Bank Risk-Taking and Impaired Monetary Policy Transmission*

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How does risk-taking affect the transmission of interest rate changes into loan issuance? We study this question in a banking model with agency frictions. The risk-free rate affects bank lending via a portfolio adjustment and a loan risk channel. The former implies that the bank issues more loans when the risk-free rate falls. The latter implies that the bank may issue fewer loans because lower risk-free rates lead to higher risk-taking. Thus, the loan risk channel can counteract the portfolio adjustment channel. There exists a reversal rate, so that loan supply even contracts due to higher risk-taking. The model's implications square with recent evidence on monetary transmission.

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1. Introduction

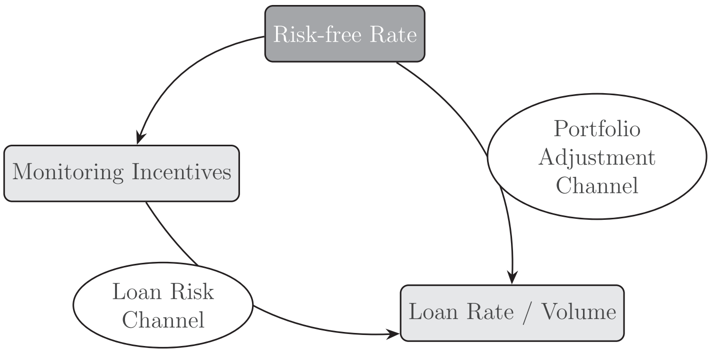
Central banks in several advanced economies have until recently kept their policy rates at historically low levels, often close to the zero lower bound. The extant literature has highlighted two key concerns on interest rate policies in such an environment. First, lower policy rates may induce banks to take more risks, which could pose a threat to financial stability (Borio and Zhu 2012). Second, lower rates could also depress bank profits to the point where banks respond less to additional monetary stimulus (Eggertsson et al. 2019) or even reduce the supply of credit to the economy (Brunnermeier, Abadi, and Koby 2023). Both phenomena have been studied in separate theoretical frameworks, but empirical evidence covering the recent period of low interest rates also suggests a close link between them, which is difficult to reconcile with existing models: the weakening of the transmission of policy rates correlates with an increase in riskier lending (Heider, Saidi, and Schepens 2019; Miller and Wanengkirtyo 2020; Arce et al. 2021).

In the present paper, we ask how such a link between impaired transmission and risk-taking can arise. We show that if deposit rates are bounded below and banks hold a sufficiently large share of fixed-income assets whose return changes with the risk-free rate, higher risk-taking and the impairment of monetary transmission can become “two sides of the same coin.” In particular, if interest rates are at a sufficiently low level, further reductions of interest rates incentivize banks to increase risk-taking, which, in turn, weakens the transmission of policy rates into loan rates and loan volumes.

We consider a purposefully simple model of a penniless banker who uses deposits to fund the issuance of risky loans and the holdings of safe assets, such as bonds or central bank reserves. The banker can exert a monitoring effort to reduce the risk of default of her loan portfolio. Depositors can observe the loan issuance and the safe asset holdings of the banker. However, the monitoring effort is not observable (and hence uncontractible), thus creating an agency problem between the banker and her depositors.

In this setting, we study how changes in the risk-free rate affect loan rates and loan volumes. The transmission of the risk-free rate works via two channels, a direct portfolio adjustment channel and an indirect loan risk channel (see Figure 1).

Figure 1. Direct Portfolio Adjustment Channel and Indirect Loan Risk Channel



The portfolio adjustment channel reflects the conventional view of monetary transmission, which holds that lower risk-free rates are expansionary and translate into more bank lending. As in standard banking models, a lower risk-free rate reduces the return on safe assets and the opportunity cost of loan issuance. The banker, in turn, optimally issues more loans at lower loan rates (Freixas and Rochet 1997).

The indirect loan risk channel arises because changes in the risk-free rate also alter the banker's monitoring incentives, which, in turn, affect the banker's optimal loan issuance.[1] In particular, if monitoring incentives improve, loan risk declines and the banker optimally expands the issuance of loans by lowering the loan rate.

However, the risk-free rate exerts two opposing effects on monitoring incentives, implying that it is a priori not clear whether the loan risk channel amplifies or counteracts the portfolio adjustment channel. On the one hand, a lower risk-free rate reduces the profitability of safe assets and depresses expected profits. This *safe asset effect* worsens monitoring incentives. On the other hand, if the banker can pass on a lower risk-free rate to depositors, profits increase. This *deposit pass-through effect* improves monitoring

[1] We use the term "loan risk channel" to refer to the indirect effect of the risk-free rate on loan issuance via changes in monitoring incentives. Our loan risk channel should be distinguished from the "risk-taking channel," which refers to the direct effect of the risk-free rate on risk-taking incentives (Dell'Ariccia, Laeven, and Marquez 2014).

incentives. Whenever the safe asset effect dominates the deposit pass-through effect, the banker's monitoring incentives worsen, and her risk-taking increases when the risk-free rate becomes lower (and vice versa if the deposit pass-through effect dominates).

We show that the interaction between the portfolio adjustment channel and the loan risk channel can lead to three possible cases depending on the level of the risk-free rate.

First, if the risk-free rate is sufficiently high, the deposit pass-through effect dominates the safe asset effect, and the loan risk channel amplifies the portfolio adjustment channel. Second, for lower values of the risk-free rate, the safe asset effect dominates the deposit pass-through effect. The loan risk channel counteracts the portfolio adjustment channel. The banker still increases her loan issuance when the risk-free rate falls, but the increase in loan risk lessens her loan issuance. Third, if the risk-free rate is sufficiently low, the loan risk channel can even dominate the portfolio adjustment channel. In this case, further reductions in the risk-free rate lead the banker to reduce lending. The critical value below which the loan risk channel dominates the portfolio adjustment channel constitutes a reversal rate, as in Brunnermeier, Abadi, and Koby (2023). Like in their model, a precondition for the existence of a reversal rate is that bank profits decrease in the risk-free rate. In contrast to their model, the reversal rate in our model does not arise due to an exogenous constraint on future bank profits but stems from the agency friction between the banker and her depositors. We derive a simple condition for the occurrence of this "reversal scenario": the loan risk channel dominates the portfolio adjustment channel if the banker reduces her monitoring more than one-for-one in response to a reduction in the risk-free rate.

To simplify the exposition of the key mechanism behind the interaction of risk-taking and monetary policy transmission, we make two assumptions in our baseline model.

First, there is a lower bound on deposit rates; i.e., there exists a minimal return that the banker must offer on deposits for agents to be willing to hold them rather than switch to cash. This assumption reflects the empirical observation that changes in deposit rates become progressively smaller and approach a lower bound when policy rates are lowered towards negative territory (Eggertsson et al. 2019).

