Banks' Risk Exposures and the Zero Lower Bound

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Abstract

I show that the presence of a zero lower bound (ZLB) on the short-term interest rate, irrespective of whether it is binding or not, incentivizes risk averse bankers to increase their risk exposures when interest rates decline and realize losses when interest rates increase. The incentives come from bankers' desire to hedge against a non-linear deterioration in their investment opportunities caused by low rates (i.e., lower deposit spreads, lower term premium, and lower yields due to unconventional policies implemented at the ZLB). Bankers with a stronger deposit market power, as well as bankers that are more risk averse, have relatively more incentives to increase their risk exposures when rates decline.

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Understanding how different interest rate environments affect banks' decisions is key in designing sound monetary and financial stability policies. In particular, low interest rates, especially when at the zero lower bound (ZLB), pose several challenges for banks' business model which can potentially affect their behavior. First, profits from deposit spreads—the difference between the interest rate on deposits and the federal funds rate—vanish at the ZLB (Drechsler, Savov and Schnabl, 2017; Whited, Wu and Xiao, 2021; among others). Second, the compensation for taking interest rate risk (by performing maturity transformation) declines because the ZLB causes a non linear 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, hence affecting banks' asset side and their profitability (Krishnamurthy and Vissing-Jorgensen, 2011).

One plausible hypothesis is that banks increase their risk exposures 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 to increase their exposure to 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 they face an interest rate model that is subject to a ZLB. I find two key predictions. First, the presence of the ZLB causes banks to unequivocally increase their average exposures to interest rate risks as the level of rates decline.[1] This prediction, that relates the level of interest rates to banks risk taking, is purely driven by the non linearities associated with the ZLB and their effect on banks' willigness to hedge their investment opportunities.[2] That is, bankers find it optimal to take more risks when the short rate declines toward the ZLB and their investment opportunities are scarce (due to a low term premium and low spread on deposits) because this is hedge that realizes losses when the short rate increases and their investment opportunities improve.

The second set of predictions are related to the differential effects of the ZLB on banks' risk taking. I show that banks who charge a higher average spread on deposits have a stronger incentive to take more risks 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 investment opportunities of banks that charge a higher spread on deposits, on average, than those of banks that charge a lower average spread. This is because deposit spreads at the ZLB are, by definition, almost zero for all banks. Hence, those banks who charge higher average deposit spreads have a stronger incentive to hedge their invesment opportunity set by increasing their exposure to interest rate risk when rates are low and reduce their exposures while they realize losses as the level of rates increases and they can charge higher deposit spreads.

I also show that relatively more risk-averse bankers, such as those who manage banks with stricter risk-management practices or who display a higher aversion to losses,

[1] I study interest rate and term premium shocks, but the mechanisms in this paper can be extended to study other aggregate shocks that affect interest rates as well.

[2] Indeed, if banks did not incorporate the ZLB in their interest rate model, changes in the level of the interest rate have almost no effect on banks' risk taking in my setup.

would prefer to increase their exposure to risks relatively more than less risk-averse banks when facing the ZLB. This result is driven by the fact that banks' demand for long-term assets is primarily given by their preference to hedge against changes in their investment opportunities rather than by a conventional risk-return tradeoff. Because more risk averse banks have a stronger demand to hedge against changes in their investment opportunities, those banks exhibit a larger increase in their risk exposure as interest rates approach the ZLB. Interestingly, this result is against the logic prescribed by the standard mean-variance criteria for portfolio allocation, in which a more risk-averse banker would adjust her portfolio by less than a less risk-averse banker when facing a change in their investment opportunities.[3]

Finally, I use the model to study how banks' risk exposures change when facing 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 interest rate lower for a longer period of time, FG causes a deterioration in banks' investment opportunities that lasts longer. As a consequence, banks would increase their risk-taking as a part of their optimal hedging strategy. 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

[3] In the mean-variance framework, the portfolio share of the risky asset is equal to the expected return divided by the variance times risk aversion. Hence, an increase in the expected return relative to variance increases the portfolio weight but less so for higher levels of risk aversion.

declines. On the other hand, the decline in the term premium represents a deterioration in banks' investment opportunities, and therefore banks increase their exposure to risks. In my baseline calibration, the decline in the return-to-risk ratio more than compensates 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 is that the ZLB generates a strong incentive for banks to hedge against changes in the investment opportunity set in the sense of Merton (1973). More specifically, when the short rate is at the ZLB and remains there for some time, banks' investment opportunity set of deteriorates in a nonlinear way. When the rate reaches the ZLB, banks suddenly can not charge a spread on deposits, the expected excess return in performing maturity transformation (that is, the term premium) decreases in a nonlinear fashion, and banks' expected excess return on equity is low. In this adverse environment, banks find it optimal to increase their levered positions in long-term assets to compensate the low rate of return on assets and the spread on deposits. When the interest rate moves out of the ZLB, banks' investment opportunity set improves, and hence banks are willing to absorb the marked-to-market losses caused by the lift off of the short rate away from the ZLB.

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) in all the regressions. Then, I use three empirical specifications to test how banks' risk exposures change with the shadow rate and the differential effect across risk aversion and deposit beta. 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 relevant bank characteristic (risk aversion or 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.

In these empirical exercises, for banks characteristics I use banks' CAMELS (capital adequacy, assets, management capability, earnings, liquidity and sensitivity) ratings as a proxy for risk aversion and the deposit betas from Drechsler, Savov and Schnabl (2021).[4] The overall CAMELS rating is an assessment along several critical bank dimensions that summarize banks' managerial style and risk profile. The deposit beta is the average sensitivity of banks' deposits expenses to changes in the federal funds rate. The empirical results are well in line with the predictions of the model: A lower shadow rate is associated with a higher maturity gap, and this effect is more pronounced for banks with a lower deposit beta and higher risk aversion (proxied by the CAMELS rating).

Literature. There is 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 et al., 2021; Wang, 2022; Wang, Whited, Wu and Xiao, 2022; among others). This paper contributes to the literature by studying how the ZLB affect banks' risk taking behavior and propose a novel channel grounded in banks' willigness to hedge changes in

[4]I use the deposit betas available at Philipp Schnabl's website.

their investment opportunities.

1 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.

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. The drift of the pricing kernel, $\widetilde{r}_t$, is the short rate. Following the shadow rate literature, I assume the short rate follows

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

where r_{low} is a parameter (which could be either zero or negative) and r_t, the shadow rate, follows

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

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

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

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 federal funds. 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 number of long-term loan contracts 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 $1/\tau$.[5] Long-term loans cannot be defaulted.[6] 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 federal fund and deposit accounts are locally risk-free, in the sense that they are not affected by aggregate uncertainty and evolve as

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

[5] 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.

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

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).

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

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

with

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

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

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

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 exercise, 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

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

Using the Feynman-Kac formula, I write the conditional expectation (5) as

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

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 takes the following power form:

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

Then, the recursive representation of banks' problem (4) takes the form of the following Hamilton-Jacobi-Bellman equation

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

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

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

Deposits' leverage constraint is always binding $d_t = -\delta n_t$ because the spread on deposits is always positive.

2 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 three sets of parameters—namely, those from the two-factor shadow rate model and those for the 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.[7] 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.[8] In partic-

[7] The shadow rate is very similar to the effective federal funds rate in periods out of the ZLB.
[8] Assuming a positive and constant level of credit risk does not affect the analysis.

ular, 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 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 $s_t = \widetilde{r}_t - \phi(\widetilde{r}_t) = (1-\phi)\tilde{r}_t \geq 0$. Following the evidence in Drechsler et al. (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, which in the model is $\mathbb{E}[dn/n]$ of 6% per year.[9] 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=1.5 and γ=3.[10]

Only 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 $\kappa_t = \overline{\kappa}\ \forall t$. I extend the model, below, when I study the different policies that affect long-term rates.

Figure 1 shows the solution for the objects associated with the interest rate model. 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

[9] Although $\mathrm{d}n/n$ 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.

[10] I provide a sensitivity analysis on these parameters below.

is binding, while the vertical solid gray line shows the unconditional mean of the short rate. The top-left panel of Figure 1 shows the short-term rate, which, in a model with a ZLB, is obviously truncated at r_{low}. The top-right model shows the spread between the yield on loans and the short rate. Importantly, the bottom-left panel shows the term premium. In this case, in which there is only interest rate risk, the term premium in equation 1 is reduced to

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

When the lower bound on the short rate is imposed, the volatility of long-term bonds is reduced when the level of rates is low, meaning that $\frac{P_r^{(\tau)}}{P^{(\tau)}}\sigma_r$ declines when the shadow rates go into negative territory. Intuitively, this effect is due to the fact that the short-rate can only go up when it is at the lower bound—that is, the conditional distribution of the short rate is truncated at the lower bound. Finally, the bottom-right panel shows the distribution of the shadow rate.

