in the future, optimal requirements should be tightened. The reason is that a potentially binding ZLB in the future depresses franchise values today, increasing risk taking incentives. To counter these higher risk taking incentives, regulation is optimally tighter. In the baseline calibration, optimal capital requirements display strong cyclicity if the ZLB binds occasionally, varying from around 13.5% whenever the ZLB is slack, down to 7% at the ZLB.

These findings closely relate to the debate on counter-cyclical regulation, where macro-prudential measures are adjusted over the credit cycle to build up resilience in good times. In the literature, 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](#)).<sup>5</sup> In contrast, the rationale here is relevant even absent any such frictions, and solely depends on the ability of banks to adjust deposit rates in response to tightening regulation. In fact, the model abstracts from business cycle dynamics, and thus delivers a novel rationale for “counter-cyclical” capital regulation, distinct from the traditional view.

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

Given that capital requirements become less effective at the ZLB, what might be alternative desirable policies? I consider a subsidy to the funding cost of banks, that is paid whenever the ZLB binds. Such a subsidy effectively supports interest margins, and hence restores franchise values and prudence incentives. However, I find that the subsidy may actually be counter-productive in terms of overall welfare, as it induces banks to grow too big in equilibrium relative to financial markets.

The paper contributes to several strands of literature, many of which have already been mentioned. The notion that franchise value affects risk taking follows a long tradition

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<sup>5</sup>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 the banking literature (e.g. [Hellmann et al., 2000](#); [Perotti and Suarez, 2002](#); [Repullo, 2004](#); [Boyd and De Nicolo, 2005](#); [Martinez-Miera and Repullo, 2010](#)). There is some debate whether higher competition leads to more or less risk taking. For example, [Boyd and De Nicolo \(2005\)](#) show that if the moral hazard problem is placed at the borrower, more bank competition can actually reduce risk taking incentives of borrowers. The mechanism here is robust to whether the risk shifting problem is placed at the borrower or the bank. When asset returns fall, and deposit rates are constrained by the ZLB, the *total* spread between asset returns and deposit rates has to decline, translating into lower margins for borrowers *and* banks, making the risk shifting more severe.

To the best of my knowledge, this paper is the first to incorporate this “competition - stability” framework in a dynamic general equilibrium model, thereby connecting the earlier banking literature with a more recent strand that studies capital regulation in dynamic macro models with banks, such as [Van den Heuvel \(2008\)](#), [Repullo and Suarez \(2012\)](#), [Martinez-Miera and Suarez \(2014\)](#), [Begenau \(2016\)](#), [Davydiuk \(2017\)](#). None of these frameworks model deposit competition, or analyze how the overall level of interest rates and the ZLB affect regulation.

The paper also relates to a recent empirical literature that studies the relation between monetary policy and bank competition ([Drechsler et al., 2017a](#); [Scharfstein and Sunderam, 2015](#); [Xiao, 2017](#)). [Drechsler et al. \(2018\)](#) and [Hoffmann et al. \(2017\)](#) show that market power in deposit markets shields banks from interest rate risk, despite them engaging in maturity transformation. My model builds on these findings. As long as the ZLB is slack, banks can pass on changes in interest rates to depositors and maintain stable margins. The core results rely on the insight that this mechanism breaks down once the zero lower bound distorts deposit pricing. This notion is consistent with event studies around monetary policy announcements, which find that falling interest rates negatively affect bank stock prices if and only if the ZLB binds ([Ampudia and Van den Heuvel, 2018](#); [English et al., 2018](#)).

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

Finally, this paper relates 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, the contribution of this paper is to 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 here can therefore be interpreted as one in which the price level and inflation expectations are fixed.

The rest of the paper is organized as follows. Section 2 presents motivating evidence. Section 3 describes the model setup, equilibrium and calibration, and concludes with a critical discussion of the framework and its inefficiencies. Section 4 studies the interaction of the level of interest rates and bank risk taking, and Section 5 shows that the ZLB can make capital requirements less effective. Section 6 presents the normative analysis, quantifies optimal capital regulation with an occasionally binding ZLB constraint, 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) as the ZLB started binding in 2009, interest margins and bank profitability have shrunk, in particular for banks that rely most on deposit funding.

For selected years, Figure 1 plots the cross-sectional distribution of U.S. banks' deposit interest expense per unit of deposit funding.<sup>6</sup> Before 2009, the mean shifts around with the level of interest rates, but the shape of the distribution changes little (see the Internet Appendix 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

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<sup>6</sup>Following Drechsler et al. (2017a), 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.



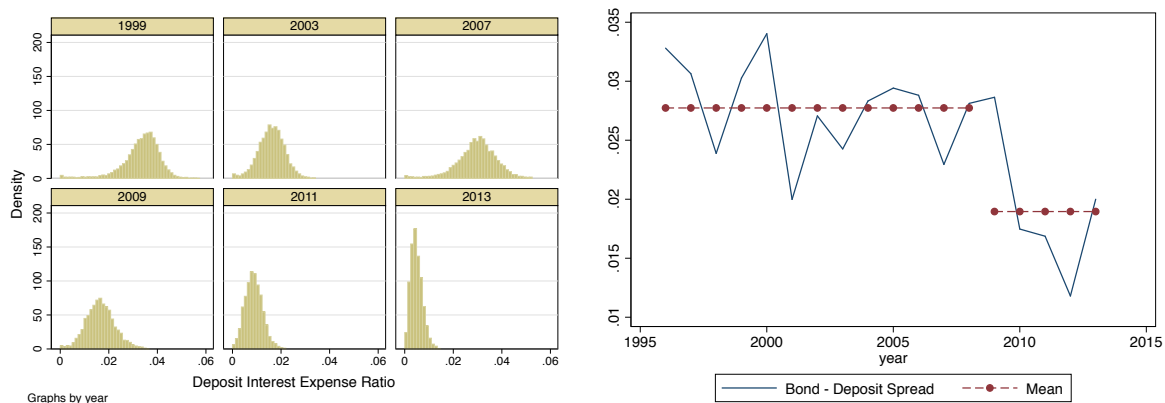


Figure 1: For selected years from 1999-2013, the left panel plots the cross-sectional distribution of deposit interest expense per unit of deposit funding across U.S. banks in the Call Reports data. The right panel plots the spread between the BofA Merrill Lynch US Corporate AAA Effective Yield (retrieved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

rate on savings accounts has been near zero since 2009.<sup>7</sup> Heider et al. (2018) 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>8</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 right panel of Figure 2, which plots the spread of corporate bond yields over median deposit interest expense.<sup>9</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. The advantage of this market-based measure is that it is not confounded by endogenous higher risk taking by banks. Still, Appendix B.1 shows that the spread between bank-level interest income and deposit

<sup>7</sup>See the FDIC website: <https://www.fdic.gov/regulations/resources/rates/previous.html>

<sup>8</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>9</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.

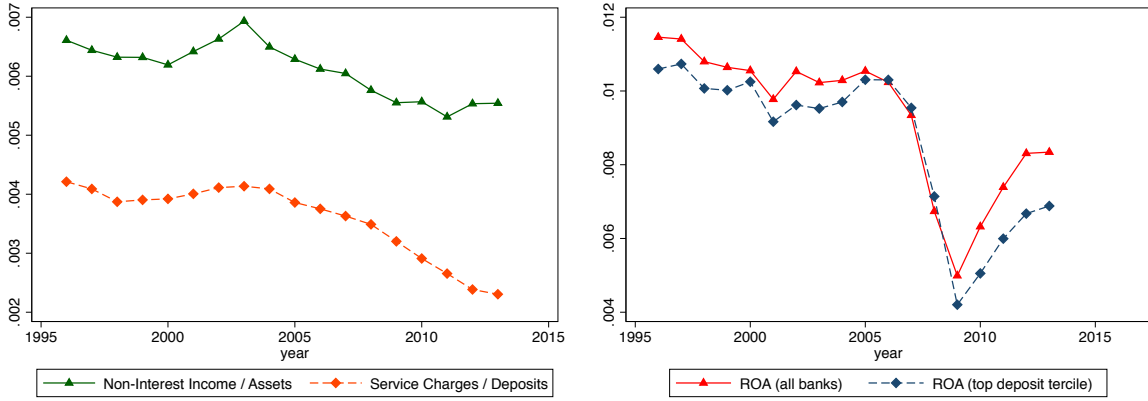


Figure 2: The left panel plots non-interest income per unit of assets, as well as service charges per unit of deposits for the median U.S. bank in the Call Reports data. Figure 11 in the appendix reports histograms for additional years. The right panel plots the median ROA (defined as net income over assets), separately across all banks and across banks in the top tercile of deposits /assets.

interest expense follows a similar pattern, dropping around 2007 (though to a lesser extent).

Even if banks are unable to set negative interest rates on deposits, they may be able to do so effectively by increasing fees. By revealed preference, if the two were equivalent banks should have charged fees rather than interest rates also away from the ZLB. Arguably, the problem is that unlike interest rates, fees are not proportional to an account's balance. Already on a low level, service charges on deposits earn a small number of around 0.37% relative to deposits before 2008. Perhaps surprisingly, this number has actually been coming down further, dropping below 0.25% (Figure 2). 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 small and falling, especially relative to the net interest income of banks, which averages around 3.9% over the period 1984-2013. As a consequence, the overall ROA of the median U.S. bank has been significantly lower since the ZLB started binding in 2009, see the right panel of Figure 2. The figure also shows that the drop in ROA is concentrated among banks that rely most on deposits funding, which arguably are most exposed to the ZLB constraint.

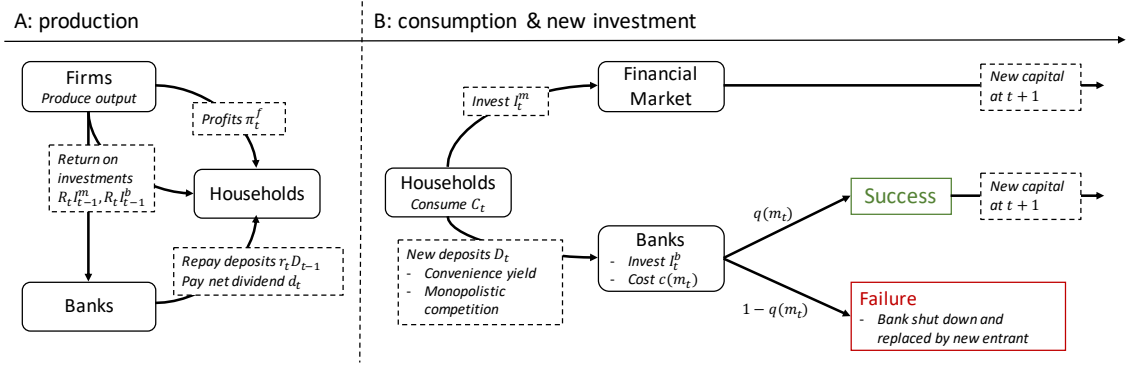


Figure 3: Flow diagram summarizing the within-period timing.

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

### 3. Model Setup

In the model, time runs discretely from  $t = 0, \dots, \infty$ , and there are three players: a representative household, a representative firm and a unit mass of banks with a mandate to maximize shareholder value.

The flow diagram in Figure 3 summarizes the timing within a period  $t$ , and gives an overview of the model. In the beginning of period  $t$  (stage A) firms produce output using physical capital as only input, and pay households and banks a return on their investments made at  $t - 1$ . Banks use the proceeds to repay depositors and pay a net dividend, which may take negative values if banks raise new equity. Firms also return their profits to households.

Afterwards (stage B), households consume and new investments are made. Households have access to a financial market, which is modeled as an investment technology that creates new physical capital in the following period. Households can also invest in bank deposits. Deposits are special, because they have a non-pecuniary convenience yield captured in the household's utility function (Van den Heuvel, 2008).<sup>10</sup>

<sup>10</sup>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

Banks set deposit rates under monopolistic competition (Dixit and Stiglitz, 1977), subject to a zero lower bound constraint. The ZLB is introduced as an exogenous contractual friction, i.e. banks are simply not allowed to set negative deposit rates. Appendix A.1 discusses two approaches to endogenizing the ZLB.<sup>11</sup> However, the main goal of this paper is to understand the *implications* of the zero lower bound for bank capital regulation and risk taking, motivated by the empirical evidence. It does not seek to explain *why* there is a lower bound, and therefore the ZLB is introduced as an exogenous friction in the main text.