Second, the banker always holds a non-negligible amount of assets whose rate of return changes in lockstep with changes in the policy rate. We assume that these are "safe assets" such as central bank reserves, government bonds, or senior tranches of mortgage-backed securities.[2] For the safe asset effect to arise, the banker's expected profit must react sufficiently to changes in the risk-free rate. That is, the banker must be somewhat constrained in reducing her safe assets in order to mitigate (or even to offset completely) the negative effect of a lower risk-free rate on her profits. There are various reasons why banks face such constraints in practice. For example, due to setup and switching costs, deposits are a quasi-fixed factor of production (Flannery 1982; Sharpe 1997). Once banks raise deposit funding before deciding on their loan issuance, deposit and loan volumes are not necessarily completely balanced.[3] As a consequence, deposits in excess of what is required to fund loan issuance may be held as reserves with the central bank or invested in short-term fixed-income securities. In addition, banks face regulatory constraints, such as reserve or liquidity requirements, that force them to cover a certain share of their deposit liabilities with safe and liquid assets, like reserves or government bonds. Moreover, since the financial crisis of 2008/09, central banks have expanded reserves through asset purchase and lending programs beyond what is required by the banking sector in aggregate (Ennis and Wolman 2015; European Central Bank 2017; Bechtel et al. 2021). Under such a regime, individual banks may end up with excess reserves without being able to instantly dispose of reserves via the interbank market (Brandao-Marques et al. 2021).

To simplify the exposition in the baseline model, we follow Acharya and Naqvi (2012) and assume that the banker has a fixed amount of deposits and cannot adjust the "intensive margin" of her deposits. Moreover, we fix the deposit amount such that the banker

[2]We could also allow the banker to invest in risky fixed-income securities, provided that their payoffs are uncorrelated with the payoffs from the bank's loans and that a no-arbitrage condition ensures that their expected return matches the risk-free rate.

[3]In practice, banks often adjust deposit volumes by changing the rate offered on deposits. Empirically, in particular at low rates, rate adjustments and, by extensions, adjustments in deposit volumes, occur rather infrequently (Paraschiv 2013; Jobst and Lin 2016; Döpp, Horovitz, and Szimayer 2022), suggesting an imperfect adjustment between loans and deposits.

is bound to hold more deposits than what she needs to fund her optimal loan issuance. Any residual deposits are invested in safe assets whose return moves in lockstep with the risk-free rate. Put differently, although the banker can trade off loan issuance and safe assets at the margin, she cannot shrink her balance sheet by issuing fewer deposits and disposing of safe assets completely.

We consider several extensions of this baseline model to probe the robustness of its mechanism. First, we analyze the effect of insured deposits on the possibility of transmission reversal. Deposit insurance (if not fairly priced) provides an exogenous subsidy to the banker that increases her profits. As a consequence, deposit insurance mitigates the problem of transmission reversal. In the limit, when all deposits are insured, the reversal rate ceases to exist. Thus, ceteris paribus, a transmission reversal constitutes less of a problem for banks that are funded with a larger share of insured deposits.

Second, we relax the admittedly stark assumption that the banker cannot adjust the intensive margin of her deposits and the size of her balance sheet. Instead, we allow the banker to endogenously choose deposits and safe assets. We consider two variants of the model that both preserve the safe asset effect. In the first, we assume that the bank faces random inflows or outflows to depositors' accounts. These random changes to deposits are matched on the banker's balance sheet by inflows and outflows of central bank reserves. As a consequence, the bank may end up holding excess reserves with a certain probability. This extension illustrates that the presence or absence of the safe asset effect depends on the banker's ability to optimally adjust her safe asset position. In particular, we recover the results in the benchmark model if the probability of a deposit inflow (i.e., ending up with excess reserves) approaches unity, whereas the safe asset effect disappears if the probability of random reserve changes goes to zero. In the second variant, instead of random deposit flows, we assume that the banker faces a liquidity requirement that forces her to hold safe assets equal to a certain share of her deposits (as in Brunnermeier, Abadi, and Koby 2023). In this case, the portfolio adjustment and the loan risk channel always move in the same direction, but both switch signs once the safe asset effect dominates the deposit pass-through effect. The dominance of the safe asset effect becomes a necessary and sufficient condition for the reversal of monetary transmission.

Related Literature. Our paper relates to a large body of literature that analyzes the transmission of monetary policy through the banking sector. The traditional view is that a reduction in policy rates reduces banks' funding cost and induces greater loan supply (Bernanke and Blinder 1988; Bernanke and Gertler 1995; Kashyap and Stein 1995). A variant of this channel is at work in our model, but we show that it can be weakened or amplified by an (a priori) ambiguous indirect loan risk channel that arises from the agency problem between the bank and its depositors.

The loan risk channel connects our paper to the literature on the risk-taking channel of monetary policy (e.g., Dell'Ariccia, Laeven, and Marquez 2014; Martinez-Miera and Repullo 2017). The risk-taking channel refers to the direct effect of interest rate changes on the bank's monitoring incentives. We show how the presence of a lower bound on deposit rates and the presence of safe asset holdings creates a novel variant of the risk-taking channel. However, the focus of our model is on the loan risk channel, i.e., the indirect effect of the risk-free rate on loan issuance via monitoring incentives.

The banks in our model face an agency problem similar to that of Dell'Ariccia, Laeven, and Marquez (2014). In contrast to Dell'Ariccia, Laeven, and Marquez (2014), who focus on the effect of leverage, we adopt the assumption of a fixed deposit volume from Acharya and Naqvi (2012) to concentrate on the effect of monetary policy on the bank's endogenous portfolio adjustment between loans and safe assets. Our model therefore complements Dell'Ariccia, Laeven, and Marquez (2014) in two ways. Firstly, in contrast to their results, even a fully leveraged bank can increase risk-taking in response to a lower policy rate because of the interaction between the deposit pass-through and the safe asset effect. Secondly, the effect of the risk-free rate on loan rates depends on the interaction between the portfolio adjustment and the loan risk channel. This decomposition allows us to show how the transmission of policy rates can become weaker at low levels of the policy rate.[4]

The dependency of monetary transmission on the level of the policy rate connects our paper to the growing literature on monetary

[4]In Dell'Ariccia, Laeven, and Marquez (2014), the total effect of interest rates on loan rates is unambiguously positive, so that a reversal of transmission cannot arise.

policy transmission in a low interest rate environment. Eggertsson et al. (2019) argue that the increasing attractiveness of cash impairs the pass-through to deposit rates when the policy rate approaches the zero lower bound or becomes negative. Brunnermeier, Abadi, and Koby (2023) show the existence of the reversal rate below which further reductions in policy rates lead to an increase in loan rates. Eggertsson et al. (2019) and Brunnermeier, Abadi, and Koby (2023) derive their results by imposing an exogenous net worth constraint that mechanically increases equilibrium loan rates. Darracq Pariès, Kok, and Rottner (2020) study the reversal rate in a general equilibrium model with agency frictions. Their net worth constraint arises because the banker can abscond with deposits. Our model complements these papers by showing how a reversal rate can arise from an agency problem and the bank's risk-taking incentives.

Several recent papers analyze the effects of excess reserves on the determination of the price level (Ennis 2018) or the effect of bank lending (Martin, McAndrews, and Skeie 2016). Our results complement Martin, McAndrews, and Skeie (2016). They argue that reserve holdings do not matter for bank lending in a frictionless economy, but they do so in the presence of balance sheet costs. We show how excess reserves affect lending in the presence of agency frictions.