Banks' Risks Exposures With Interest Rate Risk. Next, I study banks' optimal policies. To do so, the next proposition 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 $\frac{\xi_r}{\xi}$ is the sensitivity of banks' investment opportunity set to the interest rate and $\frac{P_r^{(\tau)}}{P^{(\tau)}}$ is the sensitivity of long-term loan prices to the interest rate.

Proof. See appendix.

Figure 2 shows the banks' optimal policies in the baseline calibration. I discuss below how preference parameters affect the results. The top-left panel shows the portfolio share (expression 6 in proposition 1), which increases when the short rate declines, particularly when the short rate drops below the lower bound. Importantly, as shown by the red line, the increase in α is not present in the model without the lower bound in the short rate. The top-right and bottom-left panels show the decomposition of α into the myopic and hedging components, respectively. Notice that the vast majority of the movement in α is driven by the hedging motives: Banks have a risk aversion greater than one and hence decide to increase their exposure to interest rate risk when the level of rates is low—that is, when the term premium and the spread on deposits are low—to hedge against higher rates in the future, in which the investment opportunity will be better (high term premium and spread on deposits).[11] The myopic component rises because of the decline in interest rate volatility, which improves the risk–return profile of long-term loans by reducing the variance of long-term loan returns relatively more than the decline in the term premium.[12] Finally, the bottom-right panel shows the dividend policy. Because bankers have an EIS greater than one, they increase the dividend-to-book equity ratio when rates are low.

Figure 3 elaborates further on the model's solution. The top-left panel shows banks' total risk exposure, $\alpha\sigma_p^{(\tau)}$, which is the diffusion component associated with the changes in banks' wealth, dn/n. On average, the risk exposure is negative: A positive shock to the level of the short rate, $W_{r,t}$—that is, an increase in the short rate—decreases banks'

[11] I discuss other risk-aversion parameters below.

[12] Notice that if the price of risk, $\bar{\kappa}$, was equal to $\gamma(\sigma_{r,t}^{(\tau)})^2$, then the myopic component would be constant. The hedging component, however, would not be constant.

wealth. Notice that the total risk exposure fluctuates in a nonlinear fashion across the state space because, as interest rates decline, the decrease in the quantity of risk ($\sigma_p^{(\tau)}$) more than compensates the increases in α. The top-right panel shows the conditional expectation of the return on wealth, which is increasing in the level of rates, primarily due to the presence of the deposit market power, as shown in equation 3. Finally, the bottom panels show the key components of the hedging demand. In particular, the hedging demand, as shown in equation 6, is the diffusion associated with ξ (the bottom-left panel of Figure 3) divided by the diffusion associated with $P^{(\tau)}$. As shown, P_r goes to zero as the shadow rate declines—because bonds become less sensitive to interest rate changes as interest rates are stuck at zero—pushing the hedging demand up. In the left panel, ξ_r/ξ increases as the rate declines, pushing hedging demand up as well, this effect reverses as the shadow rate declines further into negative territory. Intuitively, as the shadow rate goes to a very negative number—meaning that the level of rates will barely move in the foreseeable future—, all conditional volatility will trend to zero.

Banks' Equity Valuation. I compute banks' stock prices as the discounted present value of banks' dividend payments. Re-arranging the optimality conditions in banks' problem, the dividend can be expressed as

$$div_t = n_t \rho^{\psi} \xi_t^{1-\psi},$$

while the stochastic discount factor is (1). Then, the stock price is given by

$$p_t = E_t \left[\int_t^{\infty} \frac{m_s}{m_t} div_s \mathrm{d}s \right].$$

The top-left panel in Figure 4 shows the banks' dividend-price ratio. Notice that bank valuations decline with the lower interest rates primarily because of lower returns on equity. The top-right panel shows the exposure of banks' stock prices to an interest rate shock, which is negative on average: An unexpected interest rate shock causes a decline in p_t. The bottom-left panel displays the leverage, defined as the market value of assets ($\theta_t^{(\tau)} P_t^{(\tau)}$) divided by the market value of equity (p_t). The leverage behaves very similarly as the portfolio share, α. Finally, the bottom-right panel displays banks' equity premium.

The Role of Risk Aversion. Figure 5 compares the baseline solution against the solution with $\gamma = 1$, which is a particular case where the hedging demand for risky loans is zero. When the risk aversion coefficient is 1, the bank's optimal risk exposure is driven only by the myopic component—namely the risk–return tradeoff, as the bank behaves like a mean-variance optimizer. This behavior is due to the welfare losses associated with the deterioration of the investment opportunity set, as the shadow rate declines are perfectly offset by the marked-to-market gains of the loan portfolio. However, notice that the overall α is slightly higher, on average, in the baseline calibration with a higher risk aversion than unity. Even though the myopic demand decreases for higher risk aversion (a more risk averse bank penalizes variance relatively more), the nonlinear effect on the hedging demand more than compensates the lower myopic component. Hence, the total demand for risky loans, α, increases more in the baseline calibration than in the particular case of $\gamma = 1$ as the shadow rate declines.

Figure 6 illustrates the effect on leverage across different levels of risk aversion besides unity, which has zero hedging demand. The model predicts that more risk-averse banks would increase their risk exposures relatively more than banks with lower risk aversion. This effect is due to the hedging component. Risk-averse banks have a strong desire to smooth their investment opportunity set across different interest rate regimes. In particular, when the shadow rate is negative and the ZLB is binding, it is optimal for more risk-averse banks to increase their risk exposures relatively more than banks with relatively lower risk aversion.

The Role of Deposit Market Power. Deposit spreads are an important component of banks' business model. Bank's ability to pay an interest rate on deposits that is lower and less volatile than the fed funds rate is not only a source of profit for banks but also relevant for their risk taking decisions (Drechsler et al. (2021)). Figure 7, left panel, shows how banks optimal portfolio share, α, changes for different ϕ—which captures the sensitivity of the deposit rate to the fed fund rate, $r_t^d = \phi r_t$. The middle and right panel show the myopic and hedging components.

The figure shows that banks with a lower ϕ (i.e., banks that pass through the level of rates to depositors at a relatively slow pace and therefore charge a higher average spread on deposits) take a relatively larger exposure to interest rate risk as the level of rates rates decline. Notice that this is purely driven by the hedging component (middle panel), while the myopic component is unaffected by ϕ.[13] The intuition for this result is that the investment opportunity set of a bank with a low ϕ, who charges a larger spread on deposits, deteriorates relatively more than the investment opportunity set of a bank with high ϕ. This is because banks with low ϕ will be relatively more affected by the ZLB because they rely on average larger spreads on deposits than banks with high ϕ. As a result, banks with a lower ϕ will have an incentive to take relative higher risks in long-term loans so that they can realize relatively larger losses when rates increase and their investment opportunities improve relatively more. This result is in line with the

[13] Neither the expected return on loans, the variance of loan returns, or banks risk aversion are affected by ϕ.

evidence documented in Drechsler et al. (2021), who show that banks' ability to charge a spread on deposits affect their exposures to interest rates.

Extension to term premium shocks. Figure 8 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 9 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 10 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.

3 Empirical Analysis

The model has two main predictions. First, it predicts that the presence of the ZLB incentivizes banks to increase their exposures to interest rate risk when the interest rates decline because their want to hedge the decline in their investment opportutnies. Second, as the interest rates decline, banks that either have a lower deposit beta or are more risk averse would find it optimal to increase their risk exposures relatively more than banks with higher a deposit beta or a smaller risk aversion. The main reason for this differential result is that banks' demand for risky assets is primarely driven by the hedging component, not the myopic component.[14]

Data. I use the following data to test the model's predictions. First, I construct the maturity gap measure proposed by English et al. (2018) using the Call Reports from 1997:Q2 through 2019:Q4. The maturity gap is defined as the difference between the maturity of a bank's assets and liabilities. In the model, there is a direct mapping between the bank risk exposure α and the maturity choice. In particular, as shown in Figure 11, banks could increase their maturity exposure, holding α constant, instead of increasing α with a constant τ, to replicate their optimal risk exposure. I use the maturity gap as a proxy for risk exposure because it has a more straightforward mapping into the data than α.

To test the second model prediction—namely, the relative change in banks' risk exposures across the risk aversion and deposit beta dimensions—I use CAMELS supervisory ratings as a proxy for banks' risk aversion and the estimated deposit betas from Drechsler et al. (2021). The CAMELS rating system is on a scale from 1 to 5, with higher values indicating weaker ranking, which is associated with worse risk management practices. I interpret banks with a higher CAMELS score as those with relatively lower risk aversion than banks with a lower CAMELS score. The deposit beta from Drechsler et al. (2021) 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

[14] As elaborated Section 2, both the myopic (or risk–return tradeoff) and the hedging component rise when the interest rate declines, but hedging is relatively stronger.

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 characteristic (either CAMELS score or 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 larger bank risk exposure—a higher maturity gap.