On the asset side, banks invest in loans to a bank-dependent sector, modeled as a second investment technology that also creates physical capital for the next period.<sup>12</sup> Technologically, the physical capital created by banks is equivalent to that created via financial markets, and both earn the same gross return  $R_{t+1}$  when sold to firms in the next period. In equilibrium, banks and financial markets co-exist, because banks incur an operating cost (e.g. to maintain a branch network), and deposits have a convenience yield.

Bank investments are subject to some idiosyncratic risk, which is governed by a bank's non-contractible monitoring intensity. Banks are subject to a regulatory capital requirement that limits the leverage they can take. The only source of aggregate variation is in the household's discount factor, which varies according to a 2-state Markov process. This generates stochastic variation in the level of equilibrium interest rates, while abstracting from aggregate business cycle dynamics. The advantage of this modeling approach is

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traders (Gorton and Pennacchi, 1990; Dang et al., 2017). Its demandability may incentivize monitoring (Diamond, 1984), and facilitates the transformation of risky long-term assets into liquid and safe claims (Diamond and Dybvig, 1983; Ahnert and Perotti, 2017). Moreover, banks invest into ATM networks and electronic payment infrastructure that make deposits a convenient medium of exchange.

<sup>11</sup>A ZLB arises endogenously by explicitly introducing cash as an alternative money. It can also arise if some depositors perceive negative rates as unfair and therefore withdraw their funds. Banks may naturally be worried about losing the future value of their customer base, or even triggering a bank run.

<sup>12</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 firms and banks.

that it allows for a sustained period of low real interest rates to arise in equilibrium.<sup>13</sup>

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 the model is calibrated.

### 3.1. Firms

A representative firm operates a technology that produces output, using capital  $K_t$  as the only input,

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

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

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

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

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

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

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

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

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

### 3.2. Household Problem and Deposit 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

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<sup>13</sup>Similar formulations are used in contributions in the macro liquidity trap literature such as [Eggertsson and Woodford \(2003\)](#) and [Werning \(2011\)](#).

specializing in online banking, a big international bank with a prestigious brand, or a local bank with personal relations between clients and advisors. Alternatively, one can think of varieties representing different locations and banks differentiating spatially. Following [Dixit and Stiglitz \(1977\)](#), I model this preference by expressing  $D_t$  as a CES composite of varieties  $D_{t,i}$ ,

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

Product differentiation gives banks some market power, the degree of which is governed by the elasticity of substitution  $\eta$ .<sup>14</sup> Higher values of  $\eta$  indicate greater ease of substitutability between varieties, implying lower market power. I assume that  $\eta > 1$ , such that deposits of different banks are substitutes.

A fraction  $\omega$  of each bank's deposits are insured by the government, which funds the deposit insurance by lump-sum taxes  $T_t$ . None of the mechanisms in this paper rely on the presence of deposit insurance, and for any analytical results I set  $\omega = 0$  to minimize the number of frictions in the model. In the quantitative evaluation of optimal capital requirements in [Section 6](#), I calibrate  $\omega$  to a realistic level to reflect the presence of deposit insurance in the real world.

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  $D_t$ ,<sup>15</sup> and the problem of

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<sup>14</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., 2017a](#)).

<sup>15</sup>Solving the household problem is equally tractable using a more general utility function  $U(C_t, D_t)$ . The advantage of the quasi-linear utility formulation is that it allows to solve the model globally

the representative household is given by

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

Here,  $\gamma \geq 0$  measures the household's preference for liquidity services, and  $v(D_t) = \log(D_t)$  is the ‘‘convenience’’ utility households derive from holding deposits. The deposit rate offered by bank  $i$  is denoted  $r_{t,i}$ , and  $q_{t-1,i}$  is the probability that bank  $i$  does not fail (chosen by the bank at  $t-1$ , to be determined below). The first constraint is the household's budget constraint, and the second a non-negativity constraint on deposits.<sup>16</sup> The first-order condition with respect to  $I_t^m$  yields the household's Euler equation

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

Since  $\beta_t$  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 quasi-linear utility function, namely that the equilibrium return on physical capital is a function of the current state only.

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  $D_{t,i}$ :

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

where I use that  $\beta_t = 1/R_{t+1}$  by Eq. (4). Banks can attract more funding, the higher the deposit rate  $r_{t+1,i}$ , i.e. the lower the relative interest margin  $R_{t+1}/r_{t+1,i}$ . The elasticity

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rather than relying on perturbation techniques, even though the household problem, as well as the bank problem are both forward-looking, and interacting in equilibrium.

<sup>16</sup>Note that due to log-utility the solution is always interior.  $I_t^m$  and  $C_t$  can take negative values. When  $I_t^m < 0$ , firms disinvest and return cash to investors. Negative consumption can be interpreted as working (as in Brunnermeier and Sannikov, 2014).

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. Intuitively, 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, there is a regulatory capital requirement  $\bar{e}_t$ , that requires  $e_{t,i} \geq \bar{e}_t$ . The capital requirement is taken as exogenously given for now, and Section 6 derives the welfare-maximizing level of  $\bar{e}_t$ .

Each bank has access to a single project of variable scale  $I_{t,i}^b$ , interpreted as making loans to bank-dependent borrowers. Note that  $e_{t,i}$  is expressed as capital *per unit of deposit*, hence the total investment scale of the project is

$$I_{t,i}^b = (1 + e_{t,i})D_{t,i}(r_{t+1,i}).$$

With probability  $q_{t,i} = q(m_{t,i})$ , the project succeeds and produces one unit of physical capital per unit of investment, which is sold to the representative firm in the following period, yielding  $R_{t+1}$  per unit. Success probabilities are i.i.d. across banks, and there is no aggregate risk.<sup>17</sup>

In case of failure, the project produces nothing and the bank is in default. Shareholders enjoy limited liability, but failing banks lose their license and cannot continue operating. Each failing bank is replaced by a new entrant, but the total number of bank licenses is limited by mass 1, such that the total number of banks is constant.<sup>18</sup>

The project's success probability increases in the monitoring intensity  $m_{t,i} \geq 0$  chosen by the bank. In principle,  $q(m_t)$  can be any function with  $q'(m_t) \geq 0$ , that is bounded

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<sup>17</sup>Taken literally, in the model banks are riskier than the financial market. However, one could easily introduce risk in the financial market. In fact, because households are risk-neutral one may simply re-interpret the return in the financial market as a risky return that pays  $R_{t+1}$  *in expectation*. What matters is that there is some risk in the bank's investment, to open the possibility of bank failure and introduce the risk-shifting moral hazard that is the focus of this paper.

<sup>18</sup>Note that it is profitable for new banks to enter, since banks have market power and earn monopolistic rents.



by  $\lim_{m_t \rightarrow \infty} q(m_t) \leq 1$ , and  $\lim_{m_t \rightarrow 0} q(m_t) \geq 0$ . For concreteness I use as a functional form the CDF of the Standard Gaussian distribution,  $q(m_t) = \Phi(m_t)$ .<sup>19</sup> Banks incur a cost

$$c(m_t) = \psi_1 + \psi_2 m_t$$

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 contractible, and is chosen after raising deposit funding and choosing their leverage. Banks set the level of  $m_t$  that maximizes shareholder value, which generally does not align with the socially optimal level due to limited liability.

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

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

which consists of the bank's net interest income (defined as the net return on loans, after repaying depositors), net of the monitoring cost and equity it contributes to new loans. For new entrants,  $d_{t,i}^b < 0$ , because these banks have no interest income from previous loans and must therefore raise equity externally. Failing banks pay zero dividends as they are shut down.

A central element in the further analysis is the bank's franchise value  $V_t^b$ , which generally takes strictly positive values due to the market power of banks.<sup>20</sup> It turns out to be convenient to define  $V_t^b$  as the value of a bank's current and future loans:

$$V_t^b = \max_{m_{t,i}, e_{t,i}, r_{t+1,i}} \pi_{t,t+1}^b D_{t,i}(r_{t+1,i}, m_{t,i}) + q(m_{t,i})\beta_t \mathbb{E}_t V_{t+1}^b, \quad (7)$$

where  $\pi_{t,t+1}^b$  denote discounted expected profits per unit of deposits raised at period  $t$ ,

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

<sup>19</sup>The advantage is that this function is well behaved and bounded between 0 and 1.

<sup>20</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  $V_t^b \geq 0$

and the problem is subject to the following constraints:

$$m_{t,i} = \arg \max_{m_{t,i}} \pi_{t,t+1}^b D_{t,i} + q(m_{t,i}) \beta_t \mathbb{E}_t V_{t+1}^b, \quad (8)$$

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

$$e_{t,i} \geq \bar{e}_t, \quad (10)$$

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

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

Since a bank decides sequentially on its funding and then monitoring, the problem is solved backwards, starting with the optimal monitoring choice *for a given level of*  $D_{t,i}$  *and*  $e_{t,i}$ . The incentive-compatible  $m_t$  is characterized by the first order condition to (8):

$$c'(m_{t,i})(1 + e_{t,i})D_{t,i} = q'(m_{t,i})\beta_t [(1 + e_{t,i})R_{t+1} - r_{t+1,i}] D_{t,i} + \mathbb{E}_t V_{t+1}. \quad (12)$$

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

Denote by  $m_{t,i}^*$  the optimal  $m_{t,i}$  that solves Eq. (12). The bank chooses  $e_{t,i}$  and  $r_{t+1,i}$  taking into account how its choices may subsequently affect  $m_{t,i}^*$ . The FOC w.r.t.  $e_{t,i}$  is given by

$$\frac{\partial V_t^b}{\partial e_{t,i}} = \underbrace{q(m_{t,i})\beta_t R_{t+1} - (1 + c(m_{t,i}))}_{<0} + \underbrace{\frac{dm_{t,i}^*}{de_{t,i}} \frac{\partial D_{t,i}(r_{t+1,i}, m_{t,i})}{\partial m_{t,i}}}_{\text{Incentive effect}} \pi_{t,t+1}^b \quad (13)$$

The first term in Eq. (13) reflects the cost of equity and is always negative (because  $\beta_t R_{t+1} = 1$ , by the household's Euler Equation (4)). Equity is costly, because equity does not carry any convenience yield, and households can invest in the financial market as an alternative to bank equity, where they can create new physical capital without incurring the bank's operating cost  $c(m_t)$ .<sup>21</sup>

The second term reflects an incentive effect. Equity credibly signals to depositors that banks monitor more intensely in the second stage, allowing banks to attract more

<sup>21</sup>Note, however, that this does *not* imply that households are unwilling to hold bank stock. If bank

deposits. The bank's optimal  $e_{t,i}$  can either be at an interior solution to Eq. (13), or at the regulatory capital constraint if  $\frac{\partial V_t^b}{\partial e_{t,i}} < 0$  at  $e_{t,i} = \bar{e}_t$ .

Arguably, the empirically plausible case is that banks are at the regulatory capital constraint. This is always true under full deposit insurance ( $\omega = 1$ ), as in this case depositors become insensitive to a bank's risk taking.<sup>22</sup> For the case  $\omega < 1$ , Appendix A.4 uses the model's calibrated numerical solution to confirm that banks endogenously choose to be at the regulatory capital constraint, even in the complete absence of deposit insurance (except for some extreme cases with capital requirements near zero). For that reason, in the remainder I focus on the empirically plausible corner solution  $e_{t,i} = \bar{e}_t$  for all analytical results (any numerical results allow for the general solution).