The implications of our model are in line with empirical observations at low levels of the policy rate, such as a positive relationship between bank profits and policy rates (Ampudia and Van den Heuvel 2022; Wang et al. 2022), or a negative relationship between mortgage rates and policy rates (Basten and Mariathasan 2020; Miller and Wanengkirtyo 2020). Our model suggests an explanation for higher risk-taking at rock-bottom interest rates (Heider, Saidi, and Schepens 2019; Basten and Mariathasan 2020; Bittner, Bonfim, et al. 2021), and shows why the pass-through to loans may weaken specifically for riskier banks (Arce et al. 2021).

2. Model Setup

We consider a bank over two periods, indexed by $t = 0, 1$. The bank is run by a penniless risk-neutral bank owner/manager ("banker"). The banker can obtain deposits from a large number of risk-neutral depositors. The banker decides on the issuance of loans and on the monitoring of her loans. Monitoring entails a private cost for the banker and reduces the riskiness of her loans. Depositors cannot observe the banker's monitoring choice and the banker cannot commit to a certain level of monitoring. The main focus of our analysis is on the transmission of monetary policy to loan rates, the loan volume, and the loan risk. We take the gross risk-free interest rate $r > 0$ as the measure of monetary policy and assume that it can be perfectly controlled by the central bank.

Bank Liabilities. The banker raises deposits in period 0. Deposits are uninsured and depositors must be compensated for the risk that the banker cannot fully repay depositors in period 1.[5] Thus, to attract deposits, the banker must offer a deposit rate, r_D, which, in expected terms, matches the depositors' outside option, $u(r)$.

ASSUMPTION 1. *The depositors' outside option $u(r) \geq r$ is bounded below by $\underline{u}$, i.e., $u(r) = \underline{u}$ for all $r \leq u^{-1}(\underline{u})$. For $r > u^{-1}(\underline{u})$, $u(r)$ is continuously increasing and convex; moreover, $u'(r)$ is continuous at $u^{-1}(\underline{u})$, i.e., $u'(r)$ satisfies* $\lim_{r \downarrow u^{-1}(\underline{u})} u'(r) = 0$.

The lower bound $\underline{u}$ reflects the idea that depositors would switch to other assets, such as non-interest-bearing cash holdings, once the risk-free rate becomes too low. The lower bound is not necessarily equal to zero, as negative rates could still be compensated for in the form of non-pecuniary benefits of deposits, such as the safety and ease of making payments. The lower bound on $u(\cdot)$ is the key assumption needed for the mechanism of our model, whereas the continuity and convexity assumptions are made for the sake of technical tractability and can easily be dropped (see Section 4.3).

To further simplify the exposition of the model, we assume that the banker cannot adjust the "intensive margin" of her deposits. That is, she either raises an amount D or no deposits at all. We relax this assumption in Section 4.2 where we allow the banker to choose deposits endogenously.

ASSUMPTION 2. *The amount of deposits, D, is exogenously given.*

Bank Assets and Monitoring. The banker is a monopolist in the local loan market. The demand for loans in period 0 is described

[5] Section 4.1 considers the effect when the banker also issues insured deposits.

by a demand curve $L(r_L)$, with $L'(r_L) < 0$ and $L''(r_L) \leq 0$, where r_L denotes the gross interest rate the banker charges on loans.

Loans are risky and are repaid in period 1 with probability $q \in (0, 1)$. The banker can exert unobservable monitoring effort to influence the repayment probability of her loans. We assume that monitoring translates one-to-one into the repayment probability, i.e., the banker can choose q directly. Monitoring involves a private cost[6]

$$c(q) = \frac{\kappa}{2} q^2, \quad \text{where } \kappa > 0.$$

Alternatively, the banker can invest in a risk-free asset that yields the gross risk-free return r in period 1. One can think of the risk-free asset as government bonds or reserves held with the central bank.[7] The amount invested in the risk-free asset is denoted by R.

The bank's funding constraint in period 0 is given by

$$R + L = D. \tag{1}$$

The amount invested in the risk-free asset is determined endogenously through the banker's choice of loans as the residual $R = D - L$. Henceforth, we use $\rho \equiv \frac{R}{D} = 1 - \frac{L}{D}$ to denote the share of deposits held in the risk-free asset.

We simplify the exposition of the model by imposing the following assumption on the relationship between loan issuance and the fixed deposit volume.

ASSUMPTION 3. *The elasticity of the loan demand function,* $\eta(r_L) \equiv -\frac{L'(r_L) r_L}{L(r_L)}$, *satisfies*

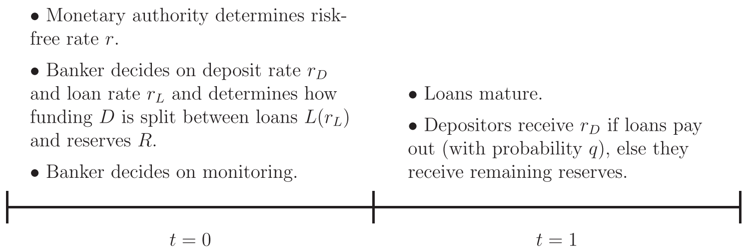
$$\eta(L^{-1}(D)) < 1.$$

Assumption 3 implies that the banker never exhausts her entire funding base to issue loans, but always holds a strictly positive

[6] For analytical tractability, we assume that monitoring costs do not depend on the banker's loan issuance. For example, $c(q)$ may represent setup costs for risk-management systems that, once in place, can be used to process a large number of loans. As we show in Appendix A.2, our results remain qualitatively unchanged if we assume a cost function that scales with the loan volume, $c(q, r_L) = \frac{\kappa}{2} q^2 L(r_L)$.

[7] The asset can be risky as long as its payoffs are not correlated with the bank loan risk and a no-arbitrage condition holds so that the asset's expected return equals the risk-free rate.

Figure 2. Sequence of Events



amount of safe assets. We relax Assumption 3 together with Assumption 2 in Section 4.2.

Sequence of Events and Equilibrium. Figure 2 shows the sequence of events in the model. An equilibrium of the model is given by a loan rate r_L^* and a deposit rate r_D^*, which jointly determine the bank's optimal loan supply, L^*, optimal safe asset holdings, R^*, and the monitoring choice, q^*. The loan rate r_L^* and the monitoring choice q^* maximize the banker's expected profits given the funding constraint (1), while the deposit rate r_D^* ensures depositor participation, given depositors' rational expectations about the bank's monitoring choice.

3. The Portfolio Adjustment and the Loan Risk Channel

Optimal Monitoring Choice. We solve the model backwards by first considering the banker's optimal choice of monitoring and then determining her optimal loan issuance. The banker's expected profits, for given r_L and R, can be written as

$$\Pi = q\left(r_L L(r_L) + rR - r_D D\right) - \frac{\kappa q^2}{2}. \tag{2}$$

The first-order condition for the optimal monitoring choice becomes[8]

$$r_L L(r_L) + rR - r_D D - \kappa \hat{q} = 0. \tag{3}$$

[8] All derivations can be found in the appendix.