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 risk exposure, more risk averse banks (those with a lower CAMELS score) and banks with a lower deposit beta, should increase their exposure relatively more than less risk-averse banks.

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.

Regressions Results: Deposit Beta. Table 3 shows the results using deposit betas as a bank characteristic. I use the banks' average deposit betas in the period 1984:Q1 to 2022:Q4 and, hence, they do not change over time, following Drechsler et al. (2021). This means $C_{i,t} = C_i$. The results for the first specification show, in column (1), 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. Interestingly, the result is particularly strong when the level of rates is low, as shown by the sub-column labeled "Low rates" (which considers the subsample in which the shadow rate is below its median value in the sample). This result is consistent with the model, which predicts the presence of the ZLB is particularly important for banks' risk taking. Indeed, the model predicts that if rates remained very high and the probability of reaching the ZLB was very small, then banks' risks' exposures would be barely affected by changes in the short rate.

Columns (2) and (3) 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).

Regressions Results: Risk Aversion. Table 4 shows the results for the three specifications. Column (1) shows that a lower shadow rate is associated with a higher maturity gap. In particular, a 100 basis point decrease in the shadow rate is associated with an average increase of 1.8 months in the maturity gap. Notice that column (1) is qualitatively consistent with the model's prediction as well as with past empirical literature (cited in the introduction) that found a statistically significant relationship between loose monetary policy and alternative measures of bank risk-taking. Again, as in the regressions using deposit beta as a bank characteristic, the results in column (1) are particularly stronger when the level of rates are lower (see subcolumn "Low rates"). This result is consistent with the first prediction of the model, that relates the level of the shadow rate with banks' risk taking.

Column (2) shows the results for the second specification, in which I test for the relative effect of the shadow rate on bank risk-taking across different CAMELS scores. I interpret a bank with a higher CAMELS score as relatively less risk averse than a bank with a lower score, because a higher CAMELS score is associated with less prudent risk-management practices. As shown in column (2), the estimated coefficient associated with the interaction between the shadow rate and the CAMELS rating, β_3, is positive. Additionally, the estimated coefficient associated with the shadow rate, β_1, remains negative as in column (1). This finding means that a reduction in the shadow rate is associated with a higher maturity gap, but this effect is relatively less pronounced for banks with higher risk aversion. In other words, banks with lower (higher) risk aversion react relatively less (more) to changes in the shadow rate, consistent with the model's prediction in which this effect is driven by the relative importance of hedging demand.

Finally, in column (3), I show the results of the third specification in which I replace the interest rate with time fixed effects and focus only on the interaction term, β_3. The interaction term remains approximately the same as in column (2), and its significance increases slightly. This result shows that the interaction term, capturing the fact that banks with a relatively higher CAMELS rating (that is, less risk averse) increase their risk exposures (captured by the maturity gap) relatively more when the level of rates increases, and the result is robust to controlling for macroeconomic factors beyond the level of the shadow rate.

4 Conclusion

Banks' investment opportunity set deteriorates in a non-linear fashion as the short rate declines toward the ZLB. This is because, at the ZLB, the compensation for taking interest rate risk declines *pari passu* with the conditional volatility of interest rates, and the spread on deposits goes to zero. In this paper, I show that risk averse bankers find it optimal to increase their risk exposures to cope with the ZLB. The ZLB generates a strong desire in banks to hedge the deterioration of their investment opportunity set by increasing their risk exposure when investment opportunities are scarce and reduce exoposures to risks when they realize losses as the level of rate increases and investment opportunities improve.

I show that banks with lower deposit betas or higher levels of risk aversion have a relatively stronger desire to increase their exposures 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). In a similar vein, as the level of rates decreases toward the ZLB, bankers with a higher risk aversion prefer to increase their risk exposure relatively more than bankers with a lower risk aversion, because they display a relatively stronger preference to hedge their investment opportunities.

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.

5 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	1.5	EIS	
	γ	3	Risk aversion	

NOTE: Parameters are expressed at an annual frequency. I describe the calibration in Section 2 of the main text. EIS is elasticity of intertemporal substitution.

TABLE 2. Summary Statistics

	Observations	Mean	25^{th} Per.	75^{th} Per.	St. Dev.
Bank-level variables					
Maturity gap (months)	148,138	44.05	25.52	57.59	25.29
CAMELS	148,138	1.84	1	2	0.9483
Deposits/assets	148,138	0.83	0.807	0.886	0.0892
Tier 1 capital ratio	148,138	0.17	0.11	0.181	0.411
Log(Total assets)	148,138	11.84	10.95	12.563	1.31
Net income/assets	148,138	0.002	0.001	0.003	0.0267
Loan/assets	148,138	0.627	0.537	0.7403	0.157
Deposit beta	139,890	0.372	0.315	0.423	0.093
Macro variables					
GDP growth (percent YoY)	91	0.023	0.016	0.033	0.017
Inflation (percent YoY)	91	0.021	0.015	0.029	0.010
Excess bond premium	91	0.051	-0.353	0.141	0.688

NOTE: This table provides the summary statistics for the data used in Section 3. The source of the data is provided in the main text. CAMELS stands for capital adequacy, assets, management capability, earnings, liquidity and sensitivity. YoY is year over year. Deposit betas are from Philipp Schnabl's website.

TABLE 3. Panel Regression: Risk Taking and Deposit Beta

	(1)			(2)	(3)
	Full sample	Low rate	High rate	Full sample	Full sample
r_t	-2.332***	-2.005***	-0.488	-3.143***	
	[0.164]	[0.495]	[0.401]	[0.251]	
$Deposit\ beta_{i,t} \times r_t$				2.197***	1.213***
				[0.549]	[0.425]
N	581,712	369,618	212,094	581,712	581,585
R^2	0.22	0.18	0.14	0.218	0.731
Sample period	1997q1-2019q4			1997q1-2019q4	1997q1-2019q4
Bank controls	Y			Y	Y
Macro controls	Y			Y	N
Bank FE	Y			Y	Y
Year-quarter FE	N			N	Y

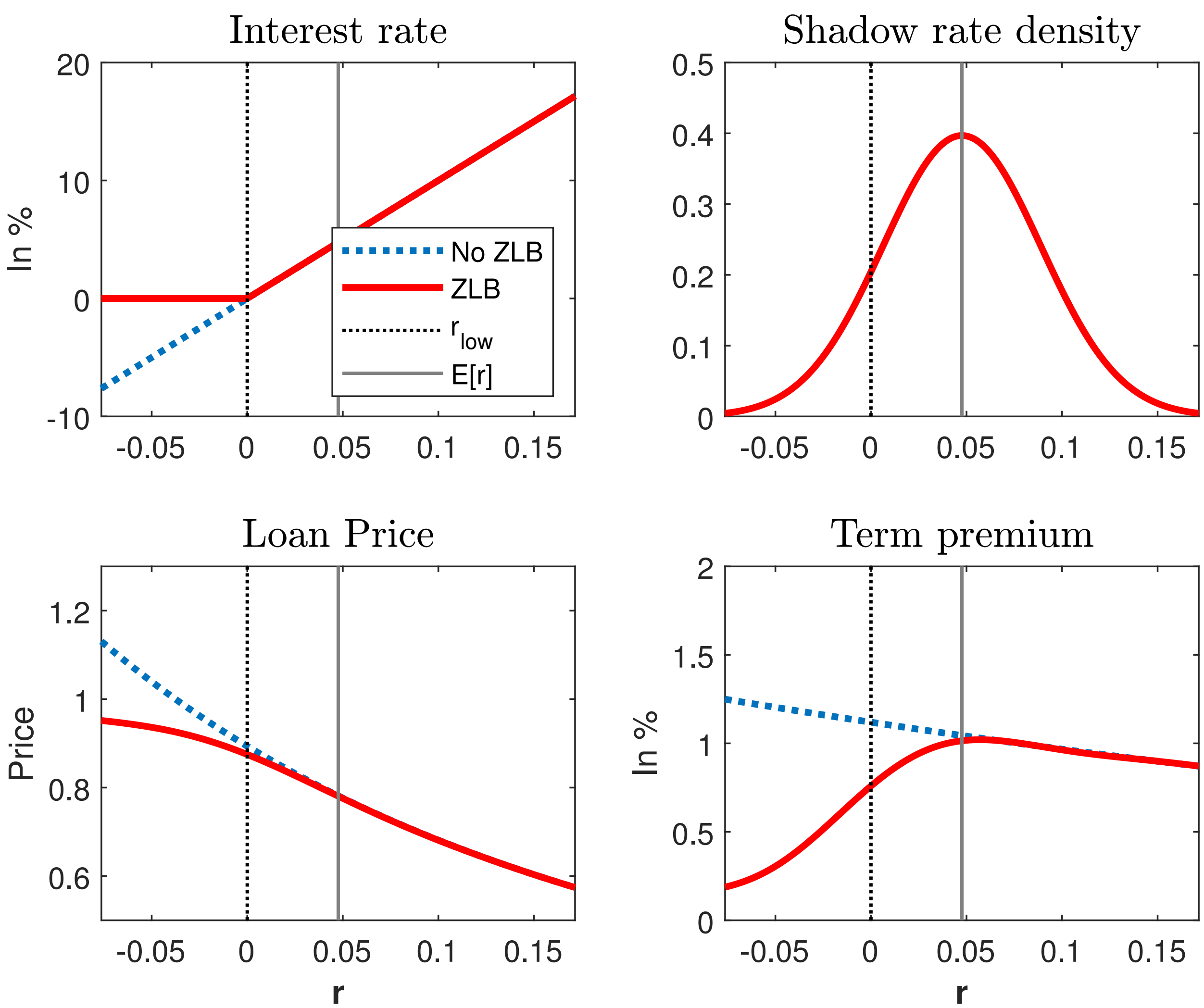
NOTE: This table shows the results of three alternative empirical specifications, reported in Section 3. The dependent variable in all specifications is bank's maturity gap, constructed as in English et al. (2018). Column 1 shows the first specification, that regresses maturity gap on the shadow rate, 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.