The first-order conditions with respect to the deposit rate implicitly defines the interior solution  $r_{t+1,i}^*$ :

$$\frac{r_{t+1,i}}{R_{t+1}} = \frac{\rho_2}{\rho_1} \left[ \frac{\eta - 1/\rho_2}{\eta - 1} - \frac{\eta}{\eta - 1} \frac{(1 - q(m_{t,i}))e_{t,i} + (1 + e_{t,i})c(m_{t,i})}{q(m_{t,i})} \right], \quad (14)$$

where

$$\rho_1 \equiv \omega + (1 - \omega) \left( q(m_t) + \frac{\eta}{\eta - 1} q'(m_t) r_{t+1} \frac{dm_t^*}{dr_{t+1}} \right),$$

$$\rho_2 \equiv \omega + (1 - \omega) \left( q(m_t) + q'(m_t) r_{t+1} \frac{dm_t^*}{dr_{t+1}} \right).$$

The deposit rate is either at the interior solution to Eq. (14), or at the corner  $r_{t+1,i} = 1$  if the ZLB binds. While (14) is a relatively complicated expression, it is useful to consider the case of full deposit insurance ( $\omega = 1$ ) for illustration, in which case  $\rho_1 = \rho_2 = 1$ , and the deposit rate can be expressed as

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

In the first case in the max-function, banks set the deposit rate at an interior solution, proportional to the return on capital. Deposit rates are below  $R_{t+1}$ , as banks pass on their costs and charge a mark-up that depends on the elasticity of substitution between

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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.

<sup>22</sup>It is easily verified that with  $\omega = 1$ ,  $\frac{\partial D_{t,i}(r_{t+1,i}, m_{t,i})}{\partial m_{t,i}} = 0$ , such that the incentive effect vanishes.

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.

In the more general case with  $\omega < 1$ , the terms  $\rho_1$  and  $\rho_2$  capture that banks have to compensate depositors for the risk they take. In setting deposit rates, banks then take into account that this affects their optimal monitoring decision  $m_t^*$  in the second stage.

### 3.4. Government

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

$$T_t = \omega(1 - q(m_{t-1}))r_t D_{t-1} \quad (15)$$

to repay depositors of failing banks.

### 3.5. Equilibrium and Model Solution

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 and the remainder of the paper I focus on symmetric equilibria, in which all banks choose the same deposit rate and monitoring intensity.

**Definition.** Given capital requirements  $\{\bar{e}_t\}_{t=0}^{t=\infty}$ , 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  $\{K_{t+1}, I_t^m, I_t^b, C_t, D_t, e_t, m_t, T_t\}_{t=0}^{t=\infty}$ , 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  $\{R_t, r_t\}_{t=0}^{t=\infty}$ , households maximize lifetime utility solving (3).
- (c) Given prices  $\{R_t\}_{t=0}^{t=\infty}$ , banks maximize their franchise value solving (7).
- (d) Market clearing is satisfied at any time  $t \geq 0$

- *aggregate resource constraint:*

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

- *capital:*

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

with

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

The set of equations describing the equilibrium is summarized in Appendix A.2. 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>23</sup> This property simplifies solving the forward-looking bank problem, as it allows to express the expected franchise value as

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

Therefore, the bank’s value function can be solved as a simple system of non-linear equations, allowing to easily solve the model globally. For ease of notation I sometimes 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 some results analytically, but also rely on a numerical solution when analytics are ambiguous, as well as for the quantification of optimal capital requirements in Section 6. For this purpose, I calibrate the model to annual U.S. data. The calibration also allows me to get a sense for the magnitude of analytical results.

The high-rate state represents “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,

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

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>24</sup> The level of rates in the low-rate state is one of the main comparative statics of interest. In the baseline calibration,  $\beta_L = 0.975$  to target the average AAA corporate bond yield over 2009-2013 at around 2.5%.

Regarding 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. I also set  $\omega = 0.57$ , equal to the aggregate amount of deposits insured by the FDIC, divided by the aggregate amount of deposits of regulated U.S. banks in 2017. The analytical results in Section 4 and 5 hold for any  $\omega$ , including  $\omega = 0$ . Only for the numerical exercises I use  $\omega = 0.57$ .

The cost function parameters  $\psi_1$  and  $\psi_2$  are set to reflect the average net non-interest expense of banks in the Call Reports data over 1984-2013, at around 2.3% of assets. The parameter  $\psi_2$  reflects the cost of monitoring, and hence governs a bank's failure probability  $(1 - q(m_H))$ . Hence, I also target the average annual proportion of banks failing in the U.S. of around 0.76% (computed by Davydiuk (2017) using the Failed Bank List issued by the FDIC). This yields  $\psi_1 = 0.011$  and  $\psi_2 = 0.018$ .

The elasticity of substitution  $\eta$  affects bank market power and hence interest margin  $R_H - r_H$ . Following Drechsler et al. (2017a) 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  $\eta = 4.5$ .

Given the calibration of the bank variables I set the parameter  $\gamma$ , which governs the preference for liquidity. Doing so, I target the ratio of aggregate deposit liabilities of U.S. chartered institutions to the aggregate U.S. capital stock, using data from the Flow of

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<sup>24</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>.

Funds. Setting  $\gamma = 0.005$  results in a ratio ratio of  $D_H/K_H = 2\%$ , consistent with Flow of Funds data.

Finally, in the baseline calibration I set the transition probabilities equal to  $P_{HH} = 0.9$  and  $P_{LL} = 0.8$ . This implies an expected duration of 10 years spent in the high-rate state, and 5 years in the low-rate state. For comparison, the Federal Funds Rate target range was at 0% for seven years, from December 2008 to December 2015. All parameter values are summarized in Table 2 in Appendix A.3.

### 3.7. First Best and Inefficiencies

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

To see how these market failures affect equilibrium outcomes, it is useful to characterize the first best allocation (FB) and contrast it to the competitive equilibrium (CE). To minimize the number of frictions, for this comparison I set  $\omega = 0$  (no deposit insurance). 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:

$$\begin{aligned}
& \max_{C_t, I_t^m, D_{t,i}, m_t, e_t} & \mathbb{E}_0 \sum_{t=0}^{\infty} \left( \prod_{\tau=0}^{t-1} \beta_{\tau} \right) [C_t + \gamma v(D_t)] \\
& \text{with} & D_t = \left[ \int_0^1 D_{t,i}^{\frac{\eta-1}{\eta}} di \right]^{\frac{\eta}{\eta-1}}, \\
& \text{s.t.} & C_t + I_t^m + \int_0^1 (1 + e_{t,i}) D_{t,i} (1 + c(m_{t,i})) = F(K_t), \\
& & K_t = (1 - \delta) K_{t-1} + I_{t-1}^m + q(m_t) (1 + e_t) D_t
\end{aligned} \tag{16}$$

From the CES aggregator it follows immediately that the planner allocates the same amount of deposit funding to each bank,  $D_{t,i} = D_t$ .

Due to the bank's operating cost, it is costlier for banks to create new physical capital than it is via the financial market. While deposits have the advantage of generating

convenience utility, the operating costs imply that bank equity is socially costly. In the competitive equilibrium, equity fulfills the role of reducing the risk taking incentives of banks, but in the first best equity is only costly and hence  $e_t = 0$ .<sup>25</sup>

The remaining variables are chosen according to the first-order conditions w.r.t.  $I_t^m$ ,  $m_t$  and  $D_t$ :

$$\beta_t R_{t+1} = 1 \quad (17)$$

$$c'(m_t) = q'(m_t) \quad (18)$$

$$D_t = \frac{\gamma}{1 - q(m_t) + c(m_t)} \quad (19)$$

These three conditions are readily compared to their counterparts in the competitive equilibrium. First, Eq. (17) is equivalent to the household's Euler Equation (3), implying that the overall level of capital accumulation is not distorted.

In contrast, Condition (18) differs from its counterparts in the CE. In the FB allocation,  $c'(m_t) = q'(m_t)$ . This is not generally true in the CE, as revealed by the bank's FOC w.r.t monitoring (12).

Similarly, Condition (19) can be compared to the demand for deposits by households in Eq. (19), after setting  $\omega = 0$  and rewriting it as

$$D_t = \frac{\gamma}{1 - q(m_t) \frac{r_{t+1}}{R_{t+1}}}. \quad (20)$$

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

These two comparisons show that misallocations arise because banks do not choose the optimal amount of risk taking, and do not provide the optimal amount of liquidity services via deposits. Limited liability gives bank shareholders an option-like payoff, as

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<sup>25</sup>One might expect that the convenience yield of deposits alone makes bank equity costly. This would only hold in a model in which the balance sheet size of a bank is fixed and the relevant opportunity cost is the interest paid on deposits. If instead banks can expand the size of their balance sheet, the relevant opportunity cost is the required return of shareholders, which in this model is given by the financial market. 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 would indeed less than  $R_{t+1}/q(m_t)$  if there is a convenience yield.



they do not fully internalize losses incurred in case of failure. This convex payoff structure induces excessive risk taking. On the other hand, monopolistic competition implies that banks may take *less* risk relative to the FB. The reason is that the bank's franchise value reflects rents due to market power, which are of private value to bank shareholders but do not add to welfare. Overall, bank shareholders trade off the gains from shifting risk on depositors against the risk of loss of franchise value. In the baseline calibration, banks take excessive risk relative to the first best (failure probability of 0.76% vs 0.17% in the first best).

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

## 4. Risk Taking and Capital Regulation at the Zero Lower Bound

The analysis in this section is of positive nature, and seeks to understand how risk taking incentives are affected by the level of interest rates, and their interaction with capital regulation. The answer depends on whether the ZLB binds whenever the economy hits the low-rate state, so a first step is to show under what conditions deposit rates do become constrained.

### 4.1. Zero Lower Bound

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

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

$$\beta_t \leq \beta_t^{ZLB}, \quad (21)$$

where  $\beta_t^{ZLB}$  is implicitly defined as the  $\beta_t$  that solves Eq. (14) at  $r_{t+1} = 1$ .

Lemma 1 defines a threshold  $\beta_t^{ZLB}$ , below which the ZLB binds. In the baseline calibration, this threshold is around 0.9669, such that deposit rates hit the ZLB when the return on capital drops below 3.5% ( $= 1/\beta_t^{ZLB} - 1$ ). The return on capital is above this threshold in the high-rate state (5.5%), while in the low-rate state  $R_L - 1 = 2.5\%$  and the ZLB binds.

## 4.2. Do Low Interest Rates Spur Risk Taking?

To answer this question, consider a marginal increase in the discount factor  $\beta_t$ . By the household's Euler Equation (4) the direct effect of an increase in  $\beta_t$  is to push down  $R_{t+1}$ . To understand how this affects risk taking, rewrite the bank's FOC w.r.t. monitoring (12) as

$$\frac{c'(m_t)}{q'(m_t)} = 1 - \underbrace{\frac{1}{(1+e_t)} \frac{r_{t+1}}{R_{t+1}}}_{\text{Margin on current loans}} + \underbrace{\frac{\mathbb{E}_t V_{t+1}}{\bar{I}_t^b R_{t+1}}}_{\text{Discounted franchise value}}. \quad (22)$$

The left-hand side increases in  $m_t$ ,<sup>26</sup> and the right-hand side reveals that falling  $R_{t+1}$  affects monitoring via a *margin channel* and a *discounting channel*. When  $R_{t+1}$  falls, banks discount their continuation value less, boosting overall franchise value. Via this discounting channel, lower interest rates induce banks to monitor more intensely, i.e. take less risk. On the other hand, a low investment return may harm interest margins and thereby induce higher risk taking. Hence, the overall effect depends on the balance between the discounting and margin channel.

The following proposition shows that at the ZLB the margin channel dominates:

**Proposition 1.** *Hold  $\beta_{t+1}, \beta_{t+2}, \dots$  fixed, and consider the comparative statics of monitoring  $m_t$  with respect to the discount factor  $\beta_t$ . If  $\beta_t > \beta_t^{ZLB}$  (binding ZLB), a necessary condition for*

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

*is that  $\beta_t \geq \frac{1}{2[\omega + (1-\omega)q(m_t^*)]}$ .*

Note that the necessary condition in Proposition 1 only fails for very unrealistic parameterizations. For example, with  $\omega = 0$  (no deposit insurance), at  $\beta_t = 0.95$  the condition

<sup>26</sup>This is easy to verify because  $c'(m_t) = \psi_2$  and  $q'(m_t)$  is the PDF of the Standard Gaussian Distribution and hence decreases for any  $m_t \geq 0$ .