Given that depositors rationally anticipate the bank's optimal monitoring choice $\hat{q}$, the interest rate on deposits that ensures depositor participation must satisfy

$$\hat{q}r_D + (1-\hat{q})\frac{rR}{D} \geq u(r). \tag{4}$$

Depositors expect to be paid r_D with probability $\hat{q}$. With converse probability, the bank defaults when loans do not pay out at maturity, and depositors obtain a senior claim over a pro rata share of the remaining safe assets. The expected repayment to the depositors must be at least as large as their outside option $u(r)$. Since the banker's expected profits are strictly decreasing in r_D, condition (4) binds at the optimum, so we can substitute

$$r_D = \frac{u(r) - (1-\hat{q})\frac{rR}{D}}{\hat{q}} \tag{5}$$

into condition (3) and solve for the optimal monitoring choice $\hat{q}$.[9]

LEMMA 1. *The banker's optimal monitoring choice is given by a function $\hat{q}(r_L, r)$ with*

$$\frac{\partial \hat{q}}{\partial r_L}\begin{cases} \geq 0 & \text{if } \frac{\hat{q}r_L - r}{\hat{q}r_L} \leq \frac{1}{\eta(r_L)} \\ < 0 & \text{else} \end{cases} \quad \text{and} \quad \frac{\partial \hat{q}}{\partial r}\begin{cases} \geq 0 & \text{if } u'(r) \leq \rho \\ < 0 & \text{else} \end{cases},$$

where $\eta(r_L) \equiv -L'(r_L)r_L/L(r_L)$ denotes the loan demand elasticity and $\rho \equiv R/D$.

The effects of r_L and r on the optimal monitoring level reflect the effects of these rates on the banker's expected profits. Whenever a marginal increase in these rates raises profits, the banker increases her monitoring and vice versa.

More specifically, a higher loan rate increases monitoring whenever the loan rate r_L is such that the Lerner index, $(\hat{q}r_L - r)/\hat{q}r$, is

[9] The equation that pins down $\hat{q}$ is quadratic and has two solutions. Following Allen, Carletti, and Marquez (2011), we choose the larger of the two roots. Moreover, as Dell'Ariccia, Laeven, and Marquez (2014), we focus on the interior solution where $\hat{q} < 1$ and abstract from the corner solution where $\hat{q} = 1$. There is a sufficiently large range of values for κ such that the interior solution exists.

lower than the inverse loan demand elasticity, $1/\eta(r_L)$, which is the standard condition for the profits of a monopolistic bank to (locally) increase in r_L (Freixas and Rochet 1997).

Whether a lower risk-free rate increases profits and leads to higher monitoring depends on the relative magnitude of two effects. On the one hand, a marginal reduction in the risk-free rate lowers the value of the depositors' outside option and thereby reduces the banker's expected deposit funding costs. This *deposit pass-through effect* increases profits by an amount $u'(r)D$ and incentivizes the banker to increase monitoring. On the other hand, a marginal reduction in the risk-free rate reduces the banker's return on safe assets. This *safe asset effect* reduces profits by R and induces the banker to reduce monitoring. Thus, a lower risk-free rate decreases monitoring if the deposit pass-through effect is smaller than the safe asset effect, i.e., if

$$u'(r)D < R \;\Leftrightarrow\; u'(r) < \rho. \tag{6}$$

Optimal Loan Issuance and Reserve Holdings. Substituting the funding constraint (1), the deposit rate (5), and the banker's optimal monitoring choice $\hat{q}(r_L, r)$ into (2) allows us to rewrite expected profits as

$$\Pi = \underbrace{\hat{q}(r_L, r) r_L L(r_L)}_{\text{Expected earnings on loans.}} + \underbrace{r(D - L(r_L))}_{\text{Earnings on reserves}} - \underbrace{u(r)D}_{\text{Cost of funds}} - \underbrace{\frac{\kappa}{2}\hat{q}(r_L, r)^2}_{\text{Monitoring cost}}. \tag{7}$$

The banker's remaining choice variable is the loan rate r_L. The optimal loan rate, r_L^*, is determined by the standard condition for loan issuance of a monopolistic bank: the Lerner index equals the inverse loan demand elasticity

$$\frac{\hat{q}(r_L^*, r) r_L^* - r}{\hat{q}(r_L^*, r) r_L^*} = \frac{1}{\eta(r_L^*)}. \tag{8}$$

At the optimum point, the elasticity of the loan demand exceeds unity, $\eta(r_L^*) > 1$. Condition (8) takes this particularly simple form because the effect of r_L on $\hat{q}$ can also be expressed in terms of the Lerner index and the inverse demand elasticity (cf. Lemma 1).

Monetary Policy Transmission. Monetary policy actions that change the risk-free rate affect the banker's optimal loan rate (and therefore the loan volume) through a *portfolio adjustment channel* and a *loan risk channel:*

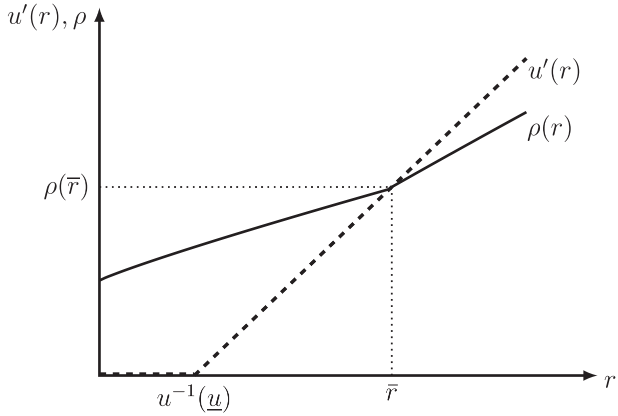
$$\frac{dr_L^*}{dr} = \underbrace{\overbrace{\frac{\partial r_L^*}{\partial r}}^{(+)}}_{\substack{\text{portfolio adjustment}\\\text{channel}}} + \underbrace{\overbrace{\frac{\partial r_L^*}{\partial q}}^{(-)} \times \overbrace{\frac{\partial \hat{q}(r_L^*, r)}{\partial r}}^{(+)/(-)}}_{\text{loan risk channel}}. \tag{9}$$

The conventional view of monetary policy transmission holds that a lower risk-free rate is expansionary because it induces an increase in bank loan issuance. The portfolio adjustment channel reflects this conventional transmission of monetary policy. Effectively, the banker solves an optimal portfolio problem by allocating her funds between two investment opportunities (loans and safe assets).[10] Given $\hat{q}$, a lower risk-free rate reduces the opportunity cost of investing in loans rather than safe assets. As a consequence, the banker optimally reduces the loan rate and increases the amount of loan issuance.