TABLE 4. Panel Regression: Risk Taking and Risk Aversion

	(1)			(2)	(3)
	Full sample	Low rate	High rate	Full sample	Full sample
r_t	-1.876***	-1.929***	-0.531	-2.129***	
	[0.180]	[0.322]	[0.408]	[0.228]	
$CAMELS_{i,t} \times r_t$				0.142**	0.131***
				[0.061]	[0.038]
N	148,138	97,980	49,638	148,138	148,138
R^2	0.70	0.74	0.80	0.70	0.74
Sample period	1997q1-2019q4			1997q1-2019q4	1997q1-2019q4
Bank controls	Y			Y	Y
Macro controls	Y			Y	N
Bank FE	Y			Y	Y
Year-quarter FE	N			N	Y

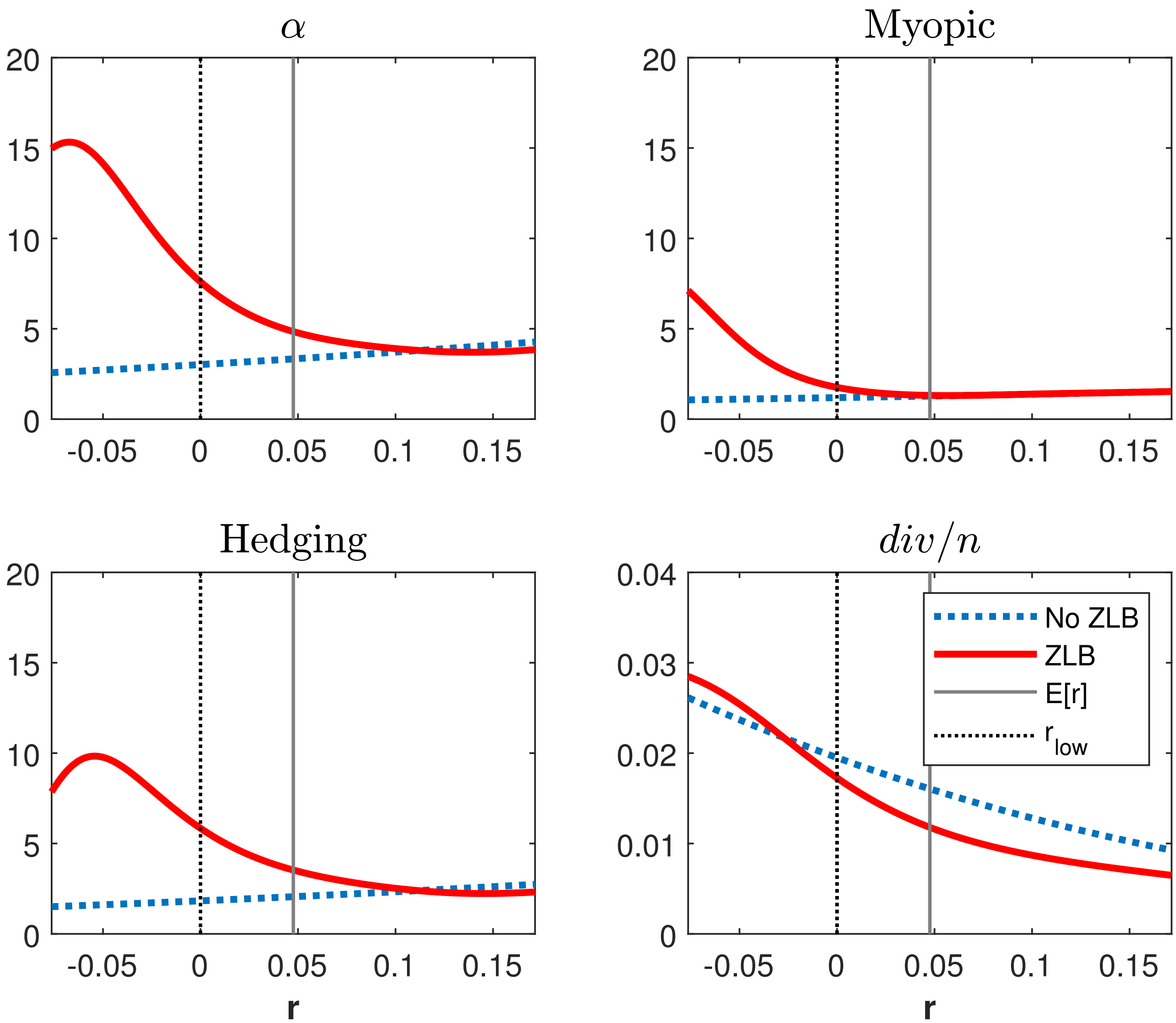
NOTE: This table shows the results of three alternative empirical specifications, reported in Section 3. The dependent variable in all specifications is bank's maturity gap, constructed as in English et al. (2018). Column 1 shows the first specification, that regresses maturity gap on the shadow rate, 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 CAMELS score 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. Interest Rates and Term Premium



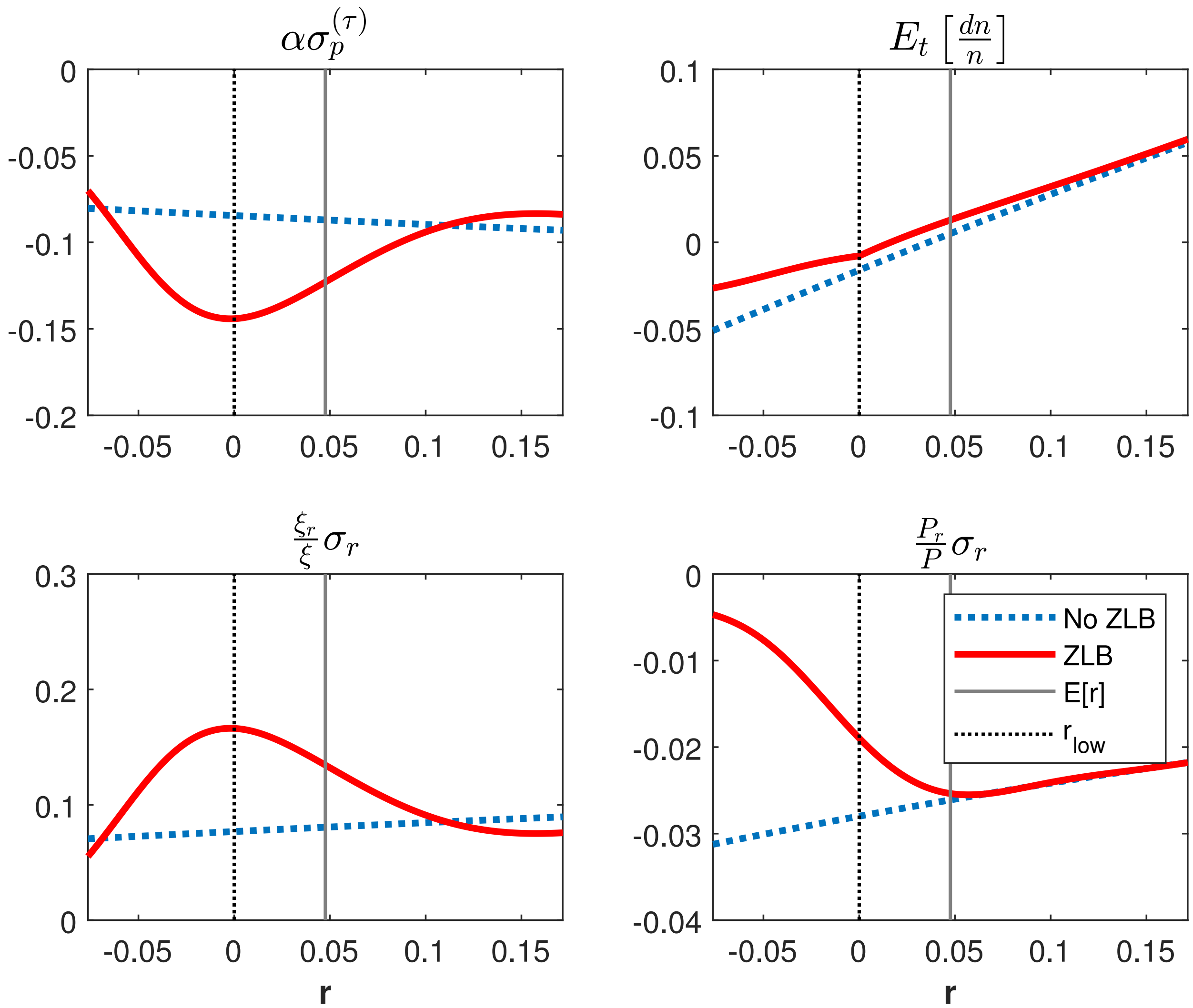
NOTE: This figure shows the model's solution when there is only interest rate risk. The horizontal axis in all panels represents the state space—namely, the shadow rate. The solid red line is the model solution. The dashed blue line is the solution without imposing the zero lower bound. The solid gray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