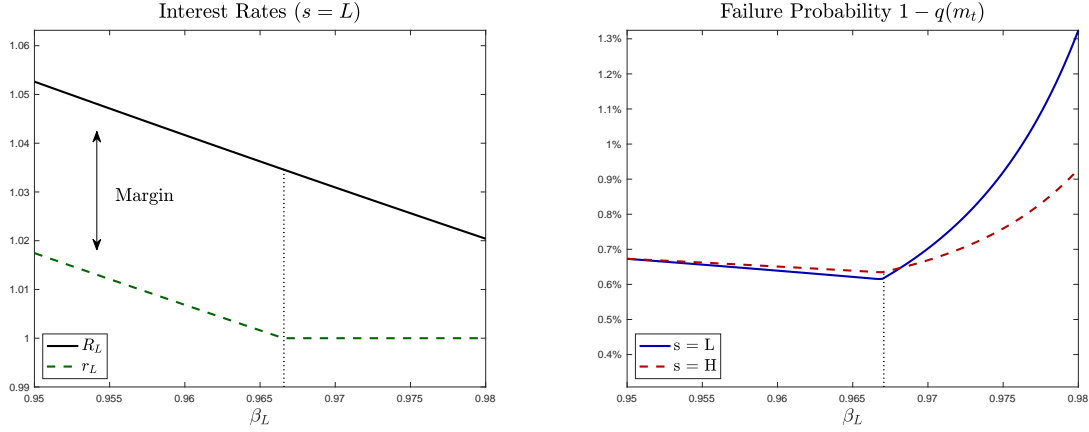


Figure 4: This figure plots equilibrium interest rates in the low-rate state ( $s = L$ ), and equilibrium bank risk taking in both the low- and high-rate states, against the discount factor in the low-rate state  $\beta_L$ . Parameters are calibrated as described in Section 3.6.

holds for  $q(m_t) > 0.526$ , i.e. for annual failure rates below 47.4%. The baseline calibration in Section 3.6 targets a failure rate below 1%, in line with the actual failure rate of U.S. banks in the data. Appendix A.5 gives the proof to Proposition 1 and derives a sufficient condition that is satisfied for an even wider parameter space. Intuitively, when the ZLB binds,

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

and any reduction in  $R_{t+1}$  eats one-for-one into interest margins, such that the margin effect dominates.

In contrast, away from the ZLB it is less clear which effect dominates. As long as banks set deposit rates according to the interior solution to Eq. (14), the relevant equilibrium ratio  $\frac{r_{t+1}}{R_{t+1}}$  is quite stable as banks can pass on a reduction in  $R_{t+1}$  to depositors (see Eq. (22)). Therefore, the discounting channel tends to dominate when the ZLB is slack, and lower interest rates actually induce *less* risk taking. While it is hard to show this point analytically, Appendix A.5 proves it for the case  $\omega = 1$ .

While the comparative statics in Proposition 1 refer to a marginal change in  $\beta_t$ , keeping  $\beta_{t+1}, \beta_{t+2}, \dots$  fixed, Figure 4 uses the model's numerical solution to verify that the same results obtain when changing  $\beta_L$  along the entire equilibrium path. In the left panel of Figure 4 banks can decrease deposit rates proportionately as long as  $\beta_L \leq \beta_L^{ZLB}$ , guaranteeing a stable interest margin. In contrast, when  $\beta_L > \beta_L^{ZLB}$  the ZLB binds and margins shrink.

The right panel of Figure 4 plots the equilibrium failure probability  $1 - q(m_t)$  against the discount factor  $\beta_L$ . The discounting effect dominates as long as the ZLB is slack ( $\beta_L \leq \beta_L^{ZLB}$ ), even though the magnitude of the effect is quite modest. Failure probabilities fall by a few basis points as the return on capital falls from above 5% (at  $\beta = 0.95$ ) to around 3.5% (at  $\beta = \beta_L^{ZLB}$ ). When the ZLB binds, the margin channel dominates and falling interest rates result in a sizable increase in risk taking. The annual probability of failure more than doubles from around 0.6% to above 1.3%, as the return on capital falls from 3.5% (at  $\beta_L = \beta_L^{ZLB}$ ) to 2% (at  $\beta_L = 0.98$ ).

Figure 4 also reveals that a binding ZLB in the low-rate state affects risk taking in the high-rate state, even though the ZLB is slack in the high-rate state ( $s = H$ , see the dashed red line). Incentives are not only affected by current profits, but also by expectations about profitability going forward.

### 4.3. Expectations Matter

Because expectations about future profitability affect franchise value, it also 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  $\hat{\beta}$ , s.t. if*

$$\beta_L \geq \hat{\beta}, \tag{24}$$

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

$$\frac{dm_t}{dP_{LL}} \leq 0, \frac{dm_t}{dP_{HL}} \leq 0$$

When  $\beta_L > \hat{\beta}$ , the ZLB binds and intermediation margins are sufficiently compressed, such that the bank's franchise value in the high-rate state exceeds that in the low-rate state ( $V_H^b > V_L^b$ ). In this case, the overall value of banks is lower, the more time the economy spends in the low-rate state. Low expected profitability erodes franchise value and boosts risk taking incentives.

The left panel in Figure 5 illustrates the result of Proposition 2. It plots the equilibrium failure probability  $1 - q(m_s)$  for  $s = H, L$ , against the likelihood of remaining in the low-

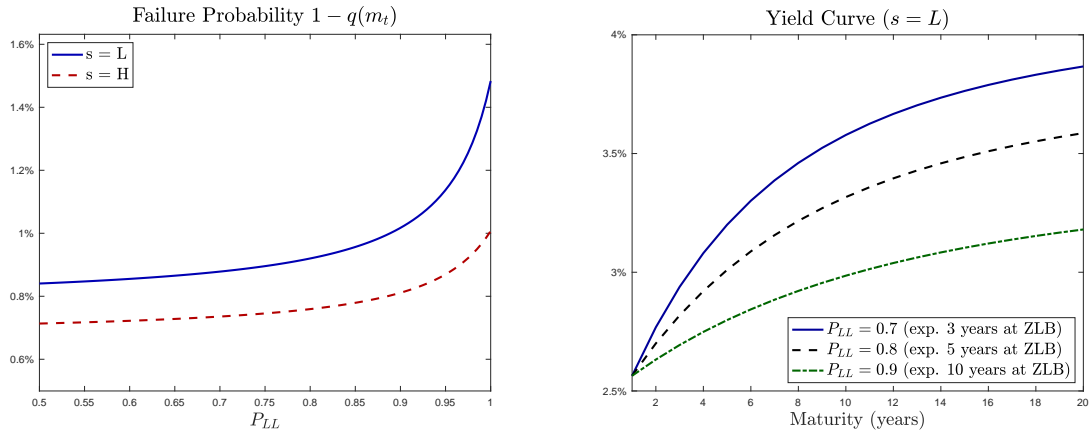


Figure 5: This figure plots bank risk taking in both the low- and high-rate states, against the probability of staying in the low-rate state (left panel). The right panel illustrates how an increase in the probability of remaining in the low-rate state  $P_{LL}$  translates into a flattening of the yield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

rate state  $P_{LL}$ . In the baseline calibration indeed  $V_H^b > V_L^b$ , such that Condition (24) is satisfied and an increase in  $P_{LL}$  results in more risk taking.

The right panel in Figure 5 connects this result to the yield curve, here computed assuming the expectations hypothesis holds.<sup>27</sup> A zero interest environment may be particularly problematic if the yield curve flattens substantially and rates are expected to be at the ZLB for long. The target range for the Fed Funds rate was lowered to 0% in December 2008, where it remained for seven years until the Fed started lifting rates in December 2015. An expected duration of seven years corresponds to a probability of staying in the low-rates state of around  $P_{LL} \approx 0.85$ . In the Eurozone rates are expected to remain near-zero for an even longer time. The ECB lowered its deposit facility rate close to zero by the beginning of 2009, and did not start the process of increasing rates by end 2018.

Even with rates in the U.S. rising, the overall level of interest rates is expected to remain low (perhaps due to demographic change and weak demand for finance by corporations, [Döttling and Perotti \(2017\)](#)). This increases the likelihood that upon the next monetary policy loosening cycle rates will hit the ZLB again. Proposition 2 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

<sup>27</sup>I.e. the forward rate from date  $t$  to  $t + \tau$  is calculated as  $R_{t,t+\tau} = (R_{t+1} \times R_{t+2} \cdots \times R_{t+\tau})^{1/\tau}$ .

the low-rate state (higher  $P_{HL}$ ), the more risk they take today.

#### 4.4. 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, [Craig and Dinger \(2013\)](#) find a positive relation between bank risk taking and deposit market competition, and [Carlson et al. \(2018\)](#) highlight the link between franchise values and bank risk in a historical setting.

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. [Drechsler et al. \(2017a\)](#) argue more generally that the closer interest rates are to zero, the more bank deposits compete with cash, and hence the lower bank market power. With a more general substitutability between cash and deposits, a reduction in interest rates would undermine bank market power even above zero. Consequently, the margin channel described in [Proposition 1](#) might already be at play with a slack ZLB. Still, franchise values and hence incentives are disproportionately affected once the ZLB binds, consistent with high-frequency studies of bank stock price reactions to monetary policy announcements ([Ampudia and Van den Heuvel, 2018](#); [English et al., 2018](#)).

The overall mechanism closely mirrors evidence in [Heider et al. \(2018\)](#). In a diff-in-diff setting, the authors show that negative policy rates in the Eurozone have eaten relatively more into the interest margin of banks with more deposit relative to wholesale funding. Consistent with the notion that tight margins spur risk taking, these banks are shown to increase their lending to riskier borrowers as interbank rates fall below zero.

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

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

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

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

## 5. The Effectiveness of Capital Requirements at the ZLB

In the model, the main policy tool to curb risk taking incentives are capital requirements:

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

$$\frac{dm_t}{d\bar{e}_t} \geq 0.$$

Intuitively, higher capital increase a bank’s “skin in the game”. As shareholders put more of their own funds at stake, their payoff becomes less convex, inducing more prudent

investment (Holmstrom and Tirole, 1997). However, at the ZLB a countervailing effect comes into play. When banks are unable to pass on the cost of capital to depositors, tight capital requirements eat into bank profitability and erode franchise value:

**Lemma 2** (Franchise Value Effect). *For a given level of monitoring  $m_t$  (but taking into account how banks optimally set deposit rates in (14)), bank profits as a function of capital requirements  $\bar{e}_t$  are given by*

$$\pi_s^b(\bar{e}_t; m_t) = \begin{cases} q(m_t) \left(1 - \frac{\rho_2 - 1}{\rho_1(\eta - 1)}\right) + \left(\frac{\rho_2 - \eta}{\rho_1 \eta - 1} - 1\right) [(1 - q(m_t))\bar{e}_t + (1 + \bar{e}_t)c(m_t)], & \text{if } \beta_t \leq \beta_t^{ZLB} \\ q(m_t)(1 - \beta_t) - c(m_t) - \bar{e}_t[1 + c(m_t) - q(m_t)], & \text{if } \beta_t > \beta_t^{ZLB} \end{cases}$$

Profits unambiguously decrease in  $\bar{e}_t$  if and only if the ZLB binds:

$$\frac{\partial \pi_t^b(\bar{e}_t; m_t)}{\partial \bar{e}_t} \leq 0 \text{ if } \beta_t > \beta_t^{ZLB}$$

Lemma 2 shows in partial equilibrium that bank profitability is negatively affected by higher capital requirements if the ZLB binds. With a slack ZLB, banks can offset an increase in capital requirements by lowering deposit rates. This can be seen when differentiating the interior solution  $r_{t+1}$  in (14) w.r.t.  $e_t$  (setting  $\omega = 1$  for ease of illustration):

$$\frac{\partial r_{t+1}}{\partial e_t} = -\frac{\eta}{\eta - 1} \left[ \frac{(1 - q(m_t)) + c(m_t)}{q(m_t)} \right] R_{t+1} < 0$$

The term in square brackets reflects the cost of equity.<sup>28</sup> Under perfect competition ( $\eta \rightarrow \infty$ ) banks just “pass on” the cost of capital. The more market power banks have (smaller  $\eta$ , larger  $\frac{\eta}{\eta - 1}$ ), the more aggressively they adjust deposit rates in response to tighter capital requirements. In contrast, when the ZLB binds,  $r_{t+1} = 1$ , and this margin of adjustment vanishes.