In contrast to the portfolio adjustment channel, the effect of the loan risk channel is ambiguous: it can either amplify or dampen the portfolio adjustment channel. To understand the intuition behind the workings of the loan risk channel, note that, ceteris paribus, a lower success probability increases the loan rate and reduces the amount of loan issuance, i.e., $\partial r_L^*/\partial q < 0$. The reason is that the bank optimally reacts to a lower success probability by increasing the loan rate in order to keep the expected marginal benefit from issuing an additional loan equal to the risk-free rate that it earns on safe assets (cf. Equation (8)). Thus, whenever the safe asset

[10] Since the volume of deposits is fixed, the optimal loan rate is independent of the costs of deposits as in the textbook version of a monopolistic bank with separable loan and deposit choices (Freixas and Rochet 1997). In Section 4.2, we show two variants of the model where the banker can choose the deposit volume.

Figure 3. Required Marginal Deposit Rate, $u'(r)$, and Reserves-Deposit Ratio, ρ



Note: To the right (left) of $\overline{r}$, the loan risk channel amplifies (weakens) the portfolio adjustment channel, as can be seen from the change in the slope of the red curve at $\overline{r}$.

effect dominates, a reduction in the risk-free rate reduces monitoring, $\partial\hat{q}/\partial r > 0$, and the loan risk channel counteracts the portfolio adjustment channel, thus weakening monetary transmission.

Proposition 1. *For a sufficiently small risk-free rate, the safe asset effect dominates the deposit pass-through effect and the loan risk channel weakens the transmission of monetary policy via the portfolio adjustment channel, i.e., there exists $\overline{r}$ such that*

$$r < \overline{r} \Rightarrow \frac{\partial \hat{q}}{\partial r} > 0. \tag{10}$$

Figure 3 illustrates Proposition 1. Note that the lower bound on $u(r)$ implies that for $r < u^{-1}(\underline{u})$, the deposit pass-through becomes fully impaired, i.e., $u'(r) = 0$. At this level of the risk-free rate, the banker is unable to pass a lower risk-free rate through to her depositors and she becomes unable to further reduce her expected funding costs. The dashed curve in Figure 3 shows the marginal required deposit rate, $u'(r)$, which becomes flat below $u^{-1}(\underline{u})$ when the pass-through is fully impaired. However, by Assumption 3, the banker always holds a strictly positive level of reserves, even at low risk-free rates below $u^{-1}(\underline{u})$. Thus, the safe asset effect dominates the deposit pass-through effect whenever the risk-free rate falls below $\overline{r} > u^{-1}(\underline{u})$. The solid curve shows the ratio of safe assets to deposits, evaluated at the optimal loan rate, $\rho(r) = 1 - L(r_L^*(r))/D$. For r above the critical value $\overline{r}$, the loan risk channel amplifies the portfolio adjustment channel. Below the critical value $\overline{r}$, a lower risk-free rate reduces the banker's monitoring incentives, and the loan risk channel weakens the portfolio adjustment channel.[11] The slope of the ratio of safe assets to deposits becomes less steep when $r < \overline{r}$. The reason is that, due to the counteracting loan risk channel, the interest rate reduction required to achieve a given reduction in safe assets (a given increase in loan issuance) becomes larger.

Reversal of Monetary Transmission. The loan risk channel may not only weaken the portfolio adjustment channel; it can also dominate it. In this case, a lower risk-free rate leads to an *increase* in the loan rate and a *reduction* in the bank's loan supply.

PROPOSITION 2. *The loan risk channel dominates the portfolio adjustment channel, i.e.,* $\frac{dr_L^*}{dr} < 0$*, if and only if*

$$\frac{\partial \hat{q}(r_L^*, r)}{\partial r} \frac{r}{\hat{q}(r_L^*, r)} > 1. \tag{11}$$

To understand the intuition behind Proposition 2, recall that, on the one hand, a lower success probability makes loan issuance relatively less profitable compared to holding safe assets, implying that the bank cuts back its loan issuance when q is lower. On the other hand, a lower risk-free rate reduces the return on safe assets and makes holding safe assets less profitable. If the reduction in the risk-free rate lowers the success probability and the profitability of loans by more than the profitability of reserves, the bank prefers to hold more safe assets, despite the lower risk-free rate. However, for the profitability of loans to fall by more than the profitability of safe

[11] Observe that condition (10) is only a sufficient condition. It does not rule out the possibility that the safe asset effect dominates the deposit pass-through effect at a higher level of the risk-free rate (above $\overline{r}$). Whether such a case can arise depends on the other properties of $u(r)$ and $L(r_L)$, such as the curvature or magnitude of its rate of change.

assets, the banker's monitoring must react strongly enough, i.e., a reduction in r must lead to an overproportional reduction in $\hat{q}$.

PROPOSITION 3. *If monitoring costs are sufficiently high, then the loan risk channel dominates the portfolio adjustment channel if the risk-free rate becomes sufficiently low: that is, for* $\kappa > \underline{\kappa}$*, there exists a critical value* $\hat{r} < \bar{r}$ *such that*

$$r < \hat{r} \Leftrightarrow \frac{dr_L^*}{dr} < 0.$$

The critical value $\hat{r}$ *is strictly increasing in the bank's monitoring cost* κ*.*

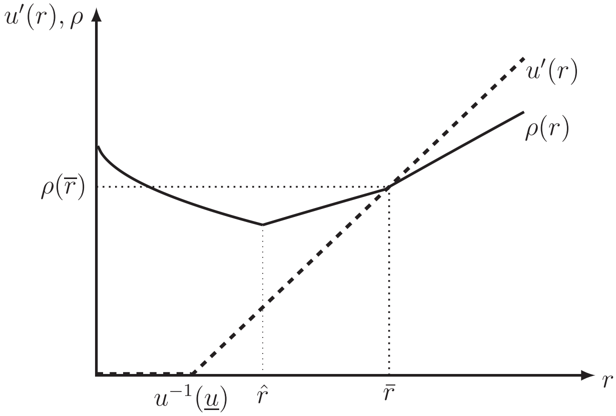
Proposition 3 translates the condition in Proposition 2 into a critical value for the risk-free rate. In particular, whenever the monitoring costs are sufficiently high and the risk-free rate falls below the critical rate, the elasticity of $\hat{q}$ becomes sufficiently large so that the loan risk channel becomes the dominant transmission channel of monetary policy. As in Brunnermeier, Abadi, and Koby (2023), below $\hat{r}$, reductions in the risk-free rate are contractionary rather than expansionary and $\hat{r}$ constitutes a *reversal rate.*

Figure 4 illustrates Proposition 3. As in Figure 3, it plots the required marginal deposit rate $u'(r)$ (dashed curve) against the ratio of safe assets to deposits, ρ (solid curve). However, in Figure 4, we assume that $\kappa > \underline{\kappa}$, so that the reserves-deposit ratio becomes downward sloping for values of r below the reversal rate $\hat{r}$. Since the reversal rate is equal to the point at which the loan risk channel just offsets the portfolio adjustment channel, it follows that the reversal rate must be strictly below the threshold $\bar{r}$.

Figure 5 summarizes our results by illustrating how the transmission of *changes* in the risk-free rate in our model depends on the prevailing *level* of the risk-free rate.

