Banks' Risk Exposures and the Zero Lower Bound

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Abstract

I show that the presence of the zero lower bound (ZLB) incentivize banks to increase their positions in long-term assets and/or to increase the maturity of their portfolio when the short rate declines. This is because banks try to compensate for the fact that the ZLB negatively affects their investment opportunities by setting the deposit spreads to zero and by causing a decline in the volatility of interest rates. As a result of this behavior, banks are willing to take losses after the short rate leaves the ZLB because their investment opportunities improve. Banks with a stronger deposit market power have stronger incentives to increase their risk taking when rates decline as they can absorb larger losses when interest rate increase.

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Understanding how different interest rate environments affect banks' decisions is key in designing sound monetary and financial stability policies. The 2023 banking turmoil underscores such importance. In particular, low interest rates, especially when at the zero lower bound (ZLB) for a prolonged period of time, pose several challenges for banks' business model hence potentially affecting their behavior. First, profits from deposit spreads—the difference between the interest rate on deposits and the federal funds rate—vanish at the ZLB. Second, the compensation for taking interest rate risk (by performing maturity transformation) declines because the ZLB causes a nonlinear reduction in conditional volatility of long rates (King, 2019). Third, periods in which the ZLB is binding are associated with the implementation of unconventional monetary policies, which are designed to reduce long-term yields even further (Krishnamurthy and Vissing-Jorgensen, 2011), hence affecting banks' asset side and their profitability.

One plausible hypothesis is that banks increase their risk taking activities when facing the ZLB in order to compensate for the deterioration in their investment opportunities. Put differently, low interest rates incentivize banks to "reach for yield" as they face lower expected returns and their profitability becomes compromised. Indeed, previous empirical literature has documented that banks tend take more risks in response to lower interest rates (Dell'ariccia, Laeven and Suarez, 2017; Jiménez, Ongena, Peydró and Saurina, 2014; Maddaloni and Peydró, 2011; Paligorova and Santos, 2017, among others). However, testing the reach-for-yield hypothesis is particularly difficult when interest rates are at the ZLB because, by definition, the short rate fluctuates little, if at all, at the ZLB. If anything, studying the effect of the ZLB in banks' risk taking requires some modelling structure.

In this paper, I study banks' portfolio allocations when interest rates are subject to a

ZLB. I find two key predictions. First, the presence of the ZLB causes banks to unequivocally increase their leveraged positions in long-term loans. If banks could not adjust their leverage—due to regulation and/or other frictions—they would increase the maturity of their long-term assets as the level of rates decline toward the ZLB. However, the lengthening of their assets' maturity and/or the increase in their leverage does not necesarilly translate into a higher total exposure to interest rate risk as the short rate decline toward the ZLB. This is because the ZLB reduces the conditional volatility of interest rate risk. Thus, even though banks would increase their leveraged positions (and/or increase the maturity of their long-term assets), the total quantity of interest rate risk in banks' balance sheets may remain unchanged (or even decline slightly).

This prediction, that relates the level of interest rates to banks risk taking, is driven by the nonlinearities associated with the ZLB and their effect on banks' expected returns together with the ability of long-term loans to hedge banks' investment opportunities.[1] As the short rate decline toward the ZLB, two forces incentivize risk averse banks to increase their positions in long-term assets. First, the conditional volatility of interest rates decline, pushing up the return-to-risk ratio of long-term assets. Second, because banks' expected returns decline (due to a decline both in the term premium and in the deposit spread), risk averse bankers have an incentive to increase their positions in long-term assets as a hedge: they seek to compensate the lack of profitability when rates are low and are willing to realize losses as the interest rate increases and their investment opportunities improve (as the term premiums and deposit spread in-

[1] All results in the model are driven by the presence of the ZLB. If banks did not incorporate the ZLB in their interest rate model, changes in the level of the interest rate would have almost no effect on banks' risk taking in my setup.

crease).[2]

The second prediction of the model is related to the differential effects of the ZLB on banks' risk taking. A salient feature of banks is their ability to fund their activities using deposits that pay a lower interest rate than the federal fund rate (Drechsler, Savov and Schnabl (2017), among others). However, the ZLB limits banks' abilities to charge a spread on deposits, because, by definition, the spread on deposits is zero at the ZLB. The model predicts that banks who charge a higher average spread on deposits have a stronger incentive to increase their positions in long-term assets when rates decline than those banks that charge a lower average spread on deposits. The intuition for this result is that the ZLB causes a relatively stronger deterioration in the profitability of banks that charge a high average spread on deposits than those of banks that charge a low average spread. Hence, those banks who charge high average deposit spreads have a stronger incentive increasing their positions in long-term assets when rates are low because they can absorb higher losses as the interest rate increase (when they charge higher deposit spreads).

I use the model to study how banks' risk taking changes with unconventional monetary policies. These policies are usually implemented when the short rate is at the ZLB and have a direct effect on long-term rates and, hence, on banks' portfolios. In these exercises, I find that forward guidance (FG)—a policy that keeps rates at the ZLB during a prolonged period of time—unambiguously promotes risk taking, while quantitative easing (QE)—a policy that causes a reduction in the term premium—has an ambiguous effect on bank risk taking. By keeping the short rate at the ZLB for a longer period

[2] In the appendix, I offer an alternative explanation, in which the ZLB loosens a financial friction hence incentivizing banks to load on long-term assets. Results are conceptually equivalent in the sense that in both frameworks banks increase their positions in long-term assets as a response to a worsening in investment oppotunities (captured, in the alternative framework, by a lower Tobin's Q at the ZLB),

of time, FG causes a deterioration in banks' investment opportunities that lasts longer than what otherwise be in the case that the short rate increased earlier. As a consequence, banks would increase their their leveraged positions (or the maturity of their assets) as a part of their optimal portfolio allocation.[3] On the other hand, QE, which I model as an exogenous shock to the term premium, reduces the expected excess return on long-term assets and therefore incentivizes banks to reduce their risk exposure as the return-to-risk ratio declines. However, the decline in the term premium represents a deterioration in banks' investment opportunities, hence pushing banks' hedging motives increase their exposure to long-term assets. In my baseline calibration, the decline in the return-to-risk ratio offsets the increase in banks' desire to hedge, and therefore the banks' risk exposure declines with an exogenous shock to the term premium.

The main mechanism driving the results consists of two forces that incentivize banks to adjust their porfolios. The first force is the so-called myopic component of the portfolio demand (Merton, 1973): when the short rate approaches the ZLB, interest rate volatility and the term premium decline, and the return-to-risk ratio for taking interest rate risk improves. That is, banks can obtain a better return per unit of variance, even though the absolute level of term premium declines. The second force is the hedging component: banks increase their risk taking in order to balance—or hedge—the decline in expected returns (in deposits spreads and term premium) with the increase in their wealth (from higher asset valuations). In sum, banks increase their leveraged positions in long-term assets as the short rate decline toward the ZLB because both the myopic and hedging component increase as the short rate decline toward the ZLB . The

[3]Alternatively, as I shown in the appendix, a risk neutral banker would increase their leveraged positions because their financial frictions are less relevant when the short rate is at the ZLB.

key assumption for the results is that banks are managed by risk averse bankers.[4] In the appendix, I provide an alternative framework in which bankers are risk neutral but face a friction to adjust their risk exposure. The qualitative results are the same than in the main model (i.e., risk taking increases in the presence of the ZLB), and the parameter capturing tighteness of the friction plays the same role as risk aversion in the main model.

I test the model's predictions using microdata for U.S. commercial banks. Guided by the model's predictions, I construct the maturity gap measure from English, Van den Heuvel and Zakrajek (2018) (the difference between the maturity of banks' assets and liabilities) as a proxy for banks' interest rate risk exposure. To capture the model's key state variable, the shadow rate, I use the shadow rate estimated by Wu and Xia (2016). Then, I use three empirical specifications to test how banks adjust their positions in long-term assets when the shadow rate changes as well as the differential effect for banks with different deposit betas. First, I regress the maturity gap onto the shadow rate (controlling for many macroeconomic and bank-level variables), with the objective of testing the relationship between banks' risk taking and the level of short rate. Second, I regress the maturity gap onto the shadow rate interacted with the bank's deposit beta, with the objective of testing the differential effects predicted by the model. Third, I test the second specification but using time fixed-effects instead of controls for aggregate macroeconomic conditions. The results from the empirical evidence are well in line with the prediction of the model. A decline in the shadow rate is strongly associated with a banks displaying a larger maturity gap. In addition, banks with a stronger deposit market power—that is, banks with a lower deposit beta—display a relatively larger

[4] The hedging component needs a risk aversion greater than one.

increase in the maturity gap.

Literature. There is an extensive literature studying the interaction between banks and interest rates, mainly motivated by banks' important role in the transmission of interest rates shocks into the macroeconomy. (Dell'ariccia, Laeven and Marquez, 2014; Drechsler, Savov and Schnabl, 2018; Di Tella and Kurlat, 2021; Bolton, Li, Wang and Yang, 2020; Whited, Wu and Xiao, 2021; Wang, 2022; Wang, Whited, Wu and Xiao, 2022; Begenau, Piazzesi and Schneider, 2015; among others). The events of March 2023 spurred a renewed interest in how banks manage interest rate risk. For example, McPhail, Schnabl and Tuckman (2023) find that the swap position of the average U.S. bank has essentially zero exposure to interest rates. Granja, Jiang, Matvos, Piskorski and Seru (2024) and Jiang, Matvos, Piskorski and Seru (2023) study the impact of the sudden increase in interest rates during 2022-2023 on the valuation of banks' assets and its implications for financial stability. De Marzo, Krishnamurthy and Nagel (2024) estimate the franchise value of U.S. banks and find that it has positive, rather than negative, duration risk. Haddad, Hartman-Glaser and Muir (2024) study a model in which banks are vulnerable to large increase in the level of interest rates increase, because such increases increase the chance that depositors decide to leave the bank. Abdymomunov, Gerlach and Sakurai (2024) document that lower rates are associated with small reductions in NIMs when expressed in basis points but large in dollar terms and that banks have incentives to hold assets with longer maturity in periods of low rates. Paul (2023) shows that the term premium and banks net interest margin are positively correlated.

My paper is broadly consistent with the recent literature but the key contribution is to emphasize the role the ZLB plays in undertanding banks' risk taking behaviour. The ZLB affects banks' investment opportunities in a nonlinear fashion by changing the conditional volatility of interest rates as well as reducing the deposit spreads to zero. Unconventional policies, typically conducted when the ZLB is binding, tend to affect banks' investment oppotunities even more, hence affecting banks' risk taking decisions.

1 Motivating Evidence

In this section, I report the evidence that motivates the model and that I use below in the empirical part of the paper. The left panel of Figure 1 shows the evolution of the shadow rate, following Wu and Xia (2016), and banks' maturity gap, following English et al. (2018). The maturity gap is computed as the difference between the weighted-average repricing/maturity period of assets and liabilities and it is available since Q2-1992. I show the maturity gap for banks with high and low deposit betas, because banks' ability to fund with cheap deposits is a key feature of their business model and a characteristic that I exploit in the empirical section.[5] The evidence shows two salient facts. First, banks' maturity gap display a negative correlation with the shadow rate. In particular, episodes when the shadow rate moved from negative to positive territory, such as 2015 and in 2021, maturity gap has consistently declined. Also, when the shadow rate dropped into large negative territory around 2012-2013, the maturity gap increased substantially. Second, the evidence indicates that banks with a higher deposit beta (those who have deposit rates that are more sensitive to changes in the short-term interest rate) report a relatively larger marturity gap.

The right panel of Figure 1 shows the shadow rate in solid blue and the volatility of interest rate shocks around the FOMC meetings. I compute the volatility of interest rate

[5] I use the deposit betas from Philip Schnabl's website, which are constructed using Call Report data, as the maturity gap.

shocks as the standard deviation of changes in the 2-year nominal interest rate around the FOMC meetings, following Hanson and Stein (2015). As shown, the volatily of interest rate surprises decline sharply when the shadow rate is in the negative territory. This is because the ZLB truncates the conditional distribution of the short-term interest rate: At the ZLB, the short-term interest rate can only increase or stay at zero. The decline in the volatility of interest rate shocks is a particular feature of the ZLB and play a crucial importance in the model's mechanism.