Figure 6 confirms the partial equilibrium result of Lemma 1 in general equilibrium. 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  $P_{LL}$ .

With  $\beta_L = 0.95$  the ZLB is slack at all times, and if anything capital requirements have an overall positive effect on  $V_L$ . In contrast, with  $\beta_L = 0.975$  the ZLB binds and higher

<sup>28</sup>Relative to the financial market, bank equity is expensive because banks incur operating costs  $c(m_t)$ , and fail with prob.  $(1 - q(m_t))$ , while investing via the financial market does not carry any cost, and produces physical capital with certainty.



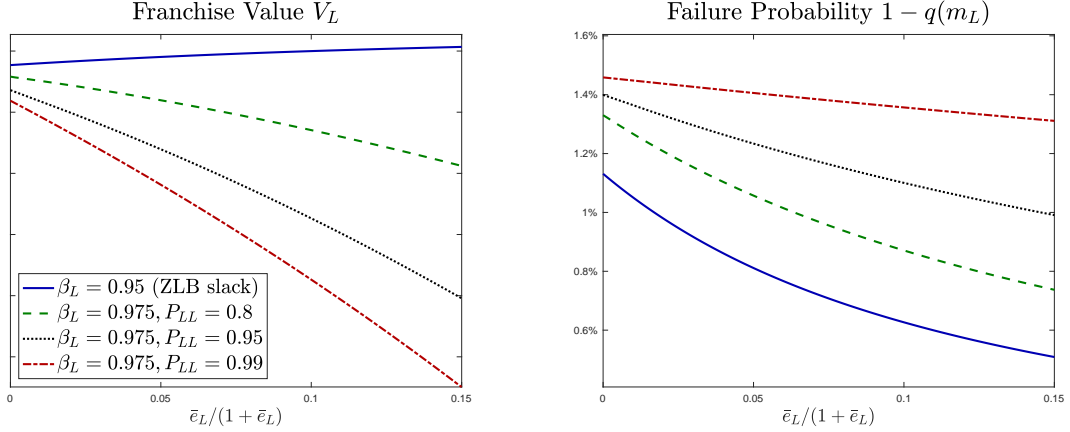


Figure 6: This figure plots franchise values (left panel) and risk taking (right panel) in the low-rate state, against the capital requirement  $\bar{e}_L$ . Different lines represent different levels of interest rates and probability of remaining in the low-rate state. Parameters are calibrated as described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

capital requirements erode profitability, consistent with Lemma 1. This adverse effect is particularly strong the higher  $P_{LL}$ , i.e. the longer the economy remains at the ZLB in expectation.

The right panel of Figure 6 shows the implications for equilibrium monitoring. The more the capital requirement depresses franchise values, the less it curbs risk shifting incentives. For example, franchise values drop much more with  $\beta_L = 0.975$  and  $P_{LL} = 0.99$  than in the baseline calibration with  $\beta_L = 0.975$  and  $P_{LL} = 0.8$  (representing an expected duration of 5 years at the ZLB). Accordingly, the line representing  $P_{LL} = 0.99$  in the right panel is flatter, i.e. a marginal increase in capital requirements reduces risk shifting incentives relatively less.

Via the skin-in-the-game effect, higher capital requirements always reduce risk taking (Proposition 3), but the franchise value effect works some way against the skin-in-the-game effect, rendering capital requirements overall less effective. In the limiting case  $P_{LL} = 1$ , the franchise value effect completely overrules the skin-in-the-game effect, such that capital regulation no longer has any effect on risk taking incentives. This result can be shown analytically:<sup>29</sup>

**Proposition 4.** *Suppose  $\beta_L > \beta_L^{ZLB}$  (ZLB binds in the low-rate state). In the limiting*

<sup>29</sup>To see that the capital requirement becomes ineffective, evaluate (22) at  $s = L$  and  $r_L = 1$ , using  $D_L$  from (20) and  $V_L$  from (27). After some algebra, it can be seen that in the limiting case  $P_{LL} = 1$  all  $\bar{e}_L$  drop out from the right hand side of (22), implying that  $m_L$  is unaffected by  $\bar{e}_L$ .

case  $P_{LL} = 1$  (the ZLB binds forever), equilibrium monitoring  $m_L$  is unaffected by the level of capital requirements,

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

**Capital requirements and franchise value.** Using a Monti-Klein model of bank competition, [Hellmann et al. \(2000\)](#) show that higher capital requirements may more generally undermine bank franchise value. This is in contrast to the result in [Figure 6](#), where lowering deposit rates can fully undo the negative impact on profitability as long as the ZLB remains slack.<sup>30</sup> Hence, whether capital requirements do or do not reduce franchise value away from the ZLB depends on modeling choices. However, this is besides the main point. The general result here is that at the ZLB higher capital requirements *disproportionately* affect franchise values. Clearly, the ZLB eliminates one margin of adjustment, such that higher capital requirements must inevitably have a more negative effect on bank profitability when the ZLB binds.

## 6. Optimal Capital Regulation

The previous analysis highlights two key positive insights: one, the ZLB can increase bank risk taking incentives. Two, the ZLB can make capital requirements less effective in reducing risk taking incentives, exactly during times when they are already high. The natural follow-up question is what this means for optimal capital regulation.

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<sup>30</sup>Modeling differences to [Hellmann et al. \(2000\)](#) are the monopolistic competition setup, and the general equilibrium approach taken in this paper. In [Hellmann et al. \(2000\)](#) equity is priced by the opportunity cost of funds of bank owners, and banks face an exogenous demand for deposits as well as a choice between two investment opportunities with exogenously given returns. Here, households price the required return on equity and assets (via financial market investments), and the demand for deposits is also derived from household optimization. This equilibrium approach is useful when studying the effect of changing interest rates, as shifts in the household's discount factor affect the entire spectrum of required returns and interest rates.

## 6.1. Welfare Benchmark

To answer this question, I calculate the welfare-maximizing, state-dependent levels  $\{e_H^*, e_L^*\}$ . An advantage of the general equilibrium approach here is that the representative household's lifetime utility delivers a clear welfare benchmark. To calculate welfare, I simulate the model for 100,000 random paths of length of 200 years, starting in the low-rate state. I then pick the combination of capital requirements that maximizes the average lifetime utility across the 100,000 draws. To be very clear about the constrained efficiency exercise here, the approach takes as given the level of competition and deposit insurance, i.e. they are not part of the policy choice set. I also do not consider policies that directly alleviate the ZLB constraint.<sup>31</sup>

While deposit insurance is not a critical element for the risk shifting problem and analytical results in Section 4, I realistically set  $\omega = 0.57$  for the quantitative exercise, in line with U.S. data. I further introduce a quadratic social cost of bank failures  $\chi[1 - q(m_{t-1})]^2$ . Realistically, resolving banks can be quite costly, especially if many institutions fail together. This failure cost is borne by the government, such that taxes reflect both the cost of deposit insurance as well as failure costs:

$$T_t = \omega r_t D_{t-1} + \chi[1 - q(m_{t-1})]^2$$

Since the cost enters the model via lump sum taxes, agents do not internalize the social cost of bank failures, and hence all other equilibrium conditions are unaffected.<sup>32</sup>

To calibrate the cost of bank failures  $\chi$  I use budget figures from FDIC's 2017 Annual Report.<sup>33</sup> In 2017, the FDIC spent \$430 million on their Receivership Management program, reflecting costs of managing resolved assets, and amounting to 0.0022% of GDP. Solving  $\frac{\chi[1-q(m_{t-1})]^2}{Y_t} = 0.000022$  for  $\chi$ , yields  $\chi = 0.75$ .

While these two elements help to get a realistic assessment of the optimal level of capital requirements in the model, I also report robustness of the results to varying  $\omega$  and  $\chi$  (including  $\chi = 0$ ).

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<sup>31</sup>Beyond the scope of this paper, such policies could include abolishing paper money, or a higher inflation target.

<sup>32</sup>While the failure cost is not internalized by any agents in the competitive equilibrium, it does affect the first best allocation, see Appendix A.8.

<sup>33</sup><https://www.fdic.gov/about/strategic/report/index.html>

## 6.2. Results

Figure 7 plots the welfare-maximizing capital requirements for different levels of the household's discount factor in the low-rate state  $\beta_L$ . When  $\beta_L < \beta_L^{ZLB}$ , interest rates are high and the ZLB is slack. In this region, the optimal capital requirement is around 10-11% in both the low-rate and high-rate state, somewhat above the level currently required according to the Basel III regulatory framework.<sup>34</sup>

In contrast, when the ZLB binds in the low-rate state ( $\beta_L > \beta_L^{ZLB}$ ), the optimal capital requirement in the low-rate state drops significantly, while that in the high-rate state increases. That is, if the ZLB binds occasionally, optimal dynamic capital requirements are positively correlated with the level of interest rates. In the baseline calibration, the magnitude of cyclicity is quite strong, with optimal requirements around 13.5% in the high-rate state compared to 7% in the low-rate state.

What explains these results? The benefit of tighter capital requirements is that they induce banks to take less risk, while their cost is lower liquidity provision in equilibrium. Figure 8 reveals that as long as the ZLB is slack at all times ( $\beta_L < \beta_L^{ZLB}$ ), banks take too much risk and provide too little liquidity relative to the first best. In this region, optimal capital requirement trade off a reduction in risk taking against lower liquidity provision, resulting in an optimal level around 10-11%.<sup>35</sup>

When the ZLB binds occasionally ( $\beta_L > \beta_L^{ZLB}$ ) two new effects come into play. First, the franchise value effect described in Section 5 renders capital requirements less effective in curbing risk taking at the ZLB. Because capital requirements have a cost, this effect motivates a weaker use in the low-rate state, explaining the drop in  $e_L^*$  for  $\beta_L > \beta_L^{ZLB}$  in

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<sup>34</sup>In the model, the capital requirement is expressed as a fraction of non risk-weighted assets, more closely resembling the Leverage Ratio requirement. At the same time, in the model banks only invest in risky loans, which tend to carry relatively high regulatory risk-weights. The model capital requirement can therefore be interpreted as a leverage requirement on risky loans, somewhere between a leverage and a capital requirement. According to Basel III 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.

<sup>35</sup>Recall from Proposition 1 that lower discount rates induce banks to take less risk. This explains that the optimal capital requirement decreases slightly in  $\beta_L$  as long as  $\beta_L < \beta_L^{ZLB}$ , allowing for a higher level of liquidity provision while keeping equilibrium failure rates at a stable level.

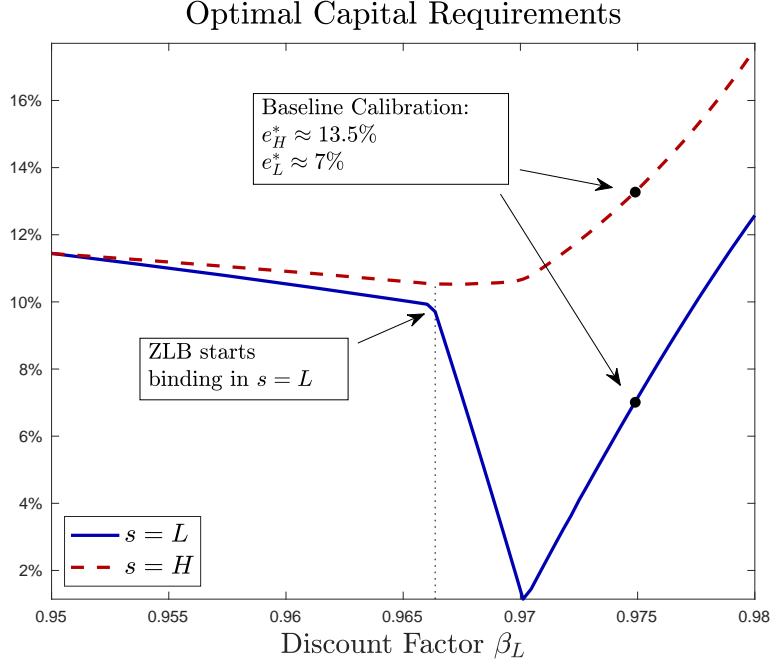


Figure 7: This figure plots the optimal state-dependent capital requirement, for different levels of the discount factor in the low-rate state. Capital requirements are expressed as a fraction of total assets ( $e_t/(1 + e_t)$ ). Parameters are calibrated as described in Section 3.6.