FIGURE 2. Banks' Optimal Policies



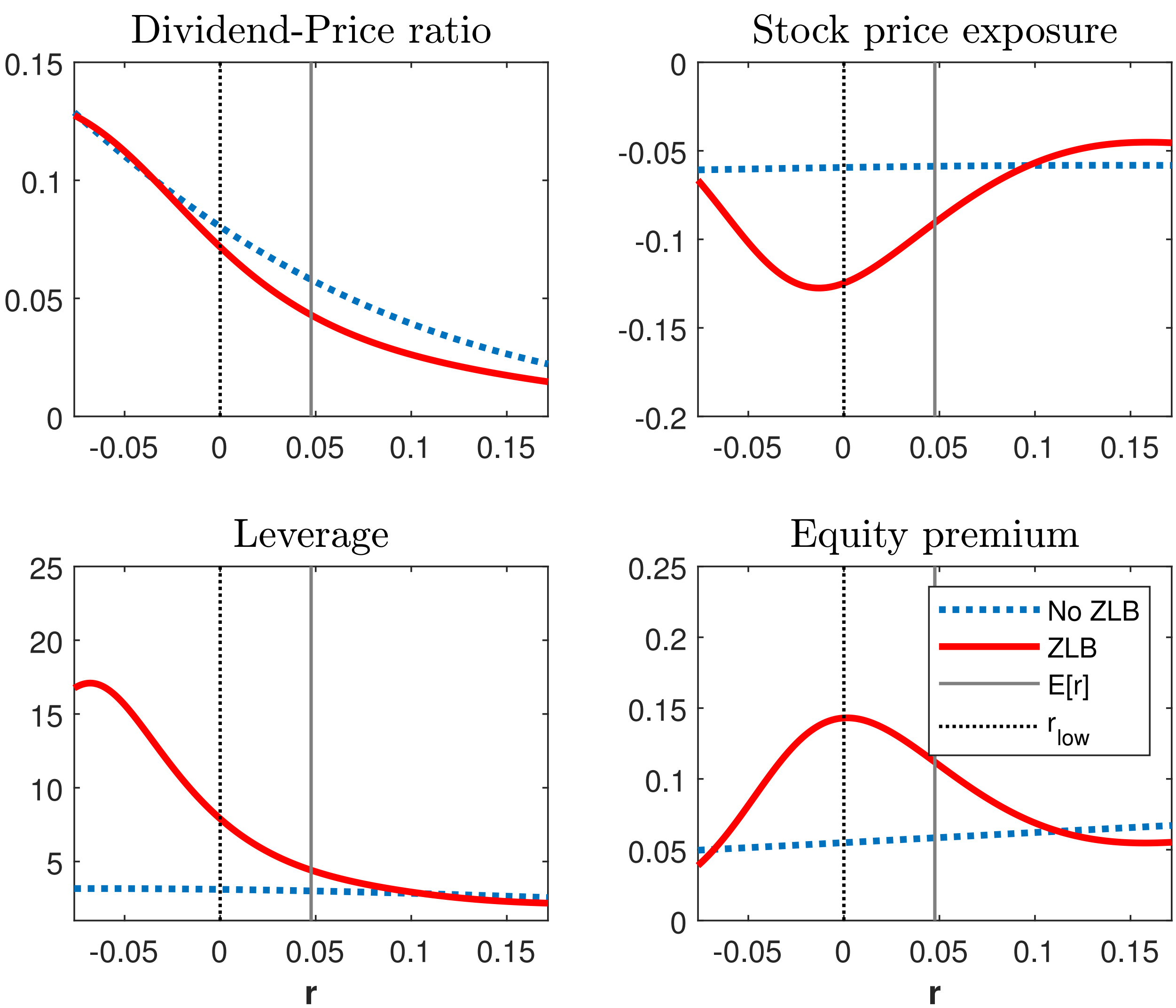
NOTE: This figure shows banks' optimal decisions when there is only interest rate risk. The portfolio share, α, and the myopic and hedging components, are shown in Proposition 1. The solid red line is the solution in the baseline calibration with a zero lower bound (ZLB). The dashed blue line is the 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 3. Banks' Risk Exposures



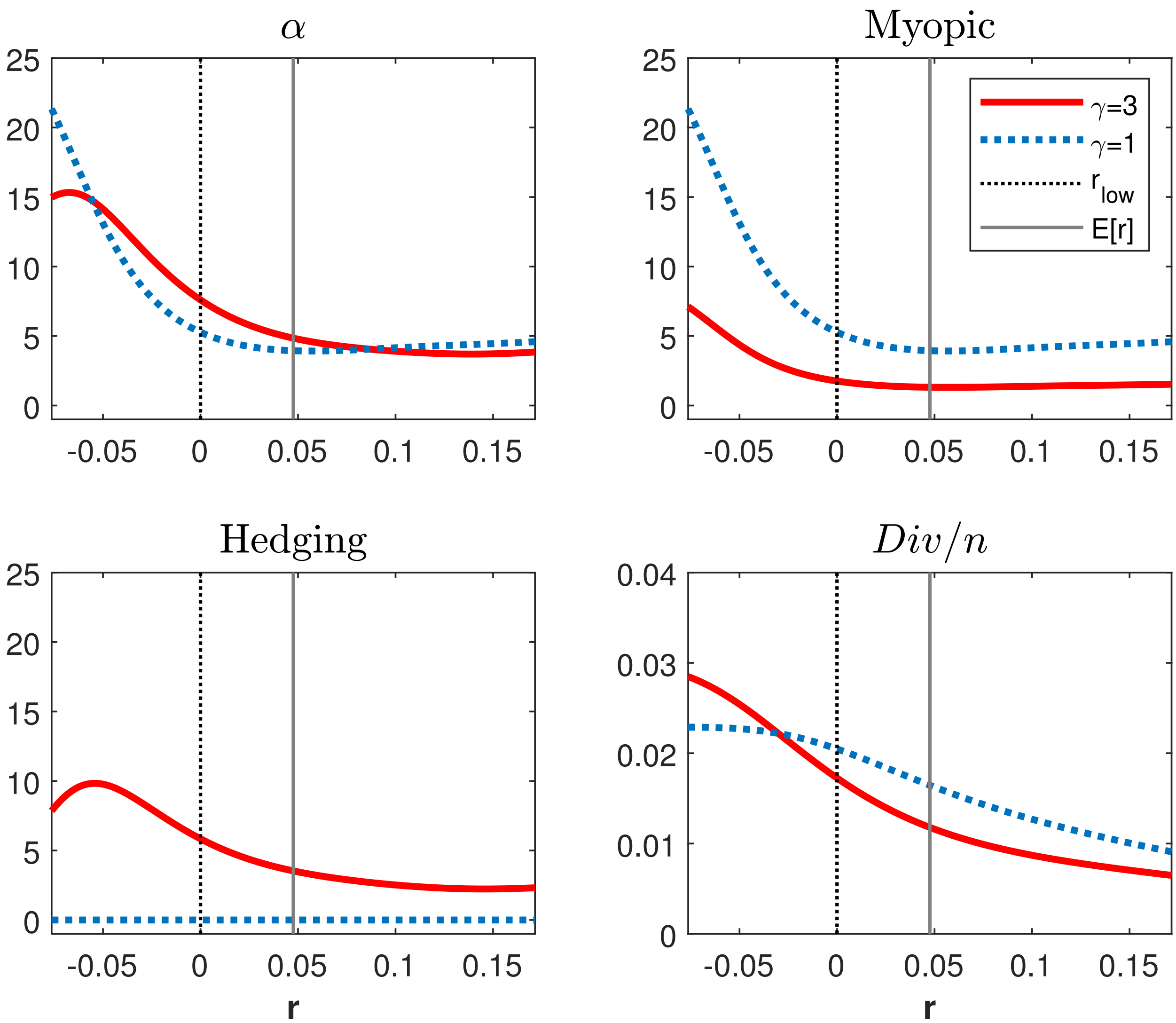
NOTE: This figure shows banks' risk exposures (top-left panel), the expected return on wealth (top-right panel) and a decomposition of the hedging demand between the conditional volatility of the banks' investment opportunity set (bottom-left panel) and the conditional volatility of long-term loans (bottom-right 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 4. Banks' Value