2 Model

I present a partial equilibrium banking model in which the short rate is bounded by the ZLB. Bankers take prices as given and optimize their portfolio subject to their budget and leverage constraints. In the baseline formulation presented below, I model risk averse bankers as an agent with preferences. One interpretation of this modelling assumption is to think of the bankers as managers who have a concentrated position in the bank's equity and face incentive scheme (see Section 2.1 in Di Tella and Kurlat (2021)). In the appendix, I show that the results from the model are qualitatively similar to the results obtained in a framework where bankers are risk neutral but face a friction when they deviate their leverage from a given target. Hence, one could interpret risk aversion in the model as capturing the tighteness of a friction that limits how much the banker can adjust his leverage.

Prices. Economic conditions are summarized by a pricing kernel, $m_t > 0$, following

$$\frac{\mathrm{d}m_t}{m_t} = -\widetilde{r}_t \mathrm{d}t - \kappa_t \mathrm{d}W_{r,t} - \kappa \mathrm{d}W_{\kappa,t}, \tag{1}$$

where W_r and W_κ are uncorrelated aggregate Brownian motions in a probability space $(\Omega, \mathcal{P}, \mathcal{F})$ with the usual properties. The drift of the pricing kernel, $\widetilde{r}_t$, is the short rate. Following the shadow rate literature (e.g., Black (1995)), I assume the short rate follows

$$\widetilde{r}_t = \max\left(r_{low}, r_t\right),$$

where r_{low} is a parameter reflecting the effective lower bound and r_t, the shadow rate, follows

$$\mathrm{d}r_t = \lambda_r\left(\bar{r} - r_t\right)\mathrm{d}t + \sigma_r \mathrm{d}W_{r,t}.$$

The diffusion components in the pricing kernel (1), κ_t and κ, represent the prices associated with shocks W_r and W_κ, respectively. In other words, the variable κ_t captures fluctuations in the price of interest rate shocks and follows

$$\mathrm{d}\kappa_t = \lambda_\kappa\left(\bar{\kappa} - \kappa_t\right)\mathrm{d}t + \sigma_\kappa \mathrm{d}W_{\kappa,t},$$

while the parameter κ represents the price of shocks to the price of interest rate uncertainty, which I assume is constant.

Banks' balance sheets. Banks can trade three instruments: long-term loans, deposits, and a generic wholesale money market account that pays the short rate as a return. Let n_t denote banks' net worth. It is given by the accounting identity

$$n_t = \theta_t^{(\tau)} P_t^{(\tau)} + b_t + d_t, \tag{2}$$

where $\theta_t^{(\tau)}$ is the quantity of long-term loans in the balance sheet, $P_t^{(\tau)}$ is the price of the loan, b_t is the value of the federal fund account, and d_t is the value of the deposit account. For simplicity, I assume loans pay an exponentially decaying coupon $\tau e^{-\tau s}\mathrm{d}t$ at each $s \geq t$, and hence the average maturity is given by $1/\tau$.[6] Long-term loans cannot be defaulted.[7] Then, the total return on the loan is given by

$$\frac{\mathrm{d}P_t^{(\tau)}}{P_t^{(\tau)}} = \mu_t^{(\tau)}\mathrm{d}t + \sigma_{r,t}^{(\tau)}\mathrm{d}W_{r,t} + \sigma_{\kappa,t}^{(\tau)}\mathrm{d}W_{\kappa,t},$$

where $\mu_t^{(\tau)}$, $\sigma_{r,t}^{(\tau)}$, and $\sigma_{\kappa,t}^{(\tau)}$ are determined in equilibrium.

The returns on the money market and deposit accounts are locally risk-free, in the sense that they are not affected by aggregate uncertainty and evolve as

$$\begin{aligned} \frac{\mathrm{d}b_t}{b_t} &= \widetilde{r}_t\mathrm{d}t, \\ \frac{\mathrm{d}d_t}{d_t} &= \phi\left(\widetilde{r}_t\right)\mathrm{d}t. \end{aligned}$$

Notice that deposits pay a return that depends on the short rate, $\phi\left(\widetilde{r}_t\right)$. Then, I define the difference between the interest rate on deposits and the short rate

$$s_t = \widetilde{r}_t - \phi\left(\widetilde{r}_t\right) \geq 0,$$

as the spread on deposits, which the evidence indicates is positive on average (Drechsler et al., 2017, among others).

Using the returns of banks' financial instruments, the evolution of banks' net worth

[6] I assume a single perpetual loan to avoid keeping track of the maturity dimension as a state variable when pricing long-term loans of multiple maturities.

[7] Extending the analysis to defaultable loans with a constant default intensity does not affect the qualitative predictions of the model.

is given by

$$\mathrm{d}n_t = \left[\left(\widetilde{r}_t - \frac{div_t}{n_t} - c \right) n_t + \left(\widetilde{r}_t - \phi\left(\widetilde{r}_t\right) \right) d_t \right] \mathrm{d}t + \theta_t^{(\tau)} P_t^{(\tau)} \left(\frac{\mathrm{d}P_t^{(\tau)}}{P_t^{(\tau)}} - r_t \mathrm{d}t \right), \tag{3}$$

where div_t is the dividend payment and c represents a fixed cost (proportional to banks' wealth) that banks pay to maintain their deposit franchise.

Banks' problem. I assume banks are run by a continuum of bankers featuring recursive preferences,[8]

$$U_t = E_t \left[\int_t^{\infty} f\left(div_s, U_s\right) \mathrm{d}s \right],$$

with

$$f(c, U) = \frac{1}{1-\frac{1}{\psi}} \left\{ \frac{\rho div^{1-\frac{1}{\psi}}}{\left[(1-\gamma) U\right]^{\left(\gamma - \frac{1}{\psi}\right)/(1-\gamma)}} - \rho (1-\gamma) U \right\},$$

where ψ is the elasticity of intertemporal substitution (EIS), γ is the risk aversion, and ρ is the time preference. In this specification, the banker consumes the dividends, consistent with the idea that bankers and shareholders receive a constant fraction of bank's total dividend. Then, banks' portfolio problem is given by

$$\max_{\left\{\theta_t^{(\tau)};\, d_t;\, div_t\right\}} U_t \tag{4}$$

[8]As mentioned above, I provide an alternative framework in the appendix with risk neutral bankers facing a friction to adjust their leverage. Results and mechanisim are qualitatively similar to modelling risk averse bankers.

subject to

$$n_0 \;\; > \;\; 0; (3); \text{and } d_t \geq -\delta n_t.$$

The constraint $d_t \geq -\delta n_t$ is a leverage constraint on deposits. Without such a constraint on deposits, banks would find it optimal to issue an infinite amount of deposits because of the presence of a positive deposit spread.

Recursive formulation and banks' optimal policies. I represent bankers' problem in a recursive fashion. For this, I express prices and quantities as a function of the two factors driving the pricing kernel dynamics—namely, r_t and κ_t. The price of long-term loans is the expected discounted value of its dividends under the physical measure

$$P_t^{(\tau)} = P^{(\tau)}\left(\kappa_t, r_t\right) = \mathbb{E}_t\left[\int_t^\infty \frac{m_s}{m_t}\tau e^{-\tau(s-t)}\mathrm{d}s\right]. \tag{5}$$

The conditional expectation (5) can be expressed as a partial differential equation,

$$\left(\frac{\tau}{P^{(\tau)}} - \tau - \widetilde{r}_t\right)\mathrm{d}t + \mathbb{E}_t\left[\frac{P_r^{(\tau)}}{P^{(\tau)}}\mathrm{d}r + \frac{1}{2}\frac{P_{rr}^{(\tau)}}{P^{(\tau)}}\mathrm{d}r^2 + \frac{P_\kappa^{(\tau)}}{P^{(\tau)}}\mathrm{d}\kappa + \frac{1}{2}\frac{P_{\kappa\kappa}^{(\tau)}}{P^{(\tau)}}\mathrm{d}\kappa^2\right] = -cov_t\left(\frac{\mathrm{d}m}{m}\frac{\mathrm{d}P^{(\tau)}}{P^{(\tau)}}\right),$$

with the expected excess return on loans being

$$\mu_t^{(\tau)} - \widetilde{r}_t = -cov_t\left(\frac{\mathrm{d}m}{m}\frac{\mathrm{d}P^{(\tau)}}{P^{(\tau)}}\right)/\mathrm{d}t = \kappa_t\frac{P_r^{(\tau)}}{P^{(\tau)}}\sigma_r + \kappa\frac{P_\kappa^{(\tau)}}{P^{(\tau)}}\sigma_\kappa.$$

To represent the banks' problem recursively, I use the fact that preferences are homothetic, so the value function can be written as

$$U_t = \frac{\left(\xi\left(r_t, \kappa_t\right) n_t\right)^{1-\gamma}}{1-\gamma}.,$$

where $\xi\left(r_t, \kappa_t\right)$ is an unknown function that is solved with the value function. The function $\xi\left(r_t, \kappa_t\right)$ summarizes the banker's investment opportunities. When ξ is high, the banker can sustain a high value U_t with very little wealth. In the alternative setup discussed in the appendix, ξ is very closely related to the bank's Tobin's Q. Then, the recursive representation of banks' problem (4) takes the form of the following Hamilton-Jacobi-Bellman equation

$$\begin{aligned}
0 \;=\; & \max_{\left\{\alpha_t^{(\tau)}, d_t, div_t\right\}} \frac{\rho}{1-\frac{1}{\psi}}\left\{\left(\frac{div}{n}\right)^{1-\frac{1}{\psi}} \xi^{\left(\frac{1}{\psi}-1\right)} - 1\right\} \\
& + \frac{\xi_r}{\xi}\mathbb{E}_t\left[\mathrm{d}r\right] + \frac{1}{2}\left(\frac{\xi_{rr}}{\xi} - \gamma\left(\frac{\xi_r}{\xi}\right)^2\right)\mathbb{E}_t\left[\mathrm{d}r^2\right] \\
& + \frac{\xi_\kappa}{\xi}\mathbb{E}_t\left[\mathrm{d}\kappa\right] + \frac{1}{2}\left(\frac{\xi_{\kappa\kappa}}{\xi} - \gamma\left(\frac{\xi_\kappa}{\xi}\right)^2\right)\mathbb{E}_t\left[\mathrm{d}\kappa^2\right] \\
& + \mathbb{E}_t\left[\frac{\mathrm{d}n}{n}\right] - \frac{\gamma}{2}\mathbb{E}_t\left[\frac{\mathrm{d}n^2}{n}\right] \\
& + (1-\gamma)\left(\frac{\xi_r}{\xi}\mathbb{E}_t\left[\mathrm{d}r\frac{\mathrm{d}n}{n}\right] + \frac{\xi_\kappa}{\xi}\mathbb{E}_t\left[\mathrm{d}\kappa\frac{\mathrm{d}n}{n}\right]\right),
\end{aligned}$$

subject to $n_0 > 0$, (3), and $d_t \geq -\delta n_t$. Notice that because the problem is linear in wealth, we can define the portfolio share $\alpha_t^{(\tau)}$ as a control variable instead of the number of loans $\theta_t^{(\tau)}$. The first-order condition for $\alpha_t^{(\tau)}$ is

$$\alpha_t^{(\tau)} : \mu^{(\tau)} - \widetilde{r}_t - \alpha_t^{(\tau)}\gamma\left[\left(\sigma_{r,t}^{(\tau)}\right)^2 + \left(\sigma_{\kappa,t}^{(\tau)}\right)^2\right] + (1-\gamma)\left[\frac{\xi_r}{\xi}\sigma_r\sigma_{r,t}^{(\tau)} + \frac{\xi_\kappa}{\xi}\sigma_\kappa\sigma_{\kappa,t}^{(\tau)}\right] = 0,$$

and for div_t is

$$div_t : \rho \left(\frac{div}{n}\right)^{-\frac{1}{\psi}} \xi^{\left(\frac{1}{\psi}-1\right)} - 1 = 0.$$

Finally, banks' deposits are pinned down by the deposits leverage constraintm which is always binding $d_t = -\delta n_t$ because the spread on deposits is always positive.

3 Model Solution

The solution of the model consists of a system of partial differential equations in the state variables r_t and κ_t, characterized by the banks' optimal conditions and the pricing of long-term loans. The unknown variables are banks' value function, $\xi(r, \kappa)$, and the long-term loan prices, $P^{(\tau)}(\kappa, r)$. I provide details of the numerical algorithm in the appendix.