Figure 7.<sup>36</sup>

At the same time, the binding ZLB in the low-rate state motivates a tighter capital requirement in the high-rate state, as evident by the increasing  $e_H^*$  in Figure 7. In the high-rate state, the effectiveness of capital requirements is not undermined because the ZLB is slack. Yet, risk taking incentives are heightened because banks anticipate that they may be constrained by the ZLB in the future, and hence have low expected profitability. To tame these heightened risk taking incentives, optimal capital requirements in the high-rate state are unambiguously tighter.

The left panel of Figure 8 reveals further, that equilibrium failure probabilities may be even higher under optimal regulation than in the baseline with  $e_H/(1+e_H) = e_L/(1+e_L) = 8.5\%$ . Due to the franchise value effect described in Section 5, it is optimal to allow more risk taking at the ZLB, even though risk taking incentives are already high.

<sup>36</sup>What explains the U-shaped pattern of the optimal capital requirement  $e_L^*$  in Figure 7? The marginal return to monitoring is higher at lower levels of  $m_t$ , i.e.  $q(m_t) - c(m_t)$  is concave. While the franchise value effect initially motivates a lower level of  $e_L^*$ , for very high levels of  $\beta_L$  bank risk taking is so strong that the marginal return to monitoring is very high and it becomes optimal to again increase the capital requirement as  $\beta_L$  increases further.

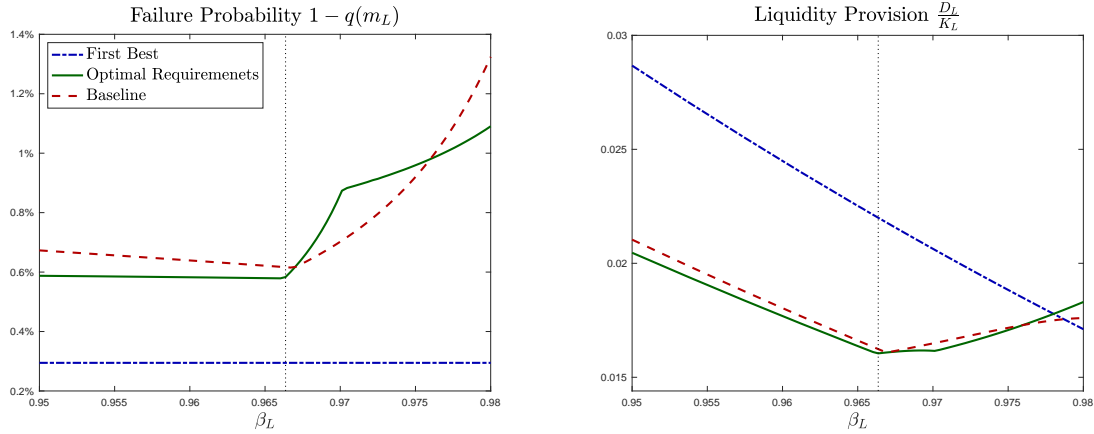


Figure 8: These graphs plot failure probabilities and liquidity provision for the first best, the competitive equilibrium with optimal capital requirements, and for the baseline with capital requirements of 8.5%. The vertical dotted line marks the threshold  $\beta_L^{ZLB}$ , beyond which the ZLB binds in the low-rate state. Parameters are calibrated as described in section 3.6.

Regarding liquidity provision, at the ZLB the equilibrium quantity of deposits grows relative to the financial market, and may even exceed the first best level (right panel of Figure 8). Intuitively, from the perspective of households deposits become quite attractive when the ZLB binds, inducing a substitution from the financial market towards deposits.

### 6.3. Discussion

The results in this section relate to the debate on counter-cyclical capital regulation. Recent contributions show that counter-cyclical leverage limits may be motivated in models with welfare-relevant pecuniary externalities (e.g. [Lorenzoni, 2008](#); [Stein, 2012](#); [Korinek and Simsek, 2016](#)). In the policy debate, a common rationale is that buffers built up in good times should be available to be used in bad times (e.g. [Goodhart et al., 2008](#)).

None of these channels are active in this model, as there are no fire sale or aggregate demand externalities, nor frictions in raising equity that would motivate dynamically adjusting optimal capital requirements. Yet, capital requirements optimally vary with the level of interest rates. The argument here is based purely on how the level of interest rates affects the ability of banks to adjust deposit rates in response to tighter regulation. To the extent that interest rates are low in bad times, the model thus delivers a novel rationale for counter-cyclical regulation.

Another implication of the franchise value effect is that monetary- and macro-prudential

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

It should be noted that the welfare analysis here should not be seen as a full-blown welfare assessment of optimal capital requirements, because it abstracts from certain elements. For example, the only source of aggregate variation is in the household's discount factors, while the model abstracts from aggregate business cycle dynamics.

## 6.4. Sensitivity Analysis

Table 1 reports sensitivity of the welfare analysis with respect to bankruptcy cost  $\chi$ , and the fraction of insured deposits  $\omega$ , for  $\beta_L = 0.96 > \beta_L^{ZLB}$  (such that the ZLB is slack at all times), and  $\beta_L = 0.975 < \beta_L^{ZLB}$  (baseline, ZLB binds occasionally).

As expected, optimal capital requirements are higher as bankruptcy costs increase, though the magnitude of the impact is modest. For example, at the baseline  $\beta_L = 0.975$  optimal capital requirements vary between 12.8% and 13.86% in the high-rate state, as  $\chi$  increases between 0 to 1.5 (= +/- 100% of its baseline level 0.75). A more generous deposit insurance also motivates tighter optimal capital requirements. For example, at  $\beta_L = 0.975$  optimal requirements vary between 9.29% and 16.71% in the high-rate state, as the fraction of insured deposits varies from 30% to 80%. Intuitively, deposit insurance is a strong distortion that make the pricing of deposits unresponsive to a bank's risk.

Importantly, in each of the columns, the distance between  $e_H^*$  and  $e_L^*$  is much wider at  $\beta_L = 0.96$  (slack ZLB), compared to  $\beta_L = 0.975$  (ZLB binds occasionally). This underlines the robustness of the key result, that optimal capital requirements vary with the level of interest rates if the ZLB binds occasionally.

		$(\omega, \chi)$				
		(0.57,0.75)	(0.57, <b>1.5</b> )	(0.57, <b>0</b> )	<b>(0.8,0.75)</b>	<b>(0.3,0.75)</b>
$\beta_L = 0.96$	$e_H^*$	10.90%	11.29%	10.51%	13.83%	7.24%
	$e_L^*$	10.53%	10.92%	6.81%	13.46%	6.84%
$\beta_L = 0.975$	$e_H^*$	13.34%	13.86%	12.80%	16.71%	9.29%
	$e_L^*$	7.13%	7.82%	6.37%	10.66%	3.20%

Table 1: This table reports optimal capital requirements for different values of  $\beta_L, \omega$  and  $\chi$ . Capital requirements are reported as a ratio of total assets ( $e_t/(1 + e_t)$ ). At  $\beta_L = 0.96$  the ZLB is slack at all times, and at  $\beta_L = 0.975$  it binds whenever the economy is in the low-rate state.

## 6.5. An Alternative Policy

Is there a better policy response than merely adjusting capital requirements at the ZLB? One way to alleviate the ZLB constraint is to pay a subsidy whenever the ZLB binds. I consider a subsidy  $\tau_t$  per unit of deposits, to replicate whatever negative rate banks would want to set if there was no ZLB constraint. That is, if  $\tilde{r}_{t+1}$  denotes the equilibrium deposit rate banks would want to set in an economy without a ZLB constraint, then the subsidy is given by

$$\tau_t = \min \{1 - \tilde{r}_{t+1}, 0\}.$$

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

The subsidy effectively eliminates the ZLB constraint for banks. Accordingly, it restores bank profitability and hence incentives, as illustrated in the top left panel of Figure 9. The figure highlights the difference between the competitive equilibrium under optimal capital requirements, with and without the subsidy, as well as a counter-factual economy absent the ZLB friction. With the subsidy, the risk taking of banks is much lower than without, and comes close to the level in an economy without the ZLB friction.

However, the overall welfare effect of the subsidy is ambiguous. The bottom left panel plots a welfare gap, defined as the relative deviation of the representative household's lifetime utility from the first best. When rates are quite low ( $\beta_L$  high), the subsidy result in a higher level of welfare, but for smaller smaller values of  $\beta_L$  the subsidy can actually worsen welfare. The reason is that the subsidy results in an inefficiently high quantity of deposits supplied in equilibrium, as banks grow relative to the financial market (see the



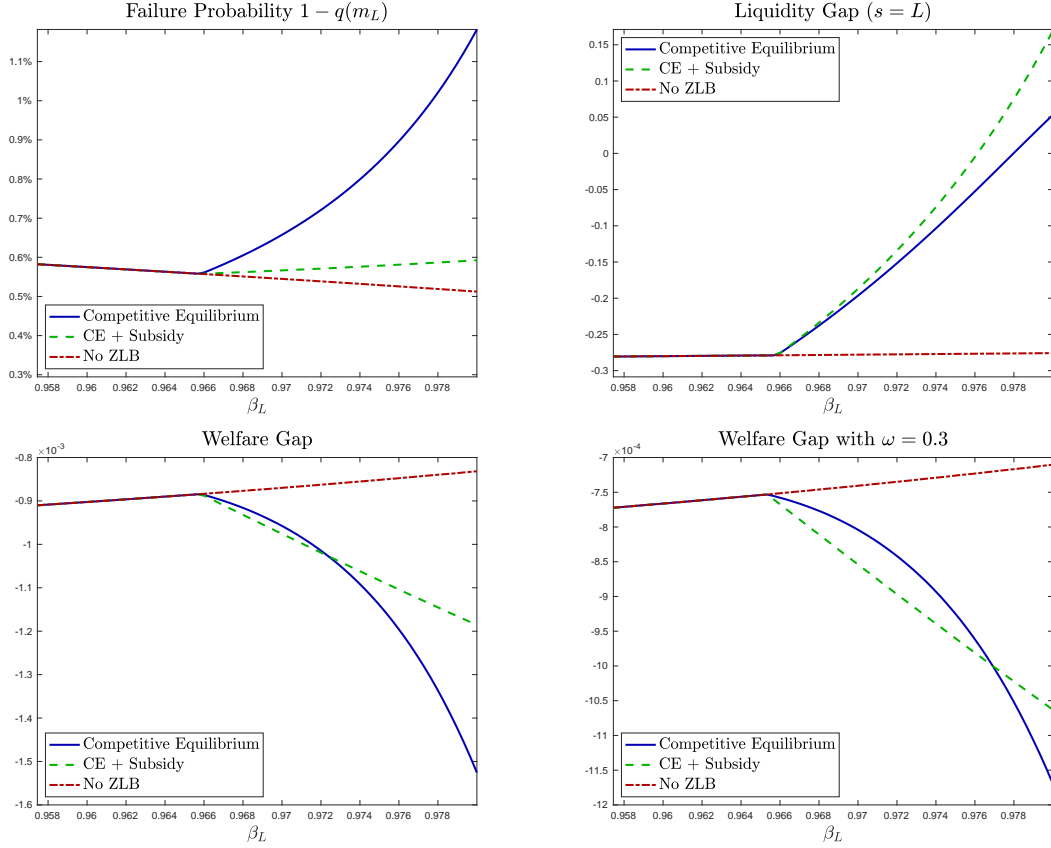


Figure 9: Risk taking (top left panel), liquidity gap (top right panel), and welfare gap relative to the first best equilibrium (bottom panels), for different levels of  $\beta_L$ , under the competitive equilibrium with optimal capital requirements, the equilibrium with a subsidy on deposits, and the equilibrium absent the ZLB friction. Other parameters are calibrated as described in Section 3.6.

top right panel, which plots the relative deviation of  $D_L$  from the first best). This effect is stronger, the more sensitive depositors are to bank risk taking, i.e. the lower the level of deposit insurance  $\omega$ . For example, with  $\omega = 0.3$  the lower risk taking induced by the subsidy results in an even stronger inflow into deposits than in the baseline  $\omega = 0.57$ , and accordingly the subsidy has a negative impact on welfare for a wider range of values  $\beta_L$  (bottom left panel).