Our analysis complements Brunnermeier, Abadi, and Koby (2023) by showing that a reversal rate can arise as a consequence of banks' risk-taking behavior. The reversal rate in their model arises due to a binding exogenous constraint on future profits, whereas the reversal in our model is a consequence of the banker's endogenous risk choice that only exists if the banker increases her risk-taking sufficiently strongly in response to a change in the risk-free rate. The

Figure 4. Reversal of Transmission when $\boldsymbol{\kappa} > \overline{\boldsymbol{\kappa}}$



Note: For $r \in (\hat{r}, \overline{r})$, the loan risk channel weakens the portfolio adjustment mechanism. For $r < \hat{r}$, the loan risk channel dominates and monetary transmission reverses.

Figure 5. Monetary Transmission and the Risk-Free Rate

transmission reversal	weakened transmission	strong transmission
$\frac{r}{\hat{q}}\frac{\partial \hat{q}}{\partial r} > 1,\ \frac{dL^*}{dr} < 0$	$0 < \frac{r}{\hat{q}}\frac{\partial \hat{q}}{\partial r} < 1,\ \frac{dL^*}{dr} > 0$	$\frac{r}{\hat{q}}\frac{\partial \hat{q}}{\partial r} < 0,\ \frac{dL^*}{dr} > 0$

$\hat{r}$ $\overline{r}$

Note: The transmission of *changes* in the risk-free rate depends on the prevailing *level* of the risk-free rate. For $r > \overline{r}$, a lower risk-free rate, r, reduces risk-taking and raises loan issuance. For $r \in [\hat{r}, \overline{r}]$, a lower r raises risk-taking and weakens loan issuance. For $r < \hat{r}$, risk-taking is too strong and transmission into loans reverses.

reversal rate in our model is just the most extreme manifestation of the more general phenomenon that the loan risk channel weakens monetary transmission for sufficiently low risk-free rates.

Implications of the Model. We use Propositions 1 and 3 to derive several testable implications from our model.

HYPOTHESIS 1. *An increase in the banker's exogenous deposit funding is associated with*

- *higher safe asset holdings, higher loan rates, and a lower loan volume;*
- *higher bank risk-taking;*
- *weaker monetary policy transmission.*

Hypothesis 1 follows because an increase in the deposit volume strengthens the safe asset effect compared to the deposit pass-through effect. As a consequence, the threshold $\bar{r}$ increases, and the range of policy rates at which the loan risk channel weakens the transmission via the portfolio channel becomes larger.

Hypothesis 1 is in line with recent empirical findings of Jimenez et al. (2012), Miller and Wanengkirtyo (2020), and Bittner, Rodnyansky, et al. (2021). Note first that an increase in deposits leads to an increase in safe asset holdings, e.g., in the form of excess reserves with the central bank or government bonds. Jimenez et al. (2012) show that banks with more liquidity on their balance sheet expand the issuance of loans less after a rate cut. However, they do not distinguish between required reserves and excess reserves. Miller and Wanengkirtyo (2020) show that, following a reduction in the policy rate, banks with larger excess reserves extend lending to riskier borrowers. Bittner, Rodnyanski, et al. (2021) further provide evidence that in the presence of a zero lower bound on deposit rates, banks that depend more on deposit funding and have greater exposure to large-scale asset purchases lend relatively less and increase their risk-taking more.

Hypothesis 2. *The reversal rate is larger if, ceteris paribus,*

- *the bank has more deposits;*
- *the bank is riskier, and its loan portfolio is more costly to monitor.*

Hypothesis 2 follows from the effects of leverage, and the monitoring cost parameter, κ, on the reversal rate $\hat{r}$ (cf. Proposition 3). Higher deposits (and a larger cost parameter κ) exacerbate the agency conflict and increase the banker's risk-taking incentives. Since higher risk-taking raises the loan rate for any value of r, the reversal rate (at which the loan risk channel offsets the portfolio channel) also increases.

Hypothesis 2 is in line with recent evidence by Arce et al. (2021), who show that a negative correlation between policy rate and loan rates can be found for banks that are poorly capitalized and whose lending is riskier. Similarly, Basten and Mariathasan (2020) and Miller and Wanengkirtyo (2020) find that lower policy rates are negatively correlated with mortgage rates, but not with interest rates on other types of loan. Hypothesis 2 is consistent with these findings to the extent that mortgage handling is relatively more costly than the origination and handling of other types of loans.

4. Extensions and Discussion

4.1 Insured Deposits

In this section, we consider how deposit insurance alters the transmission of monetary policy via portfolio adjustment and loan risk channels and the possibility of a transmission reversal. Suppose that a share $\delta \in [0, 1]$ of deposits is insured at a flat rate normalized to zero. For simplicity, insured depositors have the same outside option as uninsured depositors.[12]

As before, we solve the model backward by first deriving the banker's optimal monitoring choice and thereafter the optimal loan rate. The first-order condition for the monitoring choice is as in Equation (3), except that we replace the deposit rate r_D with the average deposit rate $\bar{r}_D$ which depends on the share of insured deposits. As uninsured depositors rationally anticipate bank monitoring $\hat{q}$, the average deposit rate is[13]

$$\bar{r}_D = \frac{(\delta\hat{q} + 1 - \delta)u(r) - (1 - \delta)(1 - \hat{q})\frac{rR}{D}}{\hat{q}}.$$

Substituting $\bar{r}_D$ into Equation (3) implicitly defines the banker's optimal monitoring $\hat{q}(r_L, r, \delta)$. Importantly, the condition for $\hat{q}$ to increase in r is the same as in Lemma 1,

[12] Our results remain qualitatively unchanged if insured and uninsured depositors have different outside options. We discuss this case in Appendix A.3.

[13] For simplicity, we assume that, after default at maturity, the bank's cash flows from reserves are split on a pro rata basis among all depositors, insured and uninsured.

$$\frac{\partial \hat{q}(r_L, r, \delta)}{\partial r} > 0 \Leftrightarrow u'(r) < \rho.$$

An increase in δ increases monitoring: $\frac{\partial \hat{q}}{\partial \delta} > 0$. This "charter value effect" of deposit insurance is described in Cordella, Dell'Ariccia, and Marquez (2018). Because the deposit rate is given when the banker chooses her monitoring, a higher share of insured deposits amounts to a greater implicit subsidy from the deposit insurance, thereby reducing the repayments to depositors and increasing the banker's profits. As a consequence, higher deposit insurance coverage strengthens monitoring incentives.[14]

The banker's expected profit takes the same form as before in Equation (7) except that the implicit subsidy from funding with a share δ of insured deposits is added. Substituting the average deposit rate and the optimal monitoring choice into the expected profits yields

$$\Pi = \hat{q}(r_L, r)L(r_L) + rR - (u(r)D) - \frac{\kappa \hat{q}(r_L, r)^2}{2} + S(\delta, r_L, r, R),$$

where $S(\delta, r_L, r, R) \equiv \delta(1 - \hat{q}(r_L, r, \delta))(u(r)D - rR)$ is the implicit subsidy from the deposit insurance. The subsidy is equal to the part of insured deposit funding costs that has to be covered by the deposit insurance in case of bank default. As can be seen from the expression for $S(\cdot)$, an increase in R reduces the implicit subsidy. This is because the deposit insurance can rely on a larger amount of safe assets to cover (part of) its liabilities in case the loans fail.