Calibration. The model has two sets of parameters—namely, those from the two-factor shadow rate model and those for banks. The shadow rate model consists of two state variables, r_t and κ_t. I calibrate the process for r_t to match the moments (mean, standard deviation, and persistence) of the shadow rate process from Wu and Xia (2016) in the period 1962 to 2021.[9] I set the parameters for κ_t to match the slope of the nominal Treasury term structure. As previously mentioned, I abstract from credit risk and focus primarily on interest rate risk, which is captured by the U.S. term structure. In particular, I set $\overline{\kappa}$, the average price of risk, to match the average yield of a five-year nominal Treasury in the same sample as the short-rate process. The remaining parameters in the shadow rate model, λ_κ, σ_κ, and κ are relevant only in the extended version of the model in which I conduct the policy experiments. I set their values to capture the level, volatility, and

[9]The shadow rate is the effective federal funds rate in periods out of the ZLB.

persistence of the five-year term premium from Kim and Wright (2005).

For banks, I model the spread on deposits in a simple linear relationship with the level of interest rate

$$\phi(\tilde{r}) = \phi\tilde{r},$$

with $\phi \in [0,1]$. Hence, the spread on deposits is $s_t = \tilde{r}_t - \phi(\tilde{r}_t) = (1-\phi)\tilde{r}_t \geq 0$. Following the evidence in Drechsler, Savov and Schnabl (2021), I set $\phi = 0.35$, which implies that the spread on deposits increases 65 basis points after a 100 basis point raise in the short rate. I set $\delta = 2.85$ to match the ratio of short-term deposits to book equity in the FR Y-9C dataset. I set c to obtain a conservative unconditional return on equity in the model of 6% per year.[10] Finally, I set EIS and risk aversion as free parameters using the consumption-based asset pricing literature as a reference. In the baseline calibration, I set ψ=0.5 and γ=4.[11]

Interest rate risk. To emphasize the main mechanisms, I focus on a version of the model in which there are no W_κ shocks—that is, I set $\kappa_t = \bar{\kappa}\ \forall t$. I extend the model, below, when I study the different policies that affect long-term rates.

Figure 2 shows the dynamics of the interest rate, the distribution of the shadow rate, the equilbrium loan prices, and the corresponging term premium. As a reference, the figure includes the solution when there is no ZLB. The vertical-dotted black line represents the point in the state space at which the bound on the short rate is binding, while the vertical solid gray line shows the unconditional mean of the short rate. The top-left panel of Figure 2 shows the short-term rate, which, in a model with a ZLB, is obviously

[10] Although dn/n does not have a direct counterpart in the data, a relatively close proxy would be net income divided by total book equity, which, on average, is approximately 10% for banks.

[11] Qualitative results do not change as long as the risk aversion is greater than one. The magnitude of the EIS affects the how dividend-to-wealth ratio changes with the level of interest rates.

truncated at r_{low}. The top-right panel shows the distribution of the shadow rate. The calibration implies an unconditional probability of a binding ZLB of 13%. The lower-left panel shows the loan price implied by the model. Notice that the price becomes less sensitive to changes in the shadow rate when the shadow rate is negative. That is, the derivative of the loan price with respect to the interest rate, P_r, is negative across the state space, but less negative as the shadow rate becomes more negative. This feature of the ZLB is important because it affects the term premium, as shown in the lower-right panel. When there is only interest rate risk, the term premium in equation (2) becomes

$$\mu_t^{(\tau)} - \widetilde{r}_t = -cov_t\left(\frac{\mathrm{d}m}{m}\frac{\mathrm{d}P^{(\tau)}}{P^{(\tau)}}\right)/\mathrm{d}t = \overline{\kappa}\frac{P_r^{(\tau)}}{P^{(\tau)}}\sigma_r.$$

When the short rate is at the ZLB and P_r decreases in absolute value, the volatility of long-term bonds declines. Intuitively, this effect is due to the fact that the short-rate can only go up when it is at the ZLB—that is, the conditional distribution of the short rate is truncated. Hence, the quantity of interest rate risk decline, which means that, for a given price of interest rate ($\overline{\kappa}$), the term premium declines. This force is relevant for banks' risk taking, as I discuss next.

Interest rate risk and banks' risk taking. Next, I study banks' optimal policies. To do so, proposition 1 presents the analytical characterization of banks' optimal portfolio share.

Proposition 1 *When there is only interest rate risk, banks' portfolio share in long-term loans is given by*

$$\alpha = \underbrace{\frac{\overline{\kappa}}{\gamma\frac{P_r^{(\tau)}}{P^{(\tau)}}\sigma_r}}_{myopic} + \underbrace{\frac{(1-\gamma)}{\gamma}\frac{\frac{\xi_r}{\xi}}{\frac{P_r^{(\tau)}}{P^{(\tau)}}}}_{hedging}, \tag{6}$$

where $\frac{\xi_r}{\xi}$ captures the sensitivity of banks' investment opportunity set to the interest rate *and* $\frac{P_r^{(\tau)}}{P^{(\tau)}}$ *captures the sensitivity of long-term loan prices to the interest rate.*

Proof. See appendix.

Figure 3 shows the banks' optimal policies in the baseline calibration. The top-left panel shows the portfolio share, α, which increases as the short rate declines, particularly when the shadow rate becomes more negative. As shown by the blue-dashed line, α would be approximately constant if the short rate was not subject to the ZLB, which implies that the results are driven by the presence of the ZLB. The top-right panel shows the myopic component associated to α. The myopic component comprises simply the ratio of the term premium to the variance of the loans (scaled by risk aversion)—also know as the return-to-risk ratio. Because the term premium is proportional to the volatilty of loans, it decreases at a slower order than the variance of loans when the level of rates is lower. Hence, the return-to-risk ratio increases, pushing up the myopic component of the portfolio share up.

The lower-left panel shows the hedging component. The hedging component is positive across the state space because banks with a risk aversion greater than one have a preference to hold long-term bonds to hedge against the deteriorarion in their investment opportunities. This is because long-term loans increase (decrease) in value when expected excess returns on loans and the deposit spread decreases (increase). In other words, long term loans allow banks to realize gains (losses) when investement opportunities are scarce (abundant). This can be seen in the second term of expression (6). The term P_r is negative because loan prices increase as the short rate decline. The term ξ_r is positive because banks' investments opportunities deteriorate as the short rate decreases. Recall ξ captures banks investment opportunities, that is, captures their ability to transform wealth into value (denoted by U). Hence, a lower levels of the interest rate translates into a lower ξ (which means $\xi_r > 0$).[12] Then, since $\gamma > 1$, the entire second term in proposition 1 is positive. The increase in the hedging component as short rate is because the conditional volatility of ξ, $\frac{\xi_r}{\xi}\sigma_r$, declines at a slower pace than the conditional volatilty of loan prices, $\frac{\xi_r}{\xi}\sigma_r$. Intutively, as I discuss in the next paragraph, this is because long-term loans have a shorter maturity than banks "investment opportunities."[13] Finally, the lower-right panel shows the optimal dividend-to-wealth ratio. The ratio is increasing in the level of rates because the EIS is smaller than one. As the level of rate increases, expected excess returns on wealth increase banks pay higher dividends.

Figure 4 elaborates further on the model's solution. The top-left and top-right panels show the numerator and denominator of the hedging component of the portfolio demand, using the same scale in both charts ease the comparison. Both components of the hedging demand decline in absolute value as the short rate approaches the ZLB. However, the numerator, $(1-\gamma)\frac{\xi_r}{\xi}\sigma_r$ remains at substantially higher values than the denominator, $\gamma\frac{P_r}{P}\sigma_r$. Intuitively, this means that banks' investment opportunities, which can be thought to hava larger duration than the long-term bond, are much more sensitive to the shadow rate than banks' assets, which have an average finite maturity. This differential effect of the shadow rate over loans and ξ incentivize banks to increase their hedging component when rates are low.

The lower-left panel shows the diffusion component associated with the law of motion for wealth, $\sigma_{n,t} = \alpha_t\frac{P_r}{P}\sigma_r$. This object represents banks' total exposure to interest rate risk: it has the leverage, α, multiplied by duration risk, $\frac{P_r}{P}\sigma_r$. The total exposure to interest rate risk remains negative although it declines (in absolute value) somewhat as

[12] In the alternative framework discussed in the appendix, I show that ξ has a similar interpretation to a traditional concept of Tobin's Q.

[13] The hedging component is the covariance between changes in ξ and loan returns, divided the variance of loan returns, scaled by $(1-\gamma)/\gamma$. The scaled covariance decline much less the scaled variance

the interest rate decline toward the ZLB. This is because even though leverage increase as the rate decline, as discussed above, the duration risk decline when the short rate declines. Finally, the lower-right panel shows the expected return on wealth, which increases with the level of rate. This result is mostly driven by the spread on deposits, which increases with the level of rates.

The role of deposit market power. Deposit spreads are salient feature of banks' business model. In fact, any other agent would be able to capture the term premium in the economy, but it is banks' ability to fund with cheap deposits is an important incentive to do so (Di Tella and Kurlat, 2021). Figure 5, left panel, shows how banks optimal portfolio share, α, changes for different ϕ. Recall ϕ captures the sensitivity of the deposit rate to the fed fund rate, $r_t^d = \phi r_t$. Notice that banks with a lower ϕ—which means higher deposit market power in the sense that the average deposit spread is higher than banks with a high ϕ—display a higher α than banks with high ϕ. This is driven completely by the hedging motives, because the myopic component of the portfolio share depends only on the term premium, loan variance, and the risk aversion parameter (none of which depends on the deposit market power). As shown by the upper-panel, the myopic component does not change with ϕ. However, as shown by the lower-left panel, banks with a low ϕ have stronger hednging motives. This is because banks with a low rates affect relatively more to banks with a low ϕ, which on average charge higher deposit spreads than banks with a high ϕ. In other words, the investment opportunities, capture by χ, are more sensitive to changes in the level fo rates when ϕ is low. Hence, banks with low ϕ have a stronger incentive to increase their allocation into loans when rates decline, because they know the losses caused by the increase in rates will be partially offset bt the cashflows generated by higher deposit spreads when the level of rates is higher. Finally, the lower-right panel shows the total exposure to interest rate risk. As can be seen, banks with higher average deposit spreads (i.e., low ϕ) display a larger exposure than banks with lower deposit spreads.

Extension to term premium shocks. Figure 6 presents the solution including $W_{\kappa,t}$ shocks. The numerical solution consists of a system of partial differential equations in two state variables, r_t and κ_t. The left panels show the solution for term premium and the right panels shows the solution for α, which are the key variables in understanding banks' responses to shocks. The top panels show the solutions across the r_t, for different levels of the κ_t variable, while the bottom panels show the solutions across the κ_t dimension for different levels of the r_t variable.

In general, the extended solution has a similar intuition as the solution presented earlier, in which only r_t is a state variable. When the interest rate declines, the term premium declines, and α_t increases for the reasons previously discussed. However, in the case of time-varying κ_t, when κ_t becomes more negative, the stochastic discount factor is more sensitive to W_r shocks. Hence, the term premium increases when κ_t is low, as noted by the dotted blue line in the top-left panel. Additionally, as κ_t becomes more negative and the term premium increases, banks increase their exposure to long-term loans, as noted by the dotted blue line in the upper-right panel. This increase in exposure is simply because, keeping the level of the interest rate fixed, a more negative κ_t increases the expected return on loans, and hence the risk–return tradeoff becomes more attractive for banks. Therefore, the level of α_t increases across κ for any given level of rates. Next, I study two different policies that are typically implemented the short rate is at the ZLB.

Policies. I conduct two policy experiments: forward guidance (FG) and quantitative easing (QE). FG is a particularly relevant tool when the interest rate is at the ZLB because it allows the monetary authority to affect the path of interest rates when it is unable to reduce the overnight rate any longer. In particular, the policy consists of the monetary authority committing to keep the short rate at the ZLB for a longer period than the one previously anticipated by market participants. In the case of QE, I take a simplistic approach and interpret this policy purely as a term premium shock. The rationale of this simplification is the idea that the purchases of long-term assets had the intention of removing duration risk from the private sector.