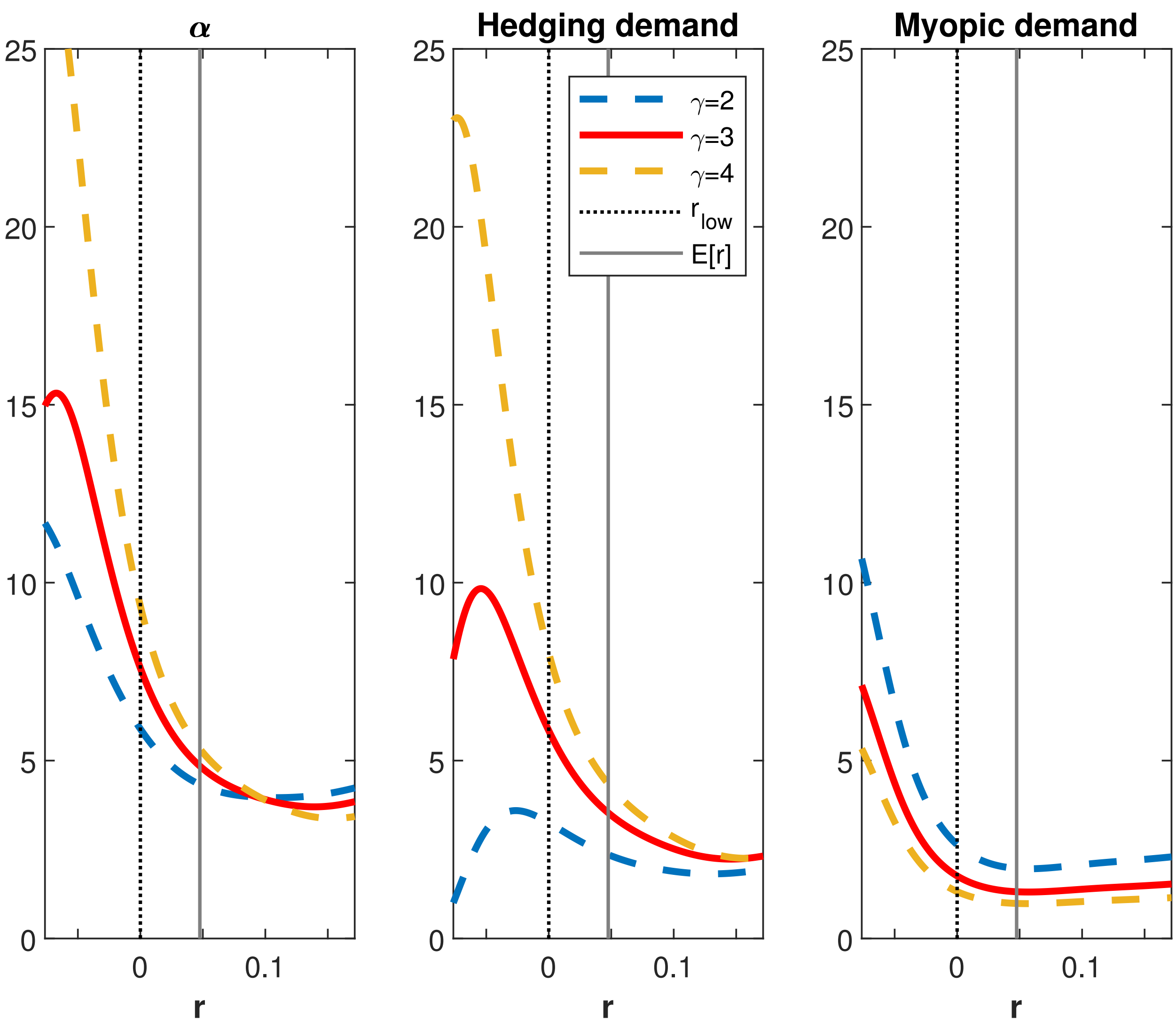
NOTE: This figure shows the banks' dividend-price ratio (top-left panel), the sensitivity of banks' stock prices to an interest rate shock (top-right panel), the banks' leverage (bottom-left panel), and the expected excess return on banks' stock prices (bottom-right panel). The solid red line is the solution in the baseline calibration with a zero lower bound (ZLB). The dotted blue line is the solution without imposing the zero lower bound ZLB. The solid gray line is the unconditional mean of the interest rate, and the dotted-black line is the ZLB.

FIGURE 5. Comparison with Log Preferences



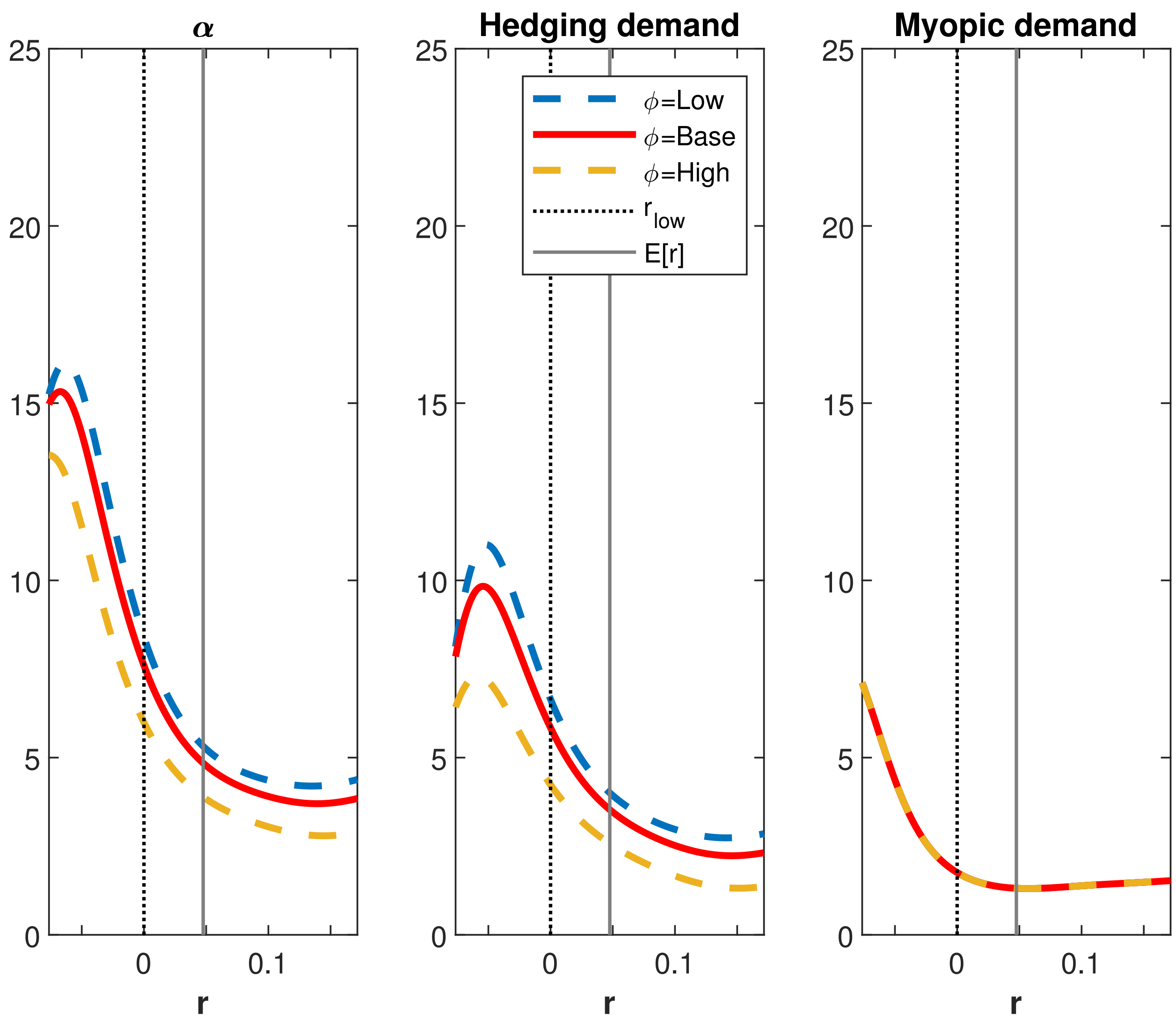
NOTE: This figure shows bank's optimal policies for the baseline risk aversion (i.e., $\gamma = 3$) and the case of $\gamma = 1$.