The transmission of monetary policy works as before through the portfolio adjustment and loan risk channels. Since optimal monitoring increases in the risk-free rate whenever the safe asset effect dominates the deposit pass-through effect, the condition for the loan risk channel to weaken monetary transmission remains formally the same as in the benchmark model with $\delta = 0$.

However, the presence of insured deposits changes the relative importance of the portfolio adjustment and loan risk channels in the transmission of monetary policy.

[14] Cordella, Dell'Ariccia, and Marquez (2018, Proposition 1) show that the charter value effect occurs if the share of deposit liabilities that are priced "at the margin" is sufficiently small. This is the case for our specification because we abstract from such deposits entirely.

Proposition 4. *Given a share δ of insured deposits, the loan risk channel dominates the portfolio adjustment channel, i.e., $\frac{dr_L^*}{dr} < 0$, if and only if*

$$\frac{\partial \hat{q}(r_L^*, r, \delta)}{\partial r} \frac{r}{\hat{q}(r_L^*, r, \delta)} > 1 + \frac{\hat{q}(r_L^*, r, \delta)\delta}{1-\delta}.$$

Comparing Propositions 2 and 4 shows that the condition for the dominance of the loan risk channel is stronger when the banker is funded with insured deposits. The reason is that the banker obtains a larger implicit subsidy from deposit insurance when she holds fewer safe assets. This asset substitution motive provides an additional incentive for the banker to increase her loan issuance when the risk-free rate falls. Thus, deposit insurance strengthens the portfolio channel and alleviates the problem of transmission reversal. Simply put, the deposit insurance subsidy mitigates the adverse effect of lower rates on the bank's profitability by increasing its profits.

Hypothesis 3. *The reversal rate $\hat{r}$ is smaller for banks that are funded with a larger share of insured deposits. In the limit for $\delta \to 1$, the reversal rate ceases to exist.*

4.2 Endogenous Deposit Choice, Deposit Shocks, and Liquidity Requirements

In this section, we briefly discuss the consequences of relaxing Assumptions 2 and 3 for our main results. In the benchmark model, the fixed amount of deposits (Assumption 2) determines the bank's balance sheet length and Assumption 3 implies that the bank holds a strictly positive amount of safe assets whose rate of return, in contrast to the loan rate, cannot be controlled by the banker. These assumptions ensure that the banker is exposed to the safe asset effect so that reductions in the risk-free rate can reduce her expected profits and lead to higher risk-taking and lesser loan issuance.

We now dispense with Assumption 2, i.e., we allow the banker to endogenously choose the amount of deposits and we consider two alternatives to Assumption 3. Under both alternatives, the banker continues to be exposed to the safe asset effect. First, we consider exogenous liquidity shocks to deposits, i.e., exogenous inflows and outflows to and from the depositors' accounts that randomly change the bank's end-of-period safe asset holdings. Second, we consider an exogenously imposed liquidity requirement, akin to the Basel regulations' liquidity coverage ratio (LCR).

It is worth pointing out that in the absence of these or other alternative assumptions, the banker in our model would have no incentives to hold safe assets. Absent the safe asset effect, the loan risk channel would always work into the same direction as the portfolio adjustment channel.

Deposit Shocks. We begin by considering a variant of the model where the bank can choose its deposits at the beginning of date 0. However, depositors are subject to a liquidity shock at the start of date 1, i.e., they face inflows and outflows to and from their deposit accounts. We assume that the bank cannot invest additional deposits in $t = 1$ into loans so that deposit flows must be balanced by an equivalent change in safe assets.[15]

To rule out precautionary motives for holding safe assets, we assume that the bank can access the central bank's standing deposit and lending facilities at an interest rate r to deposit excess reserves or to cover deposit outflows and reserve shortfalls.[16]

Furthermore, we assume that the bank can also borrow ex ante from the central bank up to a fraction $\sigma \in (0, 1)$ of its loan issuance, i.e., we impose $R \geq -\sigma L$.

Liquidity shocks, denoted x, are proportional to deposits, D, and are drawn from a continuous distribution $F(\cdot)$ and with density $f(\cdot)$ over support $[-1, z]$. zD is the maximal inflow to an individual deposit account. We assume that the liquidity shocks realize after the bank has contracted the deposit rate, set its loan rate, and has chosen the optimal monitoring effort. Without loss of generality, we set $\mathbf{E}[x] = 0$.

As before, we solve the model backwards. Given r_D, the optimal monitoring of the bank is still determined by Equation (3). The random inflows and outflows to deposit accounts affect the deposit cost

[15] Inflows to deposit accounts automatically add to the bank's central bank reserves. Outflows from deposit accounts need to be covered by running down reserves or by additional borrowing from the central bank.

[16] Allowing for a symmetric interest rate corridor around the main policy rate by making the standing borrowing rate higher than the standing deposit rate would complicate our analysis without altering the main results.

of the bank. In particular, if the bank is solvent, depositors receive r_D on their entire deposit holdings at maturity. With probability $1 - q$, the bank defaults. In this case, depositors obtain a pro rata share of the remaining assets. The expected repayment to depositors must be equal to their outside option $u(r)$ such that

$$r_D = \frac{u(r) - \frac{(1-\hat{q})r \int_{-1}^{z} \max\{R+xD,0\} dF(x)}{D}}{\hat{q}}. \tag{12}$$

By substituting r_D into Equation (3), we can solve for the bank's monitoring choice $\hat{q}(r_L, D; r)$. The partial effects of r_L, r, and D on the banker's optimal monitoring $\hat{q}$ reflect the effects of these variables on her expected profits. As before, the effects of r_L and r are ambiguous, with the respective conditions now taking into account expected deposit flows.[17] However, the effect of D on $\hat{q}$ is unambiguously negative, i.e., $\frac{\partial \hat{q}}{\partial D} < 0$. This is because $u(r) \geq r$ so deposits are relatively more expensive than borrowing from the central bank (cf. Assumption 1).

LEMMA 2. *The bank chooses a strictly positive loan issuance $L^*(r)$. Given Assumption 1, the bank minimizes its funding cost by choosing $R^* = -\sigma L^*$ and $D^* = (1 - \sigma)L^*$.*

Lemma 2 shows that the bank borrows from the central bank on a permanent basis as long as this is feasible (i.e., if $\sigma > 0$). Even though the bank does not hold a positive level of reserves ex ante, the possibility that it ends up with a positive reserve balance due to random deposit inflows implies that the loan risk channel can still mitigate and even dominate the portfolio channel.

PROPOSITION 5. *The loan risk channel dominates the portfolio adjustment channel, i.e., $\frac{dr_L}{dr} < 0$, if and only if*

$$\frac{\partial \hat{q}(r_L^*, r)}{\partial r} \frac{r}{q(r_L^*, r)} > 1 + \frac{\hat{q}(r_L^*, r) F\left(\frac{\sigma}{1-\sigma}\right)}{1 - F\left(\frac{\sigma}{1-\sigma}\right)}. \tag{13}$$

[17] See the appendix for details.