Figure 7 shows the impulse responses to two alternative interest rate shocks shown in the top-left panel. Policy b, shown in solid red, consists of an interest rate path that stays at zero for a longer period than policy a (shown in dotted blue). The implication of a path of rates that stays at the ZLB for a longer period is that banks' investment opportunity set will deteriorate more than if the short rate increases faster. As a consequence, banks will increase their leverage to long-term loans (top-middle panel) primarily driven by their desires to hedge such deterioration in their investment opportunity set (shown by the hedging demand in the lower-left panel). The myopic component (shown in the upper-right panel) also increases because the volatility of interest rates decreases more than term premium (i.e., the risk-return trade-off increases somewhat), as elaborated in Section 2. Finally, lower rates decrease banks' valuations (as shown by the increase in the dividend-price ratio in the lower-mid panel) as term premium declines (due to a lower quantity of interest rate risk).

Figure 8 shows the impulse response to a shock in κ_t conditional on the level of interest rate being at zero. The shock to κ_t is essentially an exogenous shock to the term premium because it affects the sensitivity of the stochastic discount factor to interest rate risk. I study the response conditional to the short rate being at zero because these types of policies are usually conducted when the monetary authority is unable to reduce the short rate any further. When kappa increases, the stochastic discount factor becomes less sensitive to interest rate shocks, and hence the term premium declines (as shown in the bottom-right panel). As the expected excess return on loans decreases, so does the myopic component of the loan demand (shown in the top-right panel) because the risk–return tradeoff of investing in loans is less attractive. The hedging component, however, increases. This reaction is due to banks' desire to smooth the investment opportunity set. As the term premium declines, the investment opportunity set deteriorates, and banks prefer to increase their exposure to loans in those states to realize losses when the investment opportunity set improves. On net, α declines because the effect on the myopic component dominates the effect over the hedging component. Hence, policies that intend to decrease the term premium while the short-term rate is zero may have an ambiguous effect on banks' risk-taking. On the one hand, it may decrease the risk–return tradeoff and hence reduce risk-taking via the myopic component. On the other hand, it may increase risk-taking by causing a deterioration of the investment opportunity set, and risk-averse banks would like to hedge such deterioration by increasing risk-taking.

4 Empirical Analysis

The model has two main predictions. First, it predicts that the presence of the ZLB incentivizes banks to increase their positions into long-term assets when the interest rates decline. Second, as the interest rates decline, banks that with a lower deposit beta increase their positions relatively more than banks with higher a deposit beta. The main reason for this differential result is that banks' demand for risky assets is primarily driven by the hedging component, not the myopic component.

The main predictions of the model are about α. However, the model can provide a simple and direct mapping between α and the maturity of the asset. The maturity of banks' assets is a much more convenient variable to work because it can be directly observed from the data. The blue-dotted line on the left panel of Figure 9 shows the maturity of the banks' assets that would replicate banks' desire exposure if the banks could not adjust α (which is left unchanged at a constrained level of 5, shown on the right panel). Hence, in the model, if banks did not have the opportunity of increasing α as the level of rates decline toward the ZLB, they would increase the lenght of their assets' maturity. Equivalently, if the maturity of the asset is held constant and cannot be changed (as assumed in the baseline model), then banks would increase α as the level of rate decreases. Because of this direct mapping between α and maturity, I use the maturity gap as a proxy for risk taking as it has a more straightforward mapping into the data than α.

Data. Table 2 show the summary statistics. The shadow rate comes from Wu and Xia (2016). I construct the maturity gap measure proposed by English et al. (2018) using the Call Reports from 1997:Q2 through 2023:Q4. The maturity gap is defined as the difference between the maturity of a bank's assets and liabilities. To test the second model prediction—namely, the relative change in banks' α across deposit beta dimensions—I use the estimated deposit betas from Drechsler et al. (2021). The estimated deposit betas from are the average sensitivity of banks interest rate expenses with respect to the federal funds rate, hence directly related to the parameter ϕ in the model.

Regressions. I use three empirical specifications, following Dell'ariccia et al. (2017) who have tested for the effect of interest rates (without ZLB) on banks' risk taking. The first specification is

$$\tau_{i,t} = \beta_{0,i} + \beta_1 r_t + \beta_2 C_{i,t} + \theta X_{i,t} + \mu M_t + \varepsilon_{i,t},$$

where $\tau_{i,t}$ is the bank's i maturity gap, $\beta_{0,i}$ is the bank's fixed effect, r_t is the shadow rate from Wu and Xia (2016), $C_{i,t}$ is the bank's deposit beta, $X_{i,t}$ are bank controls (size, deposit-to-asset ratio, common equity tier 1 ratio, net income, and loan-to-assets ratio), and M_t are macroeconomic controls (excess bond premium, GDP growth, and inflation). In this first specification, the model predicts $\beta_1 < 0$: A lower shadow rate is associated with a higher maturity gap. I also include a ZLB dummy into this first specification, with the objective of testing whether β_1 changes at the ZLB.

In the second specification,

$$\tau_{i,t} = \beta_{0,i} + \beta_1 r_t + \beta_2 C_{i,t} + \beta_3 C_{i,t} \times r_t + \theta X_{i,t} + \mu M_t + \varepsilon_{i,t},$$

I test for the interaction term β_3. The model predicts $\beta_3 > 0$, which means that when the shadow rate decreases and banks increase their maturity gap, banks with a lower deposit beta should increase their maturity relatively more than banks with a higher deposit beta.

Finally, I focus specifically on the interaction term ,

$$\tau_{i,t} = \beta_{0,i} + q_t + \beta_3 C_{i,t} \times r_t + \theta X_{i,t} + \varepsilon_{i,t},$$

where I include time fixed effects, q_t, instead of controlling for macroeconomic conditions as in the second specification. Again, the prediction is $\beta_3 > 0$.

Regressions Results: Deposit Beta. Table 3 shows the results. Column (1) shows that banks' maturity gap increases as the level of rates decreases (controlling for macroeconomic and bank level variables). This result, in which $\beta_1 < 0$, is consistent with the level effect predicted by the model. Column (2) incorporates a ZLB dummy into regression (1) and show that the negative effect of the shadow rate into matuirity gap is even more pronounced at the ZLB. This result is consistent with the model, which predicts the presence of the ZLB is particularly important for banks' risk taking.

Columns (3) and (4) show the results for the differential effects across banks with different deposit beta. Consistent with the model, β_2 and β_3 are positive, indicating that banks increase maturity gap as the level of rates decline, and this effect is more pronounced for banks with lower deposit betas. The mechanisim is due to the hedging component banks' demand for long-term asset. The investment opportunity set of banks with lower deposit beta—banks that charge a higher average spread on deposits—deteriorates relatively more than the one of banks with higher deposit beta as the short rate declines toward the ZLB. As a result, banks with a lower deposit beta have a relatively stronger incentive to take larger bets on long-term assets as the level of rate decline and realize losses when the level of rate increases and their investment opportunities increase (because they can charge higher spread on when the interest rate is higher).

5 Conclusion

The ZLB poses several challenges for banks business model. First, deposit spreads are zero at the ZLB. Second, as the level of rate approaches the ZLB, the conditional volatility of interest rates decline generating downward pressure in the compensation for taking interest rate risk (i.e., the term premium). Third, unconventional monetary policies affect long-term interest rates (via forward guidance and/or quantitative easing), therefore affecting banks assets as well. In this paper, I study how these peculiar effects of the ZLB affect banks risk taking decisions.

I find that the ZLB incentivize banks to increase the risk taking via increasing leveraged positions in long-term rates and/or increasing the maturity of their portfolio. There are two forces driving this result. First, the decline in the volatility of interest rates reduces the term premium but improves the return-to-risk ratio provided by long-term assets. That is, even though the term premium decline, the variance of long-term assets decline even more, hence incentivizing risk taking. Second, the decline in the term premium and the deposit spreads causes a decline in expected returns. Risk averse bankers have a preference to hedge these states by increasing their risky positions and realize losses when interest rate increase and expected returns are higher. I offer an alternative setup in the appendix in which results are qualitatively the same but driven by a leverage constrain rather than risk aversion. In such setup, the ZLB, by reducing the volatility of interest rates, loosens the leverage constraint and hence banks increase their risky positions.

I show that banks with lower deposit betas have a relatively stronger desire to increase their risky positions to long-term assets as the interest rate decline. Banks with lower deposit betas charge, on average, a relatively higher spread on deposits and therefore the investment opportunity set deteriorates relatively more than the one of banks with higher deposit betas as rates decline. Thus, banks with lower deposit have a stronger desire to hedge by increasing (reducing) their exposures to long-term assets when rates are low (high).

Finally, I use the model to study how unconventional monetary policies, such as Forward Guidance (FG) and Quantitative Easing (QE)—which tend to occur at times in which the short rate is at the ZLB—, affect banks' risk taking. I find that FG causes an unambiguous incentive for banks to increase their risks exposures because it is a policy designed to prolong the period in which the short rate remains at the ZLB (hence deteriorating banks investment opportunities for longer). QE, in contrast, can affect banks' risk taking either way. By reducing the term premium, QE incentivize banks to reduce their risk exposures (i.e., lower expected excess return on maturity transformation). However, as a lower term premium represents a bad investment opportunity for the bank, banks' incentives to hedge increase hence driving risk taking up. The ultimate result of QE on banks' risk taking depends on which force dominates.

6 Figures and Tables

TABLE 1. Calibration

	Parameter	Value	Description	Source/Target
1. *Interest rate*				
	λ_r	0.05	Interest rate persistence	Wu and Xia (2016)
	$\bar{r}$	0.0465	Avg. short rate	Wu and Xia (2016)
	σ_r	0.0033	Volatility of short rate	Wu and Xia (2016)
	r_{low}	0	Minimum interest rate	Zero lower bound
2. *Price of risk*				
	$\bar{\kappa}$	-0.1	Avg. price of rate risk	Avg. 5-year Treasury
	λ_κ	0.05	Persistence price of rate risk persistance	Kim and Wright (2005)
	σ_κ	0.015	Volatility of the price of rate risk	Kim and Wright (2005)
	κ	-0.01	Price of shocks to rate risk	Kim and Wright (2005)
3. *Banks*				
	δ	2.85	Deposit constraint	Avg. deposit leverage ratio
	ϕ	0.35	Deposit spread	Drechsler et al. (2017)
	c	0.005	Fixed costs over book equity	Avg. return on equity
	τ	5	Loan maturity	Avg. maturity gap
	ρ	0.015	Time preference	
	ψ	0.5	EIS	
	γ	4	Risk aversion	

NOTE: Parameters are expressed at an annual frequency. I describe the calibration in Section 3 of the main text. EIS is elasticity of intertemporal substitution.