Another negative effect may be that taxes raised to fund the subsidy may be distortionary (outside the model, as here taxes are lump-sum). Overall, the welfare effects of the subsidy are thus ambiguous, and it may well be counter-productive as it induces banks to grow too large in equilibrium.

## 7. Conclusion

Since the 1980s real interest rates across advanced economies have followed a steady downward trend. Low rates are likely here to stay (Summers, 2014), increasing the likelihood that short-term rates frequently hit zero in the future. This new environment of near-zero interest rates requires re-thinking some fundamental questions across macro- and financial economics. This paper presents a model that highlights potential consequences for banking regulation and risk taking.

The ZLB may increase risk taking incentives of banks, as low margins induce a search for yield when banks cannot pass on low asset returns to depositors. These effects are particularly strong if the ZLB is expected to bind for a long time. And even after monetary policy “normalization”, incentives are affected if the ZLB is expected to bind again in the future.

While the ZLB has often been discussed as a constraint to monetary policy, I show that it can also impede the effectiveness of bank capital regulation. Hence, the ZLB not only increases risk taking incentives per se, it can also makes the typical regulatory tools employed to curb risk taking less effective.

A result of these effects is that they provide an independent motivation to adjust capital requirements to the level of interest rates. Perhaps surprisingly, even though there is already more risk taking at the ZLB, these channels motivate optimally weaker requirements whenever the ZLB binds. Moreover, optimal requirements should be tightened whenever the ZLB is slack today, but there is a chance of it binding in the future. The model thus provides a novel rationale for cyclically adjusting regulation.

These points are also relevant for the debate on the interaction between monetary and macro-prudential policies. It is sometimes argued that monetary policy should focus on inflation, while macro-prudential policies should focus on financial stability. However, if there is an interaction between the two, they cannot be seen in isolation. Given that low policy rates may undermine the effectiveness of prudential regulation, an interesting avenue for future research is to study their joint determination.

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## A. Paper Appendix

### A.1. The Zero Lower Bound

This appendix discusses two ways to endogenize a (zero) lower bound on deposit rates.

**Cash** The first approach is to explicitly introduce cash as an alternative to deposits.

Several questions arise. First, how to introduce cash in the model? In the finance literature, cash is often modeled as a real storage technology that transforms resources one-for-one between periods. In the macroeconomic literature, it is instead modeled as a nominal asset offered by the government. As long as inflation is equal to zero, in both approaches cash yields a real return of zero.

A second question is how much convenience yield cash has relative to deposits. Arguably, deposits are a more convenient form of payment, thanks to electronic payment systems. On the other hand, cash may be more convenient in black market transactions.

No matter how cash is introduced, it results in *some* lower bound on deposit rates, as it offers an outside option that limits how low deposit rates can go. For a tractable macro model in which a real ZLB arises with nominal currency and zero inflation, see for example [Korinek and Simsek \(2016\)](#). Naturally, higher levels of inflation would result in a “ $-\pi$ ” lower bound if deposits are denominated in real terms.

Alternatively, suppose there is a risk-less storage technology  $M_t$  that yields slightly less convenience than deposits, say, by a factor  $1 - v_m$ . That is, suppose the utility function of households is given by

$$v(D_t, M_t) = \log(D_t + v_m M_t)$$

Then, deposit rates of insured deposits have to satisfy a lower bound

$$r_{t+1} \geq v_m.$$

If a fraction  $(1 - \omega)$  of deposits is not insured, the lower bound would also reflect some risk taking by banks:

$$r_{t+1} \geq \frac{v_m}{[\omega + (1 - \omega)q(m_t)]}.$$

**Loss of Customer Base and Fear of Bank Run** Alternatively, a zero lower bound can arise in a model with some irrational depositors, that perceive negative rates as extremely unfair and immediately withdraw all their cash as soon as they see negative rates.

Banks may worry about this for two reasons. First, banking is arguably a customer-base business, as many people don't change bank accounts very often. Hence, banks might naturally worry about customers switching banks, and losing the value of their future relationship.

Worse, news of many customers withdrawing at once may trigger a bank run. Even if only a small fraction of depositors withdraws irrationally, others may rationally withdraw their funding as well, especially if there is sufficient uncertainty about the fraction of irrational withdrawers.

## A.2. Equilibrium conditions

All equilibrium conditions can be summarized as follows:

- Firms

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

- Households

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



- Banks

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

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

$$d_t^b = [R_t(1 + e_{t-1}) - r_t]D_{t-1} - [e_t + (1 + e_t)c(m_t)]D_t(r_{t+1}),$$

$$\frac{r_{t+1}}{R_{t+1}} = \frac{\rho_2}{\rho_1} \left[ \frac{\eta - 1/\rho_2}{\eta - 1} - \frac{\eta}{\eta - 1} \frac{(1 - q(m_t))e_t + (1 + e_t)c(m_t)}{q(m_t)} \right],$$

$$\rho_1 \equiv \omega + (1 - \omega) \left( q(m_t) + \frac{\eta}{\eta - 1} q'(m_t) r_{t+1} \frac{dm_t^*}{dr_{t+1}} \right),$$

$$\rho_2 \equiv \omega + (1 - \omega) \left( q(m_t) + q'(m_t) r_{t+1} \frac{dm_t^*}{dr_{t+1}} \right),$$

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

$$e_t = \bar{e}_t$$

### A.3. Calibration

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

Table 2: 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, $\bar{e}_s/(1 + \bar{e}_s) = 8.5\%$	BIS
$\psi_1 = 0.011$	Median U.S. bank's net non-interest expense / assets 1984 - 2013, $c(m_H) = 2.3\%$	Call Reports (obtained through WRDS)
$\psi_2 = 0.018$	Average annual failure rate of U.S. banks, $1 - q(m_H) = 0.76\%$	<a href="#">Davydiuk (2017)</a>
$\eta = 4.5$	Average interest margin of U.S. banks from 1996-2013 $R_H - r_H = 3.5\%$	Call Reports (obtained through WRDS)
$\gamma = 0.005$	Deposit liabilities of U.S. chartered institutions / total U.S. capital stock, $D_H/K_H = 2\%$	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.4. Bank Problem

### A.4.1. Detailed Derivation

This appendix provides some more detail on solving the bank's problem. To arrive at the FOC w.r.t. deposit rates (14), differentiating  $V_t$  w.r.t.  $r_{t+1}$  gives (dropping  $i$  subscripts to minimize notation):

$$\frac{\partial V_t}{\partial r_{t+1}} = -q(m_t)\beta_t D_t + \pi_{t,t+1} \frac{\partial D_t}{\partial r_{t+1}} + \dots$$

$$\frac{dm_t^*}{dr_{t+1}} \left( \underbrace{q'(m_t)\beta_t [(R_{t+1}(1+e_t) - r_{t+1})D_t + \mathbb{E}_t V_{t+1}] - (1+e_t)D_t c'(m_t)}_{=0 \text{ by FOC w.r.t. } m_t \text{ (12)}} + \pi_{t,t+1} \frac{\partial D_t}{\partial m_t} \right).$$

The partial derivatives of  $D_t$  w.r.t.  $r_{t+1}$  and  $m_t$  are obtained by differentiating (5):

$$\frac{\partial D_t}{\partial r_{t+1}} = \eta[\omega + (1-\omega)q(m_t)] \frac{1}{R_{t+1}} D_t \left( 1 - [\omega + (1-\omega)q(m_t)] \frac{r_{t+1}}{R_{t+1}} \right)^{-1}$$

$$\frac{\partial D_t}{\partial m_t} = \eta[(1-\omega)q'(m_t) \frac{r_{t+1}}{R_{t+1}}] D_t \left( 1 - [\omega + (1-\omega)q(m_t)] \frac{r_{t+1}}{R_{t+1}} \right)^{-1}.$$

Setting  $\frac{\partial V_t}{\partial r_{t+1}} = 0$ , and rearranging gives (14).

The FOCs w.r.t.  $e_t$  and  $r_{t+1}$  depend on how the optimal monitoring in the second stage reacts to these two variable, i.e. on  $\frac{dm_t^*}{dr_{t+1}}$  and  $\frac{dm_t^*}{de_t}$ , respectively. These two derivatives can be derived using the Implicit Function Theorem, by first defining the FOC w.r.t.  $m_t$  (12) as a function

$$g(m_t, e_t, r_{t+1}) = \frac{q'(m_t)}{c'(m_t)} \frac{\beta_t}{(1+e_t)D_t} [(1+e_t)R_{t+1} - r_{t+1}] D_t + \mathbb{E}_t V_{t+1} - 1. \quad (25)$$

Then, the derivatives can be derived analytically as

$$\frac{dm_t^*}{dr_{t+1}} = - \frac{\partial g(m_t, e_t, r_{t+1}) / \partial r_{t+1}}{\partial g(m_t, e_t, r_{t+1}) / \partial m_t}$$

$$\frac{dm_t^*}{de_t} = - \frac{\partial g(m_t, e_t, r_{t+1}) / \partial e_t}{\partial g(m_t, e_t, r_{t+1}) / \partial m_t}.$$

### A.4.2. Binding Capital Requirement

Does the regulatory capital requirement bind, or do banks set equity at an interior solution to (13)? Table 3 reports the leverage chosen by banks if there were not capital requirements ( $\bar{e}_t = 0$ ). Banks contribute less equity if there is more deposit insurance

	$\omega$					
	0	0.2	0.4	0.6	0.8	1
$e_H$	4.94%	3.46%	1.81%	0%	0%	0%
$e_L$	0%	0%	0%	0%	0%	0%

Table 3: This table reports interior capital choices by banks, according to (13), for different levels of deposit insurance  $\omega$ . The numbers are reported as a fraction of total assets,  $e_t/(1 + e_t)$ . All other parameters are calibrated as described in Section 3.6.

(higher  $\omega$ ). Intuitively, the more depositors are insured, the less sensitive they are to the bank's risk taking, and the less value there is for banks to signal lower risk taking with more equity.

Even in the complete absence of deposit insurance banks choose to contribute less than 5% equity, below the 8.5% in the baseline calibration. With a binding ZLB in the low-rate state, banks always choose  $e_L = 0$ .

## A.5. Proof of Proposition 1

A marginal increase in  $\beta_t$  results in a decrease in  $R_{t+1}$ , by the Euler Equation (4). To see how a marginal decrease in  $R_{t+1}$  affects equilibrium monitoring, re-write the FOC (22) as a function  $g(m_t, r_{t+1}, R_{t+1}) = 0$ :

$$g(m_t, r_{t+1}, R_{t+1}) = \frac{q'(m_t)}{c'(m_t)} \frac{1}{(1 + e_t)} \left( (1 + e_t) - \frac{r_{t+1}}{R_{t+1}} + \frac{\mathbb{E}_t V_{t+1}}{D_t R_{t+1}} \right) - 1. \quad (26)$$

with  $D_t$  given by (5):

$$D_t = \frac{\gamma}{1 - [\omega + (1 - \omega)q(m_t)] \frac{r_{t+1}}{R_{t+1}}}.$$

Note that  $\mathbb{E}_t V_{t+1}$  is unaffected by a change in  $\beta_t$ , since the comparative statics keep  $\beta_{t+1}, \beta_{t+1}, \dots$  fixed. Using the Implicit Function Theorem:

$$\frac{dm_t}{dR_{t+1}} = - \frac{\partial g(\cdot)/\partial R_{t+1}}{\partial g(\cdot)/\partial m_t}.$$

It is easy to see that  $\partial g(m_t, R_{t+1})/\partial m_t \leq 0$ . Hence,  $\frac{dm_t}{dR_{t+1}} \geq 0$  has the same sign as  $\partial g(\cdot)/\partial R_{t+1}$ . If the ZLB binds,  $r_{t+1} = 1$ , and the partial derivative is given by

$$\partial g(\cdot)/\partial R_{t+1} = \frac{q'(m_t)}{c'(m_t)} \frac{1}{(1 + e_t)} \left( -\frac{1}{R_{t+1}^2} - \frac{\mathbb{E}_t V_{t+1}}{D_t^2 R_{t+1}^2} \frac{\partial(D_t R_{t+1})}{\partial R_{t+1}} \right),$$

Evaluating when  $\partial g(\cdot)/\partial R_{t+1} \leq 0$  defines a necessary and sufficient condition for  $\frac{dm_t}{dR_{t+1}} \leq 0$ . Proposition 1 gives an even weaker necessary condition

$$\frac{\partial(D_t R_{t+1})}{\partial R_{t+1}} \geq 0 \Leftrightarrow \beta_t \geq \frac{1}{2[\omega + (1 - \omega)q(m_t)]}.$$

□

With a slack ZLB,  $r_{t+1}$  is given by (14). In the case of  $\omega = 1$ , the ratio  $\frac{r_{t+1}}{R_{t+1}}$  can be expressed as a function of  $m_t$  and  $e_t$  only. Hence, in this case  $R_{t+1}$  only enters the function  $g(m_t, r_{t+1}, R_{t+1})$  via the denominator in the term  $\frac{\mathbb{E}_t V_{t+1}}{D_t R_{t+1}}$ , reflecting the discounting effect. Hence, with a slack ZLB and  $\omega = 1$ , an increase in  $\beta_t$  (= a decrease in  $R_{t+1}$ ), always results in an increase in  $m_t^*$ .