FIGURE 6. Myopic, Hedging, and α for different risk aversion



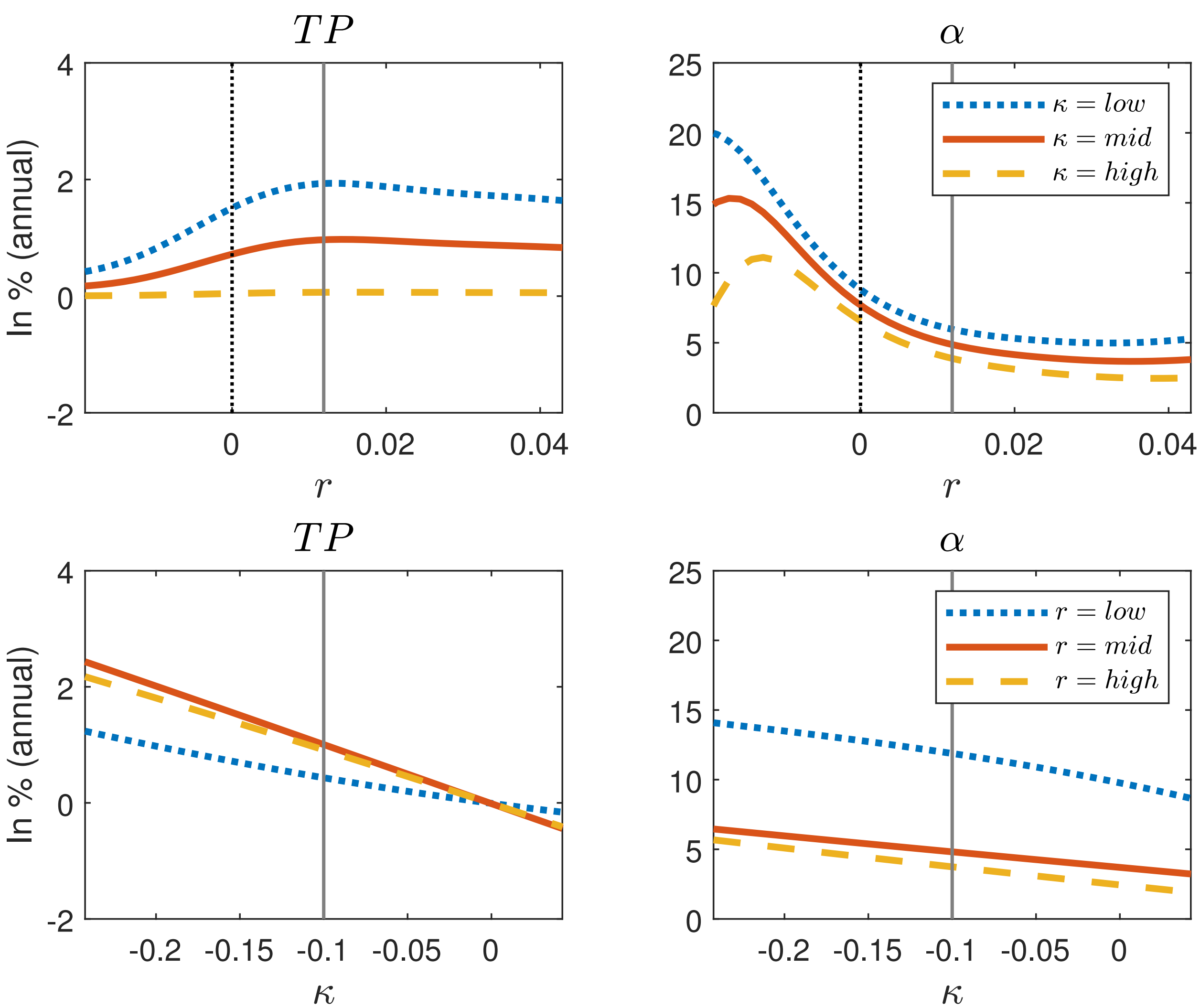
NOTE: This figure shows banks' α (left panel), the myopic demand (middle panel), and the hedging demand (right panel) for different level of risk aversion (γ). The baseline calibration, $\gamma = 3$, is displayed in solid red.

FIGURE 7. Myopic, Hedging, and α for Different Deposit Market Power



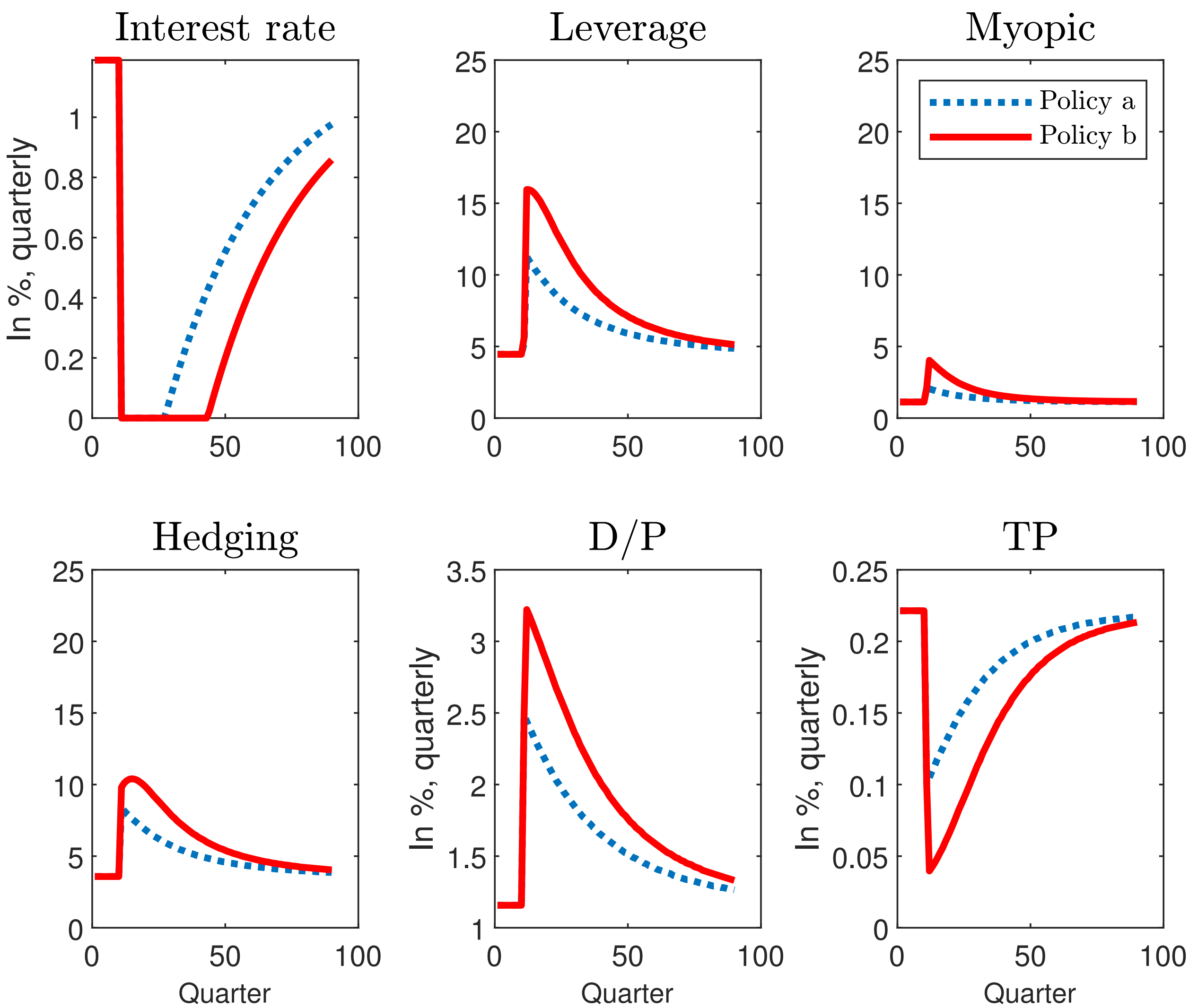
NOTE: This figure shows banks' α (left panel), the myopic demand (middle panel), and the hedging demand (right panel) for different level of deposit market power (ϕ). The baseline calibration, $\phi = 0.15$, is displayed in solid red.