TABLE 2. Summary Statistics

	Observations	Average	25^{th} Perc.	75^{th} Perc.	St. Dev.
Bank level variables					
Maturity gap (months)	621,457	45.94	26.45	60.26	26.23
Deposits/assets	621,457	0.83	0.81	0.89	0.08
Tier 1 capital ratio	621,457	0.17	0.11	0.18	0 .39
log(Total assets)	621,457	11.83	10.96	12.56	1.29
Net income/assets	621,457	0.003	0.002	0.004	0.004
Loan/assets	621,457	0.62	0.53	0.74	0.16
Macro variables					
GDP growth (YoY)	107	0.024	0.017	0.034	0.021
Inflation (YoY)	107	0.025	0.016	0.033	0.017
Excess bond premium	107	0.061	-0.353	0.172	0.663

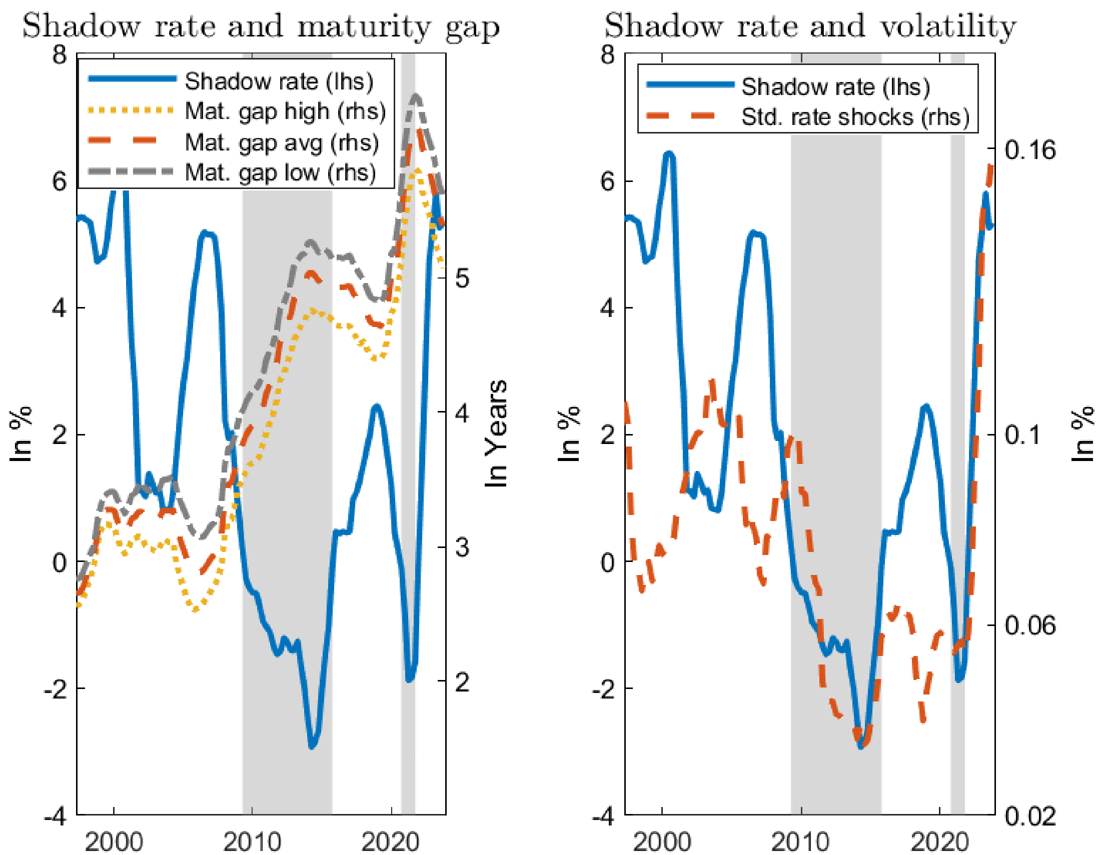
NOTE: This table provides the summary statistics for the data used in Section 4. The source of the data for banks is the Call Reports. Macro variables are from Fred and the ebp is from the updated series reported in Favara, Gilchrist, Lewis and Zakrajšek (2016). The sample is from 1997:Q2 to 2023:Q4.

TABLE 3. Panel Regression: Risk Taking and Deposit Beta

	(1)	(2)	(3)	(4)
	Maturity gap	Maturity gap	Maturity gap	Maturity gap
r_t	-1.756***	-1.396***	-2.996***	
	[0.181]	[0.290]	[0.317]	
$r_t \times ZLB_t$		-1.720**		
		[0 .841]		
$r_t \times \text{Deposit beta}_i$			1.980***	1.123***
			[0.606]	[0.401]
N	655,999	655,999	621,457	621,330
adj R^2	0.69	0.69	0.22	0.73
Sample period	1997:Q2-2023:Q4	1997:Q2-2023:Q4	1997:Q2-2023:Q4	1997:Q2-2023:Q4
Bank controls	Y	Y	Y	Y
Macro controls	Y	Y	Y	N
Bank FE	Y	Y	N	Y
Year-quarter FE	N	N	N	Y

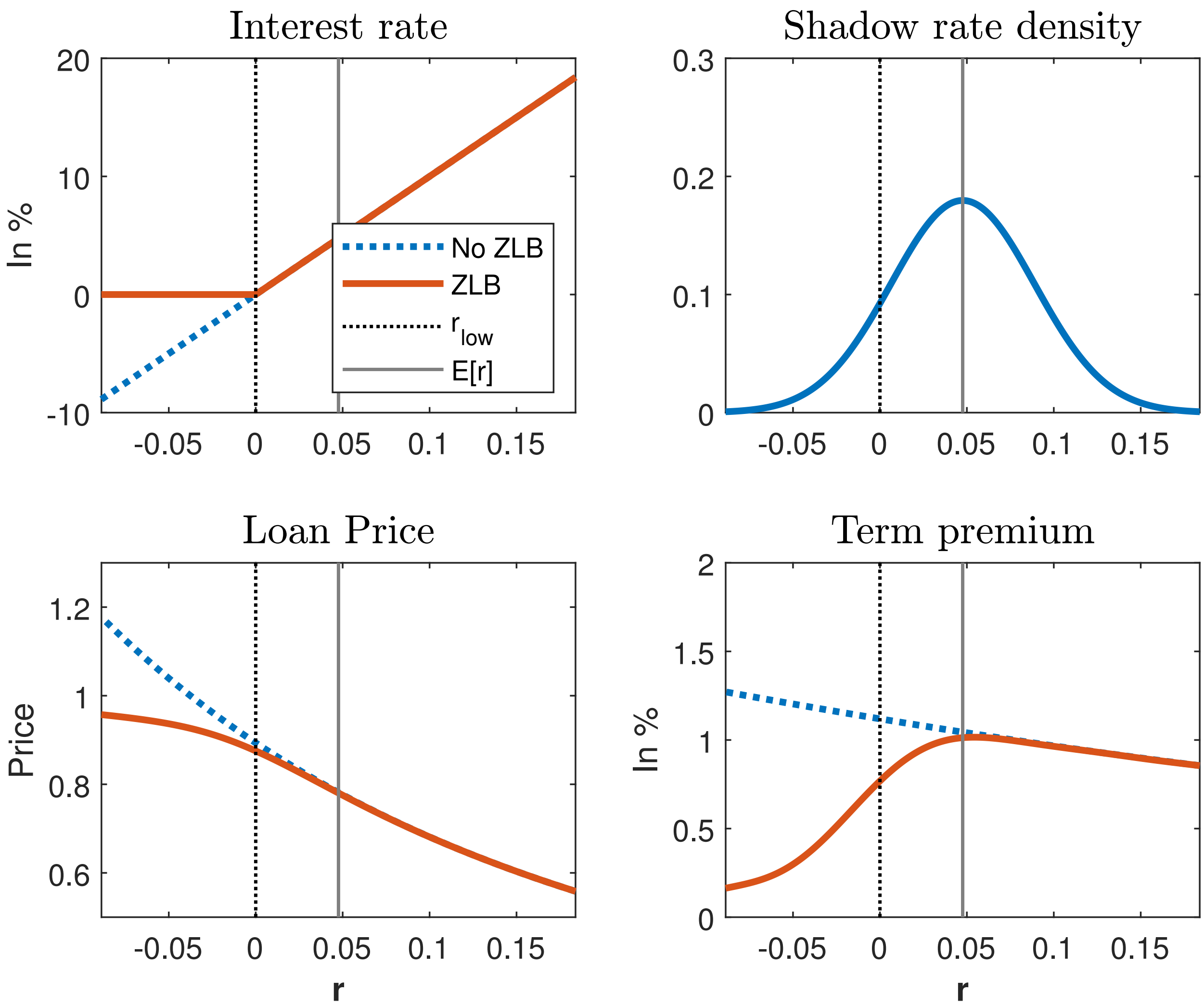
NOTE: This table shows the results of three alternative empirical specifications, reported in Section 4. The dependent variable in all specifications is bank's maturity gap, constructed as in English et al. (2018). Column 1 shows the first specification, that regresses maturity gap on the shadow rate, r_t. The subcolumn with "Low rate" ("High rate") consider the subsamples when the shadow rate is below (above) its median. Column 2 regresses the maturity gap onto the interaction between the deposit beta and the shadow rate. Column 3 is like column 2 but uses time fixed effects insted of macroeconomic controls. Bank and macroeconomic controls are reported in the text. Standard errors two-way clustered by bank and quarter are reported in brackets. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively. FE is fixed effects.

FIGURE 1. Shadow rate, interest rates volatility and banks' maturity gap



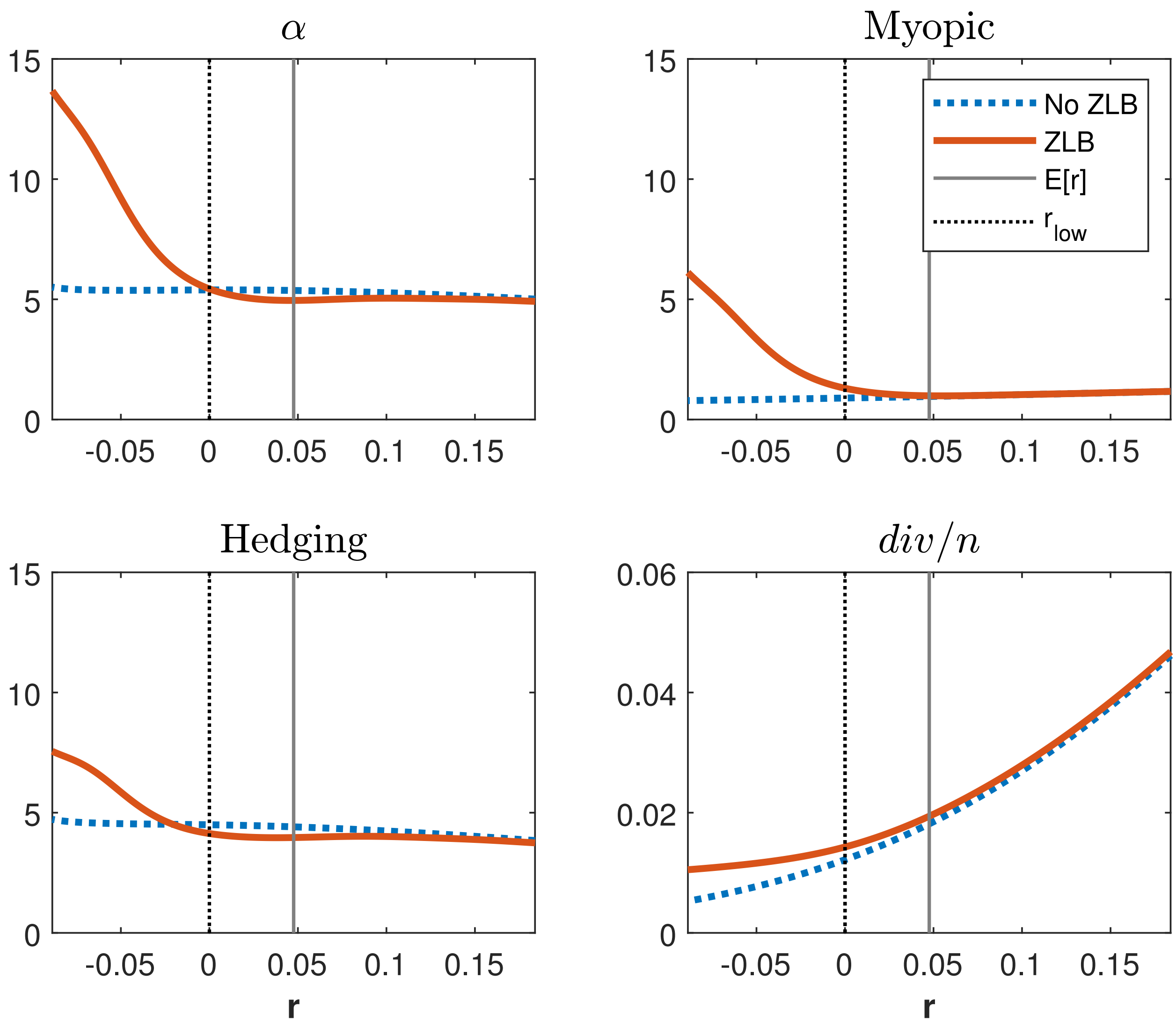
NOTE: The left panel shows, in solid blue, the shadow rate from Wu and Xia (2016) and the maturity gap, following English et al. (2018). The gray-dash-dotted line shows the matuity gap for banks with deposit betas above the sample mean. The red-dashed line shows the maturity gap for the banks with the average deposit beta, and the dotted-yellow line shows the maturity gap for banks with deposit betas below the mean. The right panel shows the shadow rate from Wu and Xia (2016) in solid blue and the standard deviation of interest rate shocks in dashed red. The interest rate shocks are changes in the two-year nominal rate around the FOMC, following Hanson and Stein (2015). I compute the quarterly average of the rolling standard deviation of the shocks for 20 FOMC meetings. The shaded gray areas indicate that the ZLB was binding.