## A.6. Proof of Proposition 2

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

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

$$V_s = \frac{1}{\Lambda} [(1 - q(m_{s'}))\beta_{s'} P_{s's'} \pi_s D(r_s) + q(m_s)\beta_s P_{ss'} \pi_{s'} D(r_{s'})], \quad (27)$$

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 (20). By lemma 1, if  $\beta_L > \beta_L^{ZLB}$ , the ZLB binds. In this case, one can write  $\pi_L$  as

$$\pi_L = q(m_L) \left[ (1 + \bar{e}_L) - \frac{1}{R_L} \right] - [\bar{e}_L + (1 + \bar{e}_L)c(m_L)]. \quad (28)$$

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

$$D(1) = \left( \frac{\gamma}{1 - [\omega + (1 - \omega)q(m_L)]/R_L} \right).$$

Clearly,  $\lim_{R_L \rightarrow 1} \pi_L < 0$ , and  $\lim_{R_L \rightarrow [\omega + (1 - \omega)q(m_L)]} D(1) = \infty$ . Hence,

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

Inspecting (27), 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  $\hat{\beta}$  s.t. for  $\beta_L > \hat{\beta}$  it must be that  $V_H > V_L$ .

(ii) From (22), monitoring increases in  $\mathbb{E}_t V_{t+1}$ . With  $V_H > V_L$  it follow immediately that  $\mathbb{E}_s V_{t+1} = P_{ss} V_s + P_{ss'} V_{s'}$  decreases in  $P_{sL}$ .  $\square$

## A.7. Proof of Propositions 3 and 4

Proposition 4 states that if the ZLB binds forever ( $P_{LL} = 1$ ), then  $dm_t/de_t = 0$ . Equilibrium risk taking is defined by  $g(m_t, e_t, r_{t+1}) = 0$ , with  $g(\cdot)$  defined in (25), and

$$\frac{dm_t}{de_t} = - \frac{\partial g(m_t, e_t, r_{t+1}) / \partial e_t}{\partial g(m_t, e_t, r_{t+1}) / \partial m_t}.$$

However, evaluating  $g(m_t, e_t, r_{t+1} = 1)$  with  $P_{LL} = 1$ , also using (27) and (28), after some algebra all  $e_t$  drop out from  $g(\cdot)$  and  $m_t$  is a function of  $\beta_t$  and other exogenous parameters only. This proves Proposition 4.  $\square$

Proposition 3 follows from the proof of Proposition 4. If in the extreme case  $P_{LL} = 1$  capital requirements have exactly zero effect on risk taking, they must have a weakly positive impact on equilibrium monitoring overall. The reason is that with  $P_{LL} < 1$  there is at least some chance that at some point the bank is not constrained by the ZLB. With a slack ZLB, capital requirements have a less negative impact on bank profitability and franchise values, as banks can pass on the cost of capital on depositors (Lemma 2).  $\square$

## A.8. First Best with Bank Failure Cost

This appendix solves the first best when bank failures generate a cost  $(1 - q_t)^2\chi$ . While the failure cost of banks is not internalized by any agents in the competitive equilibrium, it does affect the first best allocation as the budget constraint in the planner's problem is now given by

$$C_t + I_t^m + (1 + e_t)D_t(1 + c(m_t)) + \chi(1 - q(m_t))^2 = F(K_t). \quad (29)$$

Consequently, the first order condition w.r.t.  $m_t$  (18) takes into account the cost of bank failures:

$$c'(m_t) = q'(m_t) \left[ 1 + \frac{2\beta_t\chi(1 - q(m_t))}{(1 + e_t)D_t} \right].$$

The FOC's w.r.t.  $I_t^m$  and  $D_t$  are unaffected and still given by (17) and (19), respectively.

## B. Internet Appendix

### B.1. Additional Evidence on 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 10 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. (2018) 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 10 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



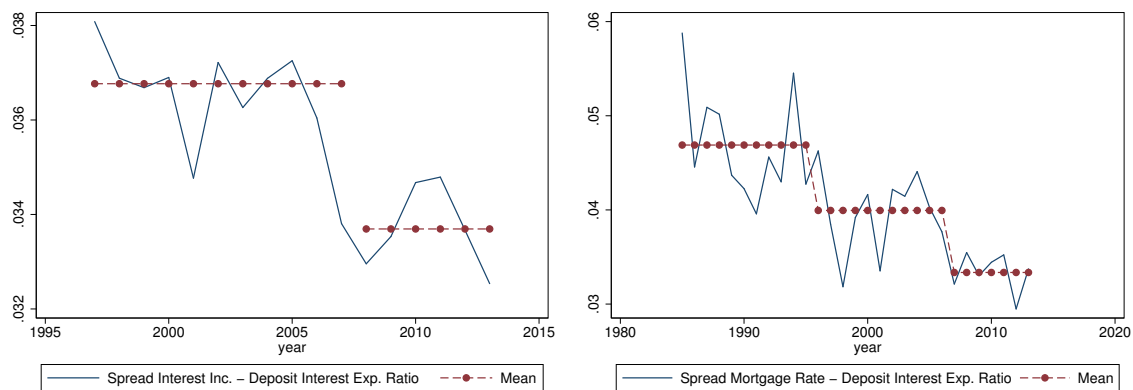


Figure 10: The left panel plots the median spread between interest income and deposit interest expense ratio, among all U.S. banks in the Call Reports data. The right panel plots the spread between the rate on 30 year mortgages and the median deposit expense ratio.

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.

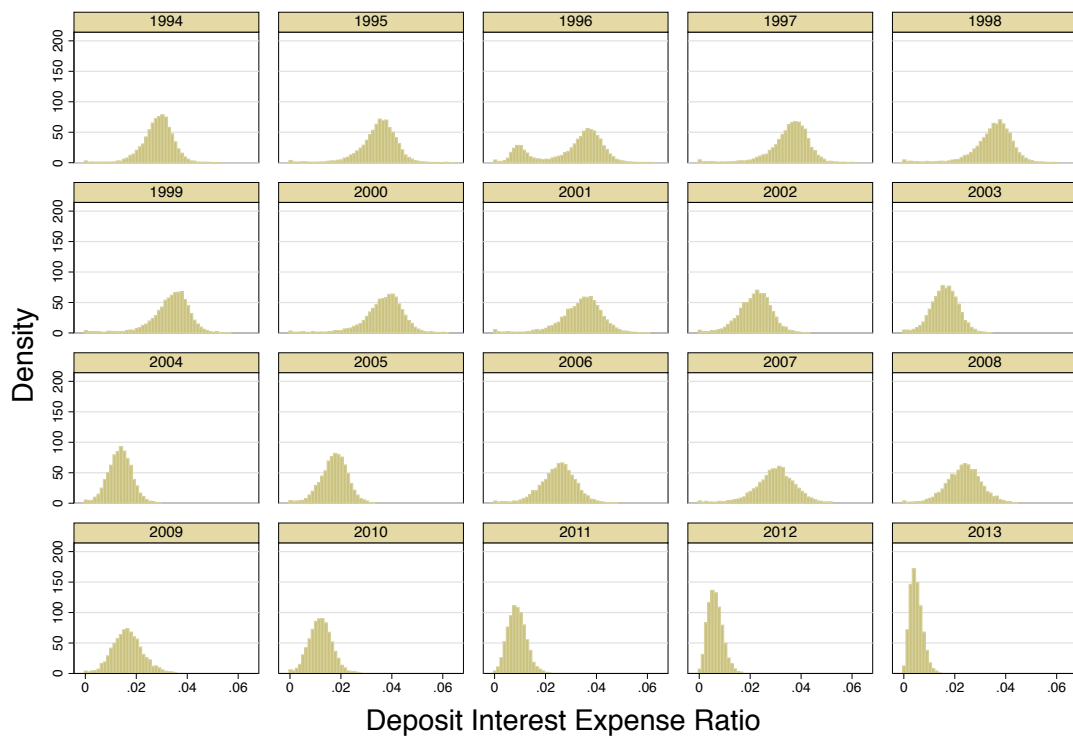
This pattern of interest margins is consistent with the model. Away from the ZLB, margins are determined by the level of competition (parameter  $\eta$  in the model). When the ZLB binds, the market power of banks breaks as depositors face cash as an attractive outside option. Accordingly, a further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

**Deposit Rates** Figure 11 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 12 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



Graphs by year

Figure 11: 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.

2008. These trends are consistent with the interpretation that after 1994 competition *between* banks increased. In 1994 the Riegle-Neal Interstate Banking and Branching Efficiency Act removed several obstacles to interstate-banking. This allowed the most efficient banks to venture into other states, explaining the increase in the average number of banks per county. At the same time, less efficient banks leave the market, explaining the decrease in the number of banks on the national level.

As the ZLB starts binding in 2008, banks again face fiercer competition. However, this time tighter competition is not the result of fiercer competition with each other, but a result of the fact that depositors have cash as an alternative source of liquidity with zero net return. Accordingly, the growth in the number of banks per county reverses, falling in tandem with 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 12 further supports this interpretation by plotting deposit Herfindahls on a national and the country level. Following Drechsler et al. (2017a), 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.

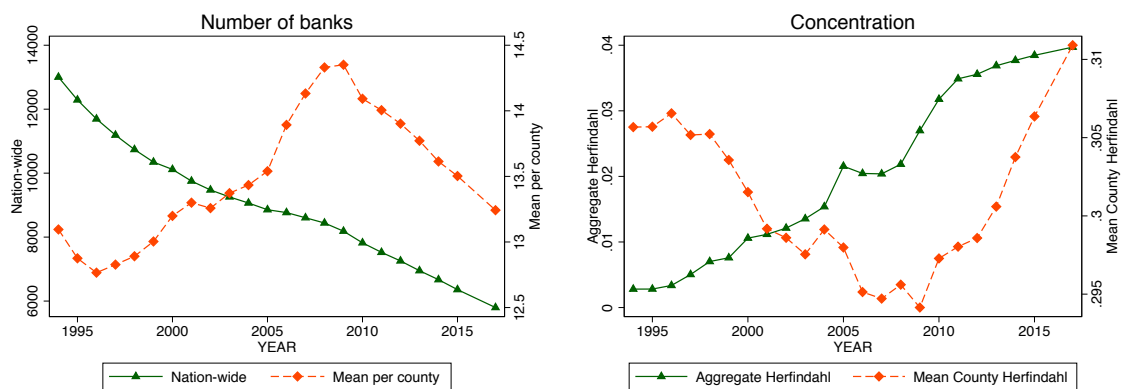


Figure 12: The left panel plots the number of banks on a nation-wide level (left axis), and the mean number of banks per county (right axis). Analogously, the right panel plots Herfindahl based on bank-level deposits on a nation-wide level, and per county.