FIGURE 8. Extended Solution



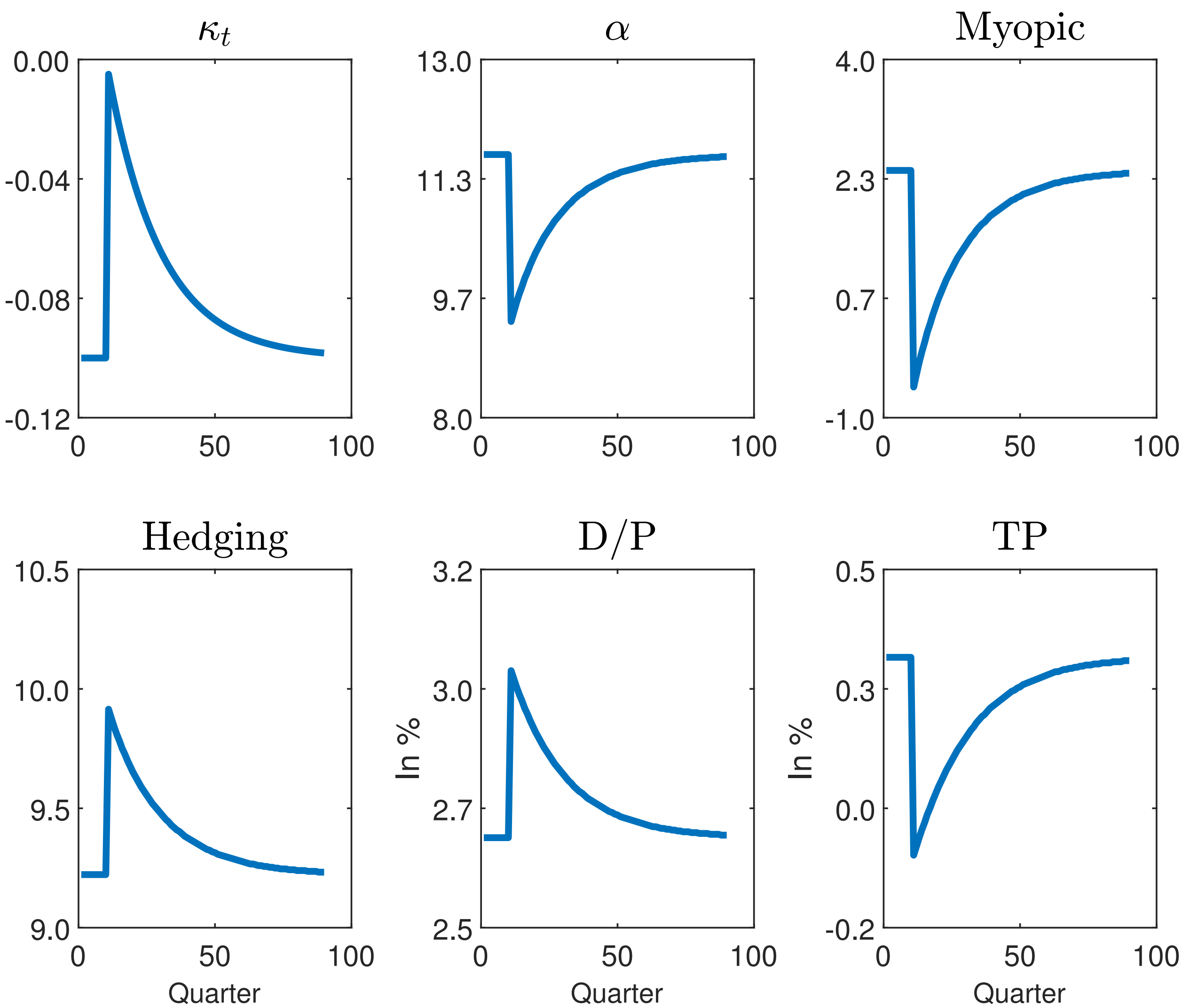
NOTE: This figure shows the solution of the extended model for the term premium (left panels) and α (right panels). The top panels show the solution across the κ_t dimension at different levels of r_t. The bottom panels show the solution across the r_t dimension at different levels of κ_t. The low (high) 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 9. Forward Guidance



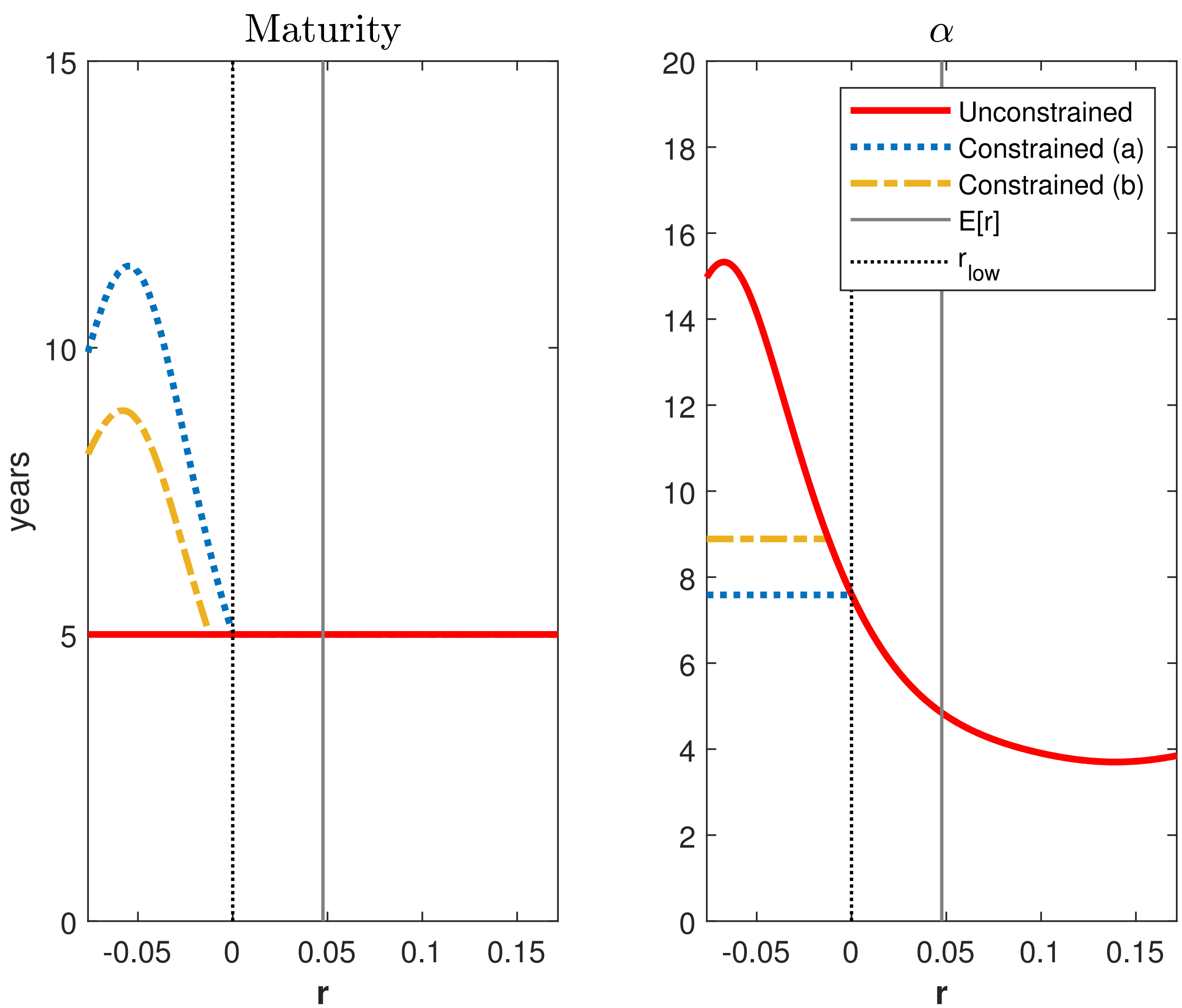
NOTES: This figure shows the impulse-response functions of the model to two alternative paths for the short rate: Policy b remains at the zero lower bound relatively longer.

FIGURE 10. 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 11. Risk Exposure: Maturity Choice versus α



NOTE: This figure shows the maturity of the loan portfolio that matches banks' optimal risk exposure when banks cannot adjust their α beyond a certain point. The left panel shows the chosen maturity, and the right panel shows the α. When banks are unconstrained, they can freely adjust α so they keep the maturity of the loan portfolio fixed at five years. The dotted blue and dashed yellow lines show the chosen maturity (left panel) for different α (right panel).

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7 Appendix

Proof of proposition 1. The first order condition for $\alpha_t^{(\tau)}$, with only interest rate risk is given by

$$\mu^{(\tau)} - \widetilde{r}_t - \alpha_t^{(\tau)} \gamma \left(\sigma_{r,t}^{(\tau)} \right)^2 + (1-\gamma) \frac{\xi_r}{\xi} \sigma_r \sigma_{r,t}^{(\tau)} = 0. \tag{7}$$

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 (7), 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.

Numerical solution. TBA.