FIGURE 2. Interest Rates and Term Premium



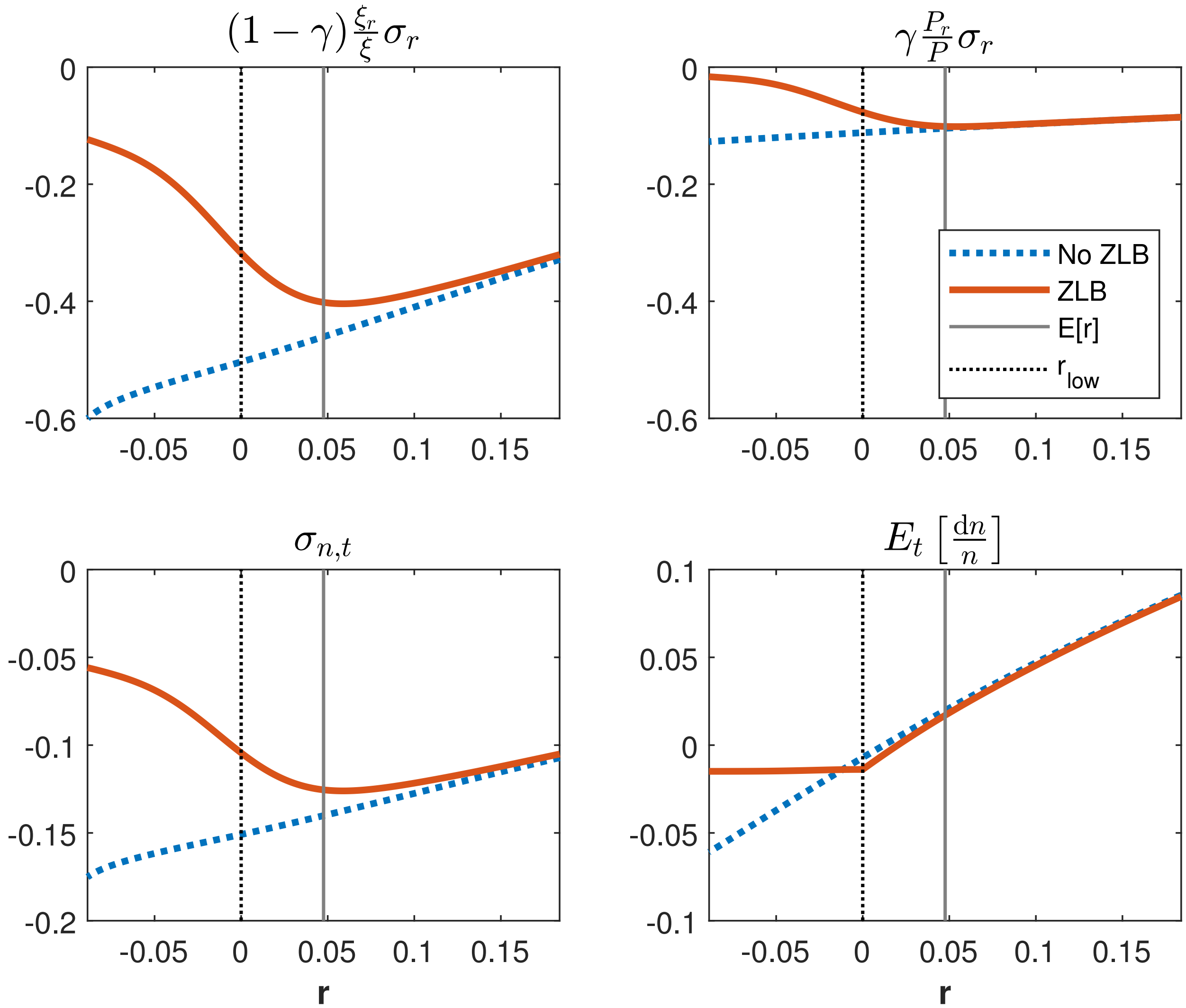
NOTE: This figure shows the model's solution when there is only interest rate risk. The horizontal axis in all panels represents the state space—namely, the shadow rate. The solid red line is the model solution. The dashed blue line is the solution without imposing the zero lower bound. The solid gray line is the unconditional mean of the interest rate and, the dotted black line is the effective lower bound.

FIGURE 3. Model Solution



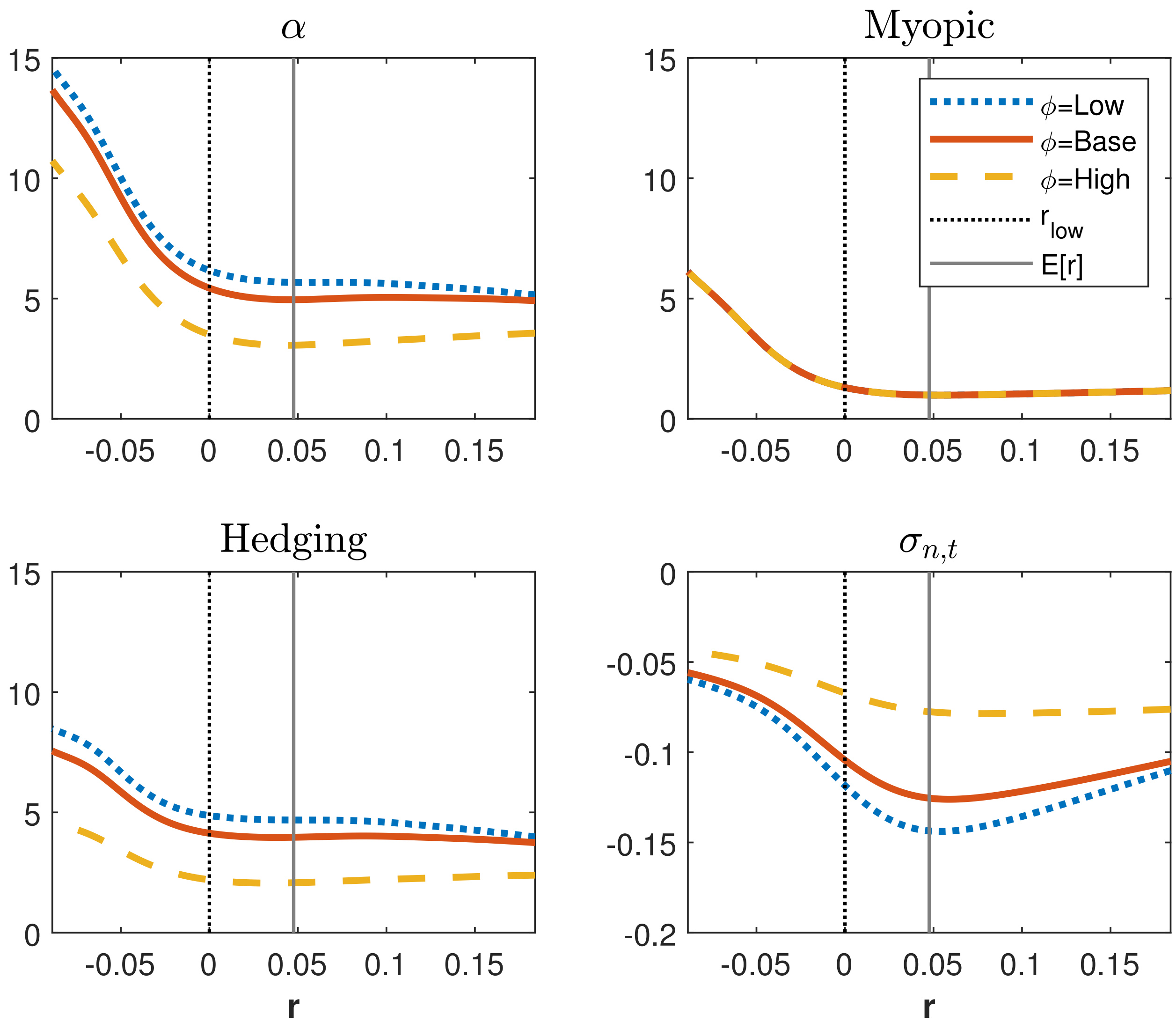
NOTE: This figure shows banks' optimal decisions when there is only interest rate risk. The portfolio share, α, and the myopic and hedging components, are shown in Proposition 1. The solid red line is the solution in the baseline calibration with a zero lower bound (ZLB). The dashed blue line is the solution without imposing the ZLB. The solid gray line is the unconditional mean of the interest rate, and the dotted black line is the effective lower bound.

FIGURE 4. Model Solution (continued)



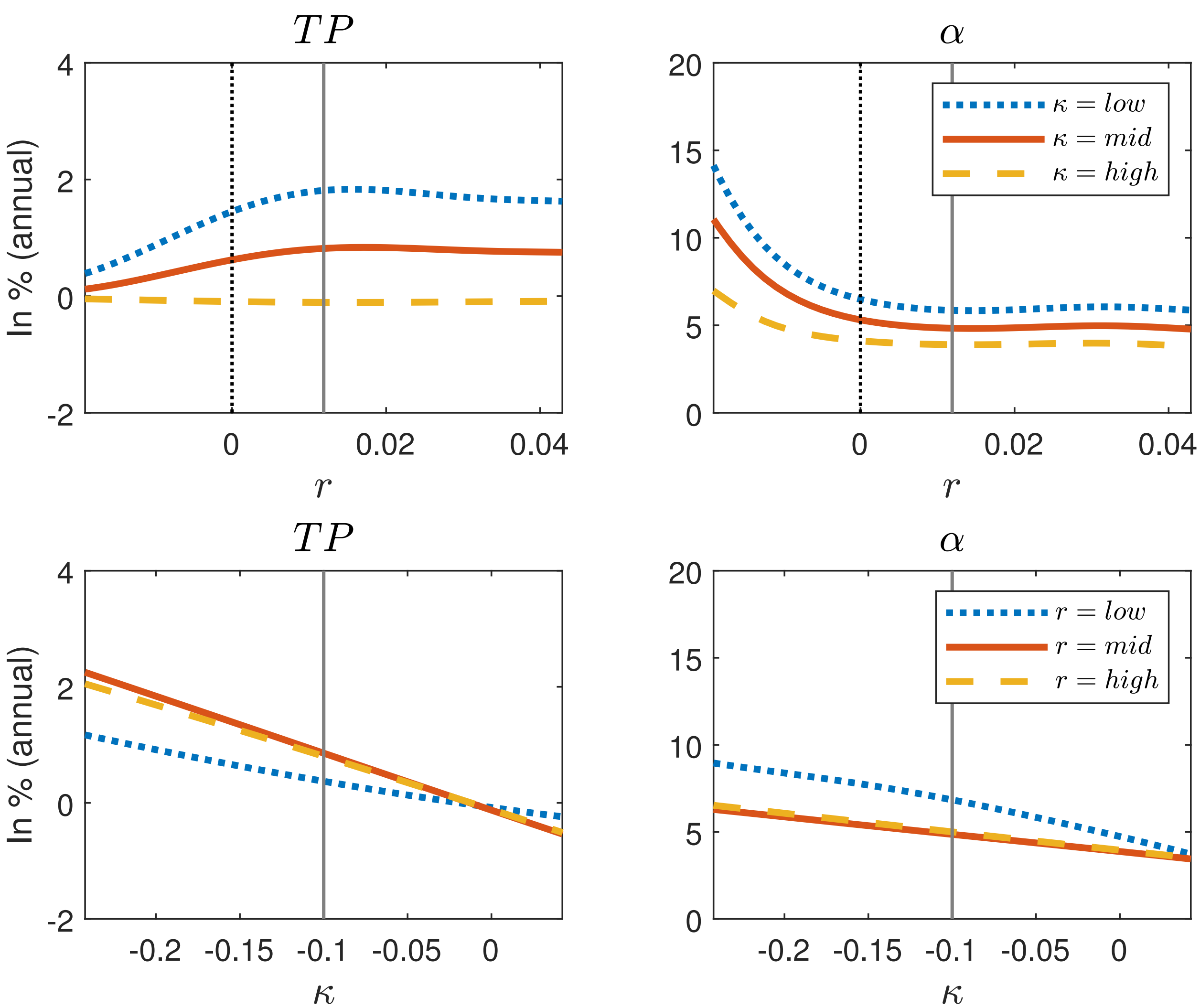
NOTE: This figure shows banks' risk exposures (top-left panel), the expected return on wealth (top-right panel) and a decomposition of the hedging demand between the conditional volatility of the banks' investment opportunity set (bottom-left panel) and the conditional volatility of long-term loans (bottom-right panel). The solid red line is the solution in the baseline calibration with a zero lower bound (ZLB). The dashed blue line is the solution without imposing the ZLB. The solid gray line is the unconditional mean of the interest rate, and the dotted black line is the ZLB.

FIGURE 5. Myopic, Hedging, and α for Different Deposit Market Power



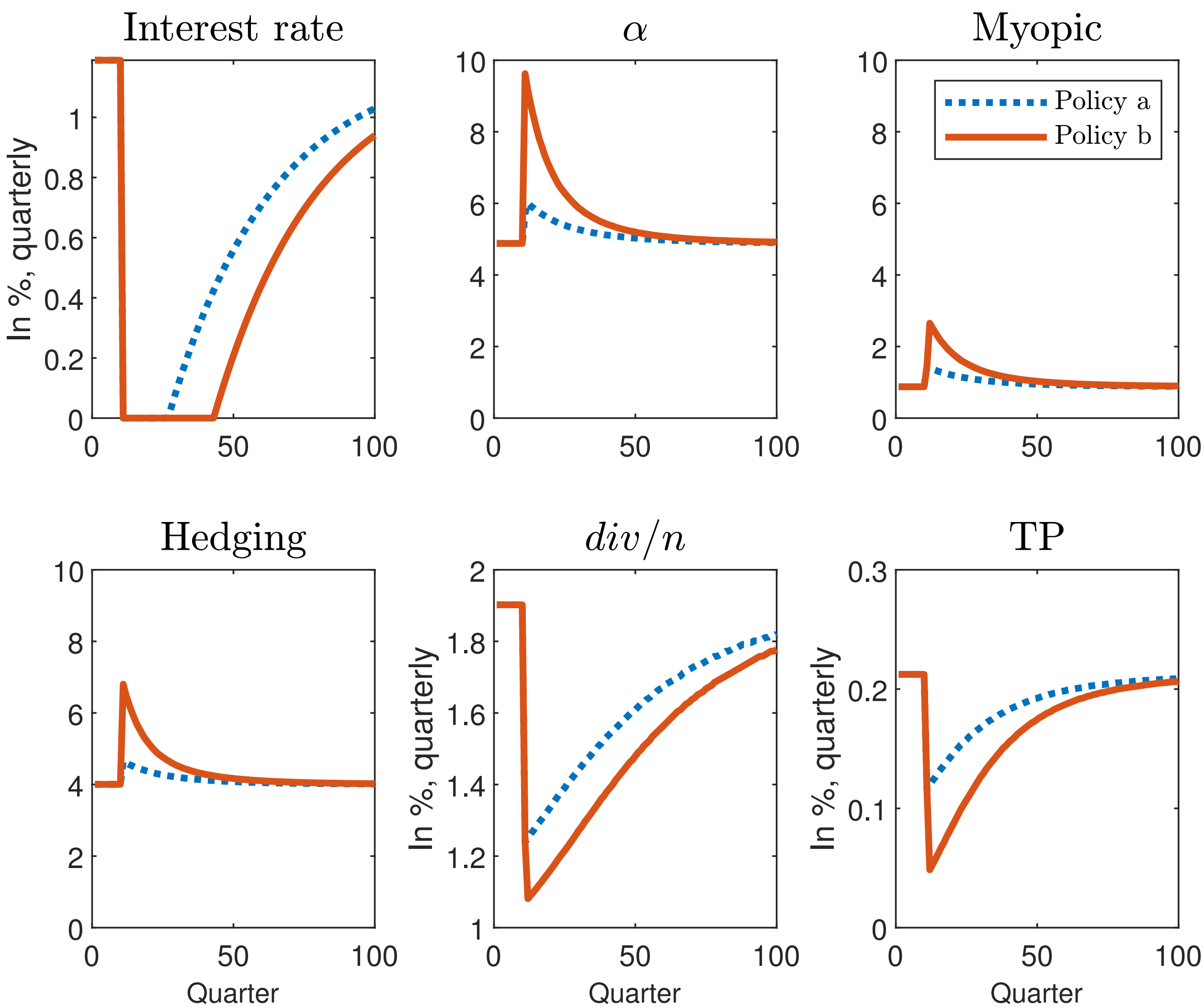
NOTE: This figure shows banks' α (left panel), the myopic demand (middle panel), and the hedging demand (right panel) for different level of deposit market power (ϕ). The baseline calibration, $\phi = 0.15$, is displayed in solid red.

FIGURE 6. Extended Solution



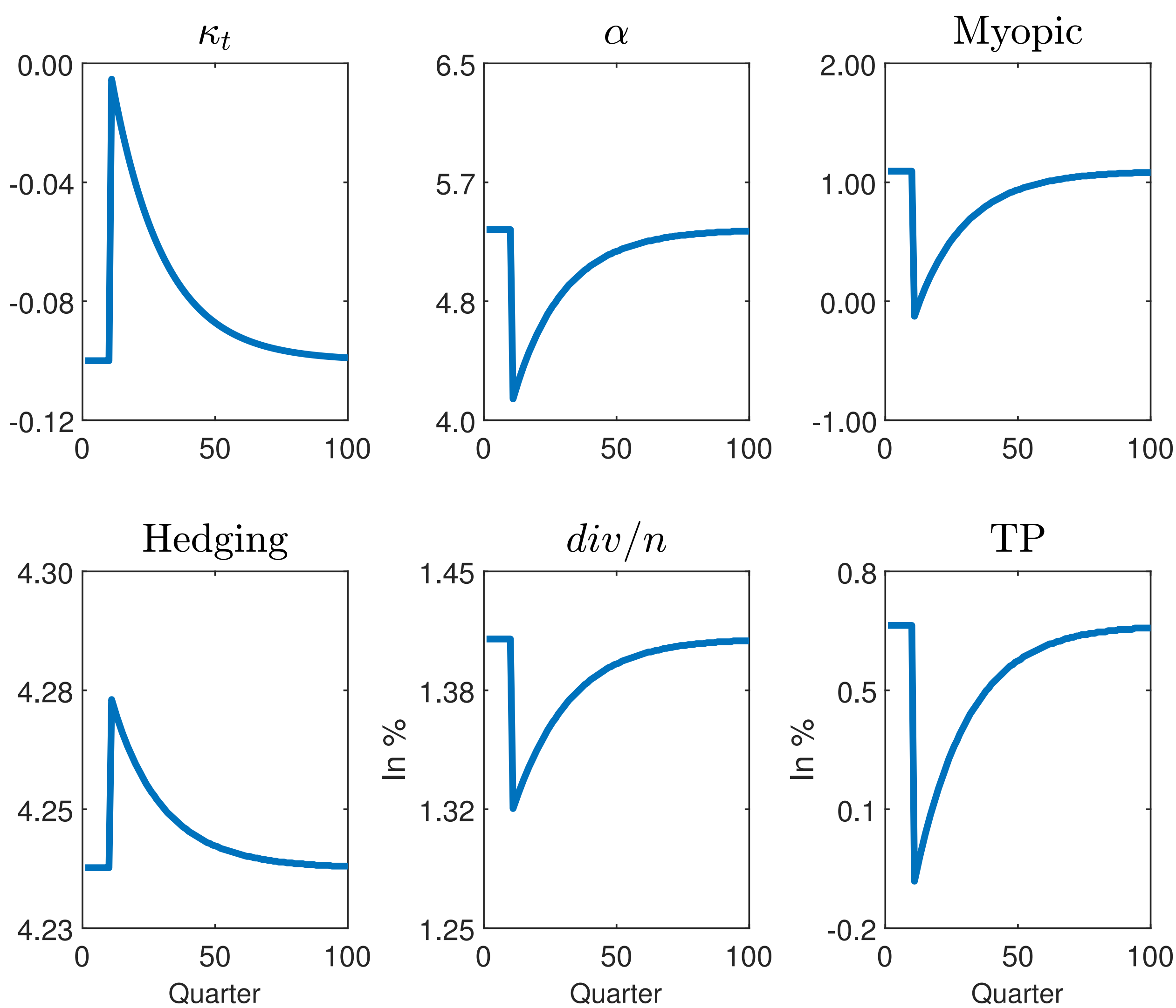
NOTE: This figure shows the solution of the extended model for the term premium (left panels) and α (right panels). The top panels show the solution across the κ_t dimension at different levels of r_t. The bottom panels show the solution across the r_t dimension at different levels of κ_t. The low (high) level is two standard deviations below (above) the mean of the corresponding state variable. The solid gray line is the point of the unconditional mean, and the dotted black line is the effective lower bound for r_t.

FIGURE 7. Forward Guidance



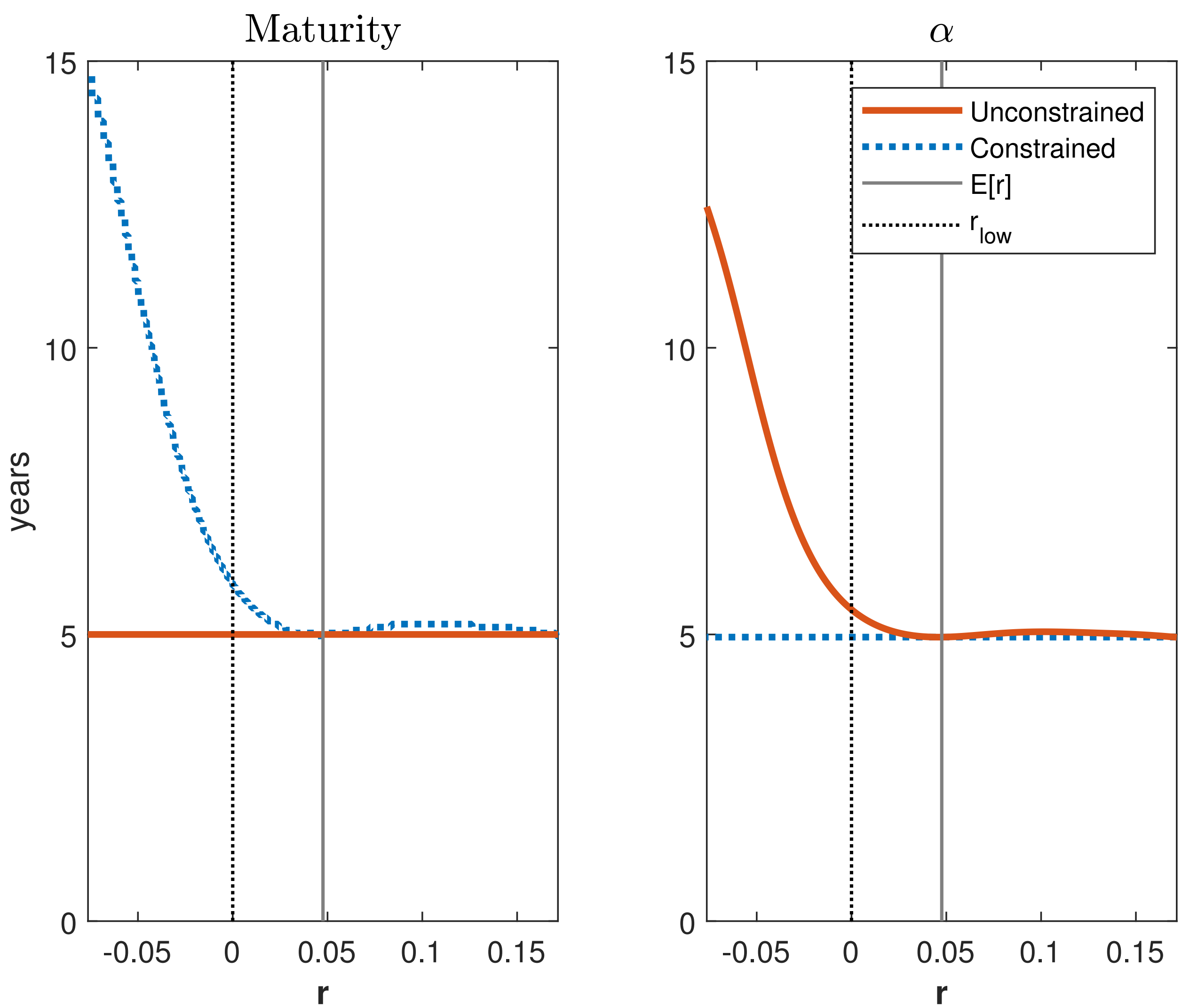
NOTES: This figure shows the impulse-response functions of the model to two alternative paths for the short rate: Policy b remains at the zero lower bound relatively longer.

FIGURE 8. Quantitative Easing (Term Premium Shock)



NOTE: This figure shows the impulse-response functions of the model to a term premium shock (that is, a shock to κ).

FIGURE 9. Maturity Choice and α



NOTE: This figure shows different combinations of maturity and α that obtain the same optimal risk exposure for banks. The solid red line shows the alpha choosen by the bank when thematurity of the loan is fixed at 5. The blue-dotted line shows the maturity of the loan choosen by the bank when α is constrained at 5.

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Appendix

A Proof of proposition 1.

The first order condition for $\alpha_t^{(\tau)}$, with only interest rate risk is given by

$$\mu^{(\tau)} - \widetilde{r}_t - \alpha_t^{(\tau)}\gamma\left(\sigma_{r,t}^{(\tau)}\right)^2 + (1-\gamma)\frac{\xi_r}{\xi}\sigma_r\sigma_{r,t}^{(\tau)} = 0. \tag{A-1}$$

Now using the definition of $\sigma_{r,t}^{(\tau)}$, from Ito's lemma on loan prices,

$$\sigma_{r,t}^{(\tau)} = \frac{P_{r,t}^{(\tau)}}{P_t^{(\tau)}}\sigma_r,$$

and the definition of term premium, $\mu^{(\tau)} - \widetilde{r}_t$,

$$\mu^{(\tau)} - \widetilde{r}_t = \overline{\kappa}\frac{P_{r,t}^{(\tau)}}{P_t^{(\tau)}}\sigma_r.$$

in (A-1), and re-arranging, gives

$$\frac{\overline{\kappa}}{\gamma\frac{P_{r,t}^{(\tau)}}{P_t^{(\tau)}}\sigma_r} + \left(\frac{1-\gamma}{\gamma}\right)\frac{\frac{\xi_r}{\xi}}{\frac{P_{r,t}^{(\tau)}}{P_t^{(\tau)}}} = \alpha_t^{(\tau)},$$

which is shown in the main text.

B Alternative framework.

I present an alternative framework to the one discussed in the main text, which delivers similar qualitative results. Instead of assuming bankers are risk averse, I assume bankers are risk neutral but face a friction to adjust their exposure to risk. I assume the dividend policy consits of randomly paying the entire net worth to shareholders, in line with models in the Gertler and Kiyotaki (2010). Bankers can trade the same instruments than in the main model but they face a friction when choosing their loan exposure. In particular, bankers have to pay cost it has to pay when adjusting their loan portfolio. I denote such cost by $\Psi\left(\theta_t^{(\tau)} P_t^{(\tau)}, n_t\right)$. Then, the evolution of bank wealth is

$$\frac{\mathrm{d}n_t}{n_t} = \left[\widetilde{r}_t - \frac{div_t}{n_t} - c + \left(\widetilde{r}_t - \phi\left(\widetilde{r}_t\right)\right)\frac{d_t}{n_t}\right]\mathrm{d}t + \frac{\theta_t^{(\tau)} P_t^{(\tau)}}{n_t}\left(\frac{\mathrm{d}P_t^{(\tau)}}{P_t^{(\tau)}} - \widetilde{r}_t\mathrm{d}t\right) + \frac{(1-\Gamma)}{2}\Psi\left(\theta_t^{(\tau)} P_t^{(\tau)}\right)\mathrm{d}t, \tag{B-2}$$

where $\Psi\left(\theta_t^{(\tau)} P_t^{(\tau)}\right)$ is the adjustment cost function (as a share of wealth), which is increasing in $\theta_t^{(\tau)} P_t^{(\tau)}$. The parameter Γ captures the tighnteness of the constraint. If $\Gamma > 1$, then, adjusting large portfolio of loans would be costly for the bank and the cost would be substracting from the ecolution of wealth. Bank's problem is

$$V_t = \max_{\left\{d_t, \theta_t^{(\tau)}\right\}} E_t \int_t^\infty \frac{m_s}{m_t}\lambda e^{-\lambda(s-t)} n_s \mathrm{d}s, \tag{B-3}$$

subject to (B-2), $n_0 > 0$, and $d_t \geq -\delta n_t$. To solve the model, I assume a quadratic adjustment function as in Ulate (2021),

$$\Psi\left(\theta_t^{(\tau)} P_t^{(\tau)}, n_t\right) = \left(\frac{\theta_t^{(\tau)} P_t^{(\tau)}}{n_t}\sigma_{P,t}^{(\tau)} - \bar{\varepsilon}\right)^2.$$

The solution of this problem consists in solving the value of the bank. Due to the homogeneity of degree one in n_t of the objective function and the budget constraint, the value V_t can be written $V_t = \psi_t n_t$. The process ψ_t has drift $\mu_{\psi,t}$ and diffusion $\sigma_{\psi,t}$. Then, the problem can be written in recursive fashion as,

$$0 = \max_{\left\{d_t, \theta_t^{(\tau)}\right\}} \frac{\lambda\,(1-\psi_t)}{\psi_t} + E_t\left[\frac{\mathrm{d}m}{m} + \frac{\mathrm{d}n}{n} + \frac{\mathrm{d}\psi}{\psi} + \frac{\mathrm{d}\psi}{\psi}\frac{\mathrm{d}n}{n} + \frac{\mathrm{d}\psi}{\psi}\frac{\mathrm{d}m}{m} + \frac{\mathrm{d}m}{m}\frac{\mathrm{d}n}{n}\right], \tag{B-4}$$

subject to (B-2), $n_0 > 0$, and $d_t \geq -\delta n_t$. The first order conditions for $\theta_t^{(\tau)}$ is

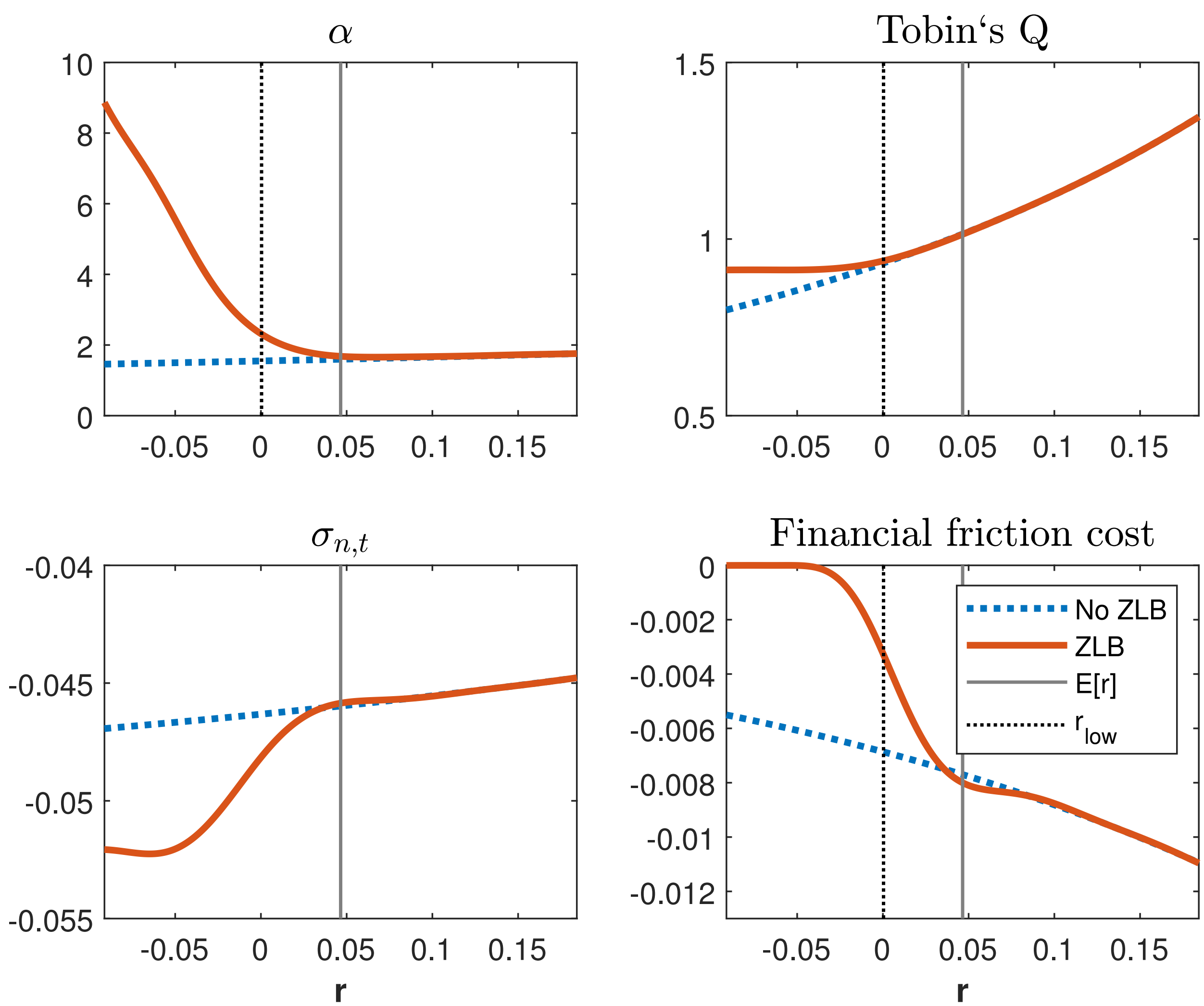
$$\frac{P_t^{(\tau)}}{n_t}\left(E_t\left[\frac{\mathrm{d}P_t^{(\tau)}}{P_t^{(\tau)}}\right] - \widetilde{r}_t\right) + (1-\Gamma)\left(\bar{\varepsilon} - \frac{\theta_t^{(\tau)} P_t^{(\tau)}}{n_t}\sigma_{P.t}^{(\tau)}\right)\frac{P_t^{(\tau)}}{n_t}\sigma_{P,t}^{(\tau)} + \frac{P_t^{(\tau)}}{n_t}\sigma_{\psi,t}^{(\tau)}\sigma_{P,t}^{(\tau)} - \kappa_t\frac{P_t^{(\tau)}}{n_t}\sigma_{P,t}^{(\tau)} = 0.$$

Inserting the first order condition in (B-4), using the pricing conditions for loans, and few steps of algebra, the expression for α is

$$\alpha \equiv \frac{\theta_t^{(\tau)} P_t^{(\tau)}}{n_t} = \frac{\bar{\varepsilon}}{\sigma_{P.t}^{(\tau)}} - \frac{1}{1-\Gamma}\frac{\sigma_{\psi,t}^{(\tau)}}{\sigma_{P.t}^{(\tau)}}. \tag{B-5}$$

Figure B-1 shows the solution for the key object of the alternative framework: α_t, ψ_t (Tobin's Q), $\sigma_{n,t} = \alpha_t \sigma_{P,t}^{(\tau)}$ (the sensitivity of bank's wealth to interest rate shocks), and $E_t\left[\frac{dn}{n}\right]$ (bank's expected return on wealth). The calibration for the interest rate is the same used in the main model. I set the parameter capturing the bank divided policy, λ, to get a Tobin's Q slighly above one in the steady state (as in Gertler and Kiyotaki (2015)). Finally, I set Γ=5, so deviation from the target exposure are costly (i.e., higher Ψ reduces dn/n). As shown, as the short rate decline toward the ZLB, α increases (upper-left panel), Tobin's Q decline (upper-right panel) due to fewer investment opportunities, and the cost of leverage constraint decline (lower-right panel). Finally, in constrast to the baseline model, $\sigma_{n,t}$ increases (in absolute value) somewhat (lower-left panel).

FIGURE B-1. Alternative Framework



NOTE: This figure shows banks' optimal decisions when there is only interest rate risk in the alternative framework. The solid red line is the solution with a zero lower bound (ZLB). The dashed blue line is the solution without imposing the ZLB. The solid gray line is the unconditional mean of the interest rate, and the dotted black line is the effective lower bound.