As Proposition 5 shows, the condition for the loan risk channel to dominate the portfolio adjustment channel is similar to condition (11) when deposits are exogenous. The difference is that condition (13) depends on the probability that the bank ends up with safe asset holdings due to inflows into its depositors' accounts.

Inflows to deposits reflect the amount of safe assets that the bank cannot adjust optimally ex ante. Therefore, the probability of ending up with a positive balance can be interpreted as a measure of the ease with which the banker can adjust her safe assets. At one extreme, if the probability of an inflow of deposits becomes negligibly small, $F(\sigma/(1-\sigma)) \approx 1$, then condition (13) could never hold. In this case, the loan risk channel and the portfolio adjustment channel always go in the same direction and a reversal rate cannot exist. As is the case for a fully levered bank in Dell'Ariccia, Laeven, and Marquez (2014, Proposition 3), a lower risk-free rate leads to less risk-taking. On the contrary, if the bank would almost surely obtain a deposit inflow, i.e., $F(\sigma/(1-\sigma)) \rightarrow 0$, then condition (13) converges to our benchmark condition (11).

Condition (13) further allows us to illustrate the effect of permanent central bank lending programs on the existence of the reversal rate.

Hypothesis 4. *The reversal rate becomes smaller if the central bank is willing to fund a larger share of the banker's lending, i.e.,* $\frac{\partial \hat{r}}{\partial \sigma} < 0$. *In the limit, for* $\sigma \rightarrow 1$*, the reversal rate ceases to exist.*

Consider the extreme case where the bank can finance its entire loan portfolio by borrowing from the central bank ex ante, i.e., $\lim \sigma \rightarrow 1$. In this case, a reversal rate would cease to exist.[18] This case is similar to the case with full deposit insurance, $\delta = 1$, in Section 4.1. The entire risk of the bank's loan issuance and the bank's exposure to interest rate risk would be borne by the central bank, and lower policy rates would unambiguously increase the bank's profit.[19]

[18] The right-hand side of Equation (13) converges to ∞, while the left-hand side assumes a finite value, implying that the condition could never be satisfied.

[19] We abstract from the possibility that the central bank can risk-adjust its interest rate when lending to the banker. In practice, central banks are able to

Binding Liquidity Requirement. Next, instead of Assumptions 2 and 3, we assume that the banker can endogenously choose her deposits, but she is required to hold a certain fraction of her deposits in the form of safe and liquid assets, e.g., reserves with the central bank or government bonds. This requirement is akin to the LCR that banks must satisfy under Basel III regulations (see Brunnermeier, Abadi, and Koby 2023 for a similar assumption). As we now show, under a binding liquidity requirement, the portfolio adjustment channel and the loan risk channel always move into the same direction. However, they both switch sign once the safe asset effect dominates the deposit pass-through effect. The banker's liquidity requirement can be written as

$$R \geq \rho D,$$

where ρ is now the exogenously given regulatory liquidity ratio. To the extent that $u(r) \geq r$, the liquidity requirement is binding. Since the expected profits are strictly decreasing in D, the banker minimizes the amount of deposits. Combining the liquidity requirement and the funding constraint yields

$$\frac{L}{1-\rho} = D.$$

Substitution into the banker's profits yields

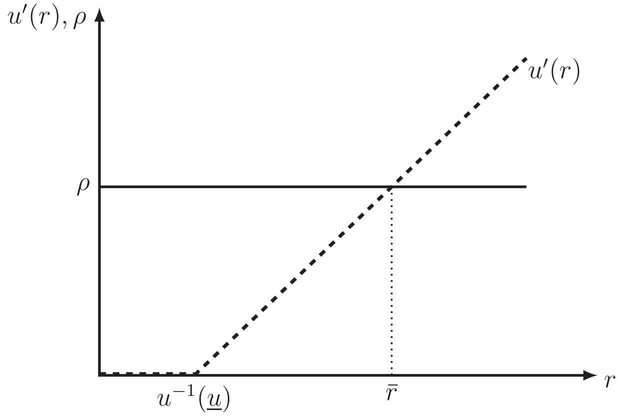
$$\Pi = q\left(r_L - \frac{r_D - \rho r}{1-\rho}\right) L(r_L) - \frac{\kappa q^2}{2}.$$

Because of the binding liquidity requirement, the direction of the portfolio adjustment channel also depends on the relationship between deposit pass-through and safe asset effect (like the loan risk channel). Thus, compared to Equation (9), the two channels are perfectly aligned, and we have

$$\frac{dr_L^*}{dr} = \underbrace{\frac{\partial r_L^*}{\partial r}}_{\substack{\text{portfolio adjustment}\\ \text{channel}}} + \underbrace{\frac{\partial r_L^*}{\partial q} \times \frac{\partial \hat{q}(r_L^*, r)}{\partial r}}_{\text{loan risk channel}} \propto \left(\frac{u'(r) - \rho}{1-\rho}\right). \tag{14}$$

achieve some degree of risk adjustment by lending against collateral and applying haircuts to riskier asset classes.

Figure 6. Reversal Rate with a Binding Liquidity Requirement



Note: For $r > \bar{r}$, the portfolio adjustment and the loan risk channel are positive, while they become negative for $r < \bar{r}$.

PROPOSITION 6. *Under a binding liquidity requirement, a reversal of monetary transmission occurs whenever the safe asset effect dominates the deposit pass-through effect. The reversal rate is*

$$\hat{r} = \bar{r}, \qquad \text{where } \bar{r} \text{ satisfies } u'(r) = \rho.$$

A higher liquidity requirement weakens the transmission of monetary policy.

Figure 6 illustrates the case of a binding liquidity requirement. Because ρ is now exogenously determined, the solid curve is flat at the level set by regulation. For $r < \bar{r}$, the safe asset effect dominates and reverses both the loan risk and the portfolio adjustment channel, i.e., a further reduction in the risk-free rate leads to a higher loan rate and a reduced loan issuance.

The case of a binding liquidity requirement allows us to emphasize a potential cost associated with liquidity requirements. The literature usually discusses the direct costs of liquidity requirements, i.e., the opportunity cost of foregoing profitable investments when a larger share of deposits is held in the form of more liquid but less profitable assets. Our model reveals another indirect cost of liquidity requirements, namely the costs that arise from the impairment of the monetary transmission channel. As can be seen in Equation (14), an increase in ρ reduces the effect of r on r_L^*. Moreover, once ρ is sufficiently high, monetary transmission is reverted.

4.3 Depositors' Outside Option

Finally, let us briefly discuss how the results in our model depend on Assumption 1. The crucial element of Assumption 1 is the lower bound on the outside option, whereas the additional assumptions (convexity of $u(r)$ and continuity of $u'(r)$) are technical and imposed for the sake of tractability. Consider the following example where depositors, instead of holding deposits, could either invest into a risk-free bond that pays r at date 1 or hold cash which provides a per-unit convenience yield θ and requires a per-unit storage cost ζ. Thus, $u(r) = \max\{1 + \theta - \zeta, r\}$ and $u'(r) = 1 - \mathbb{1}_{[r<1+\theta-\zeta]}$. For this specification of $u(r)$, the convexity and continuity assumptions ($u''(r) > 0$ and $\lim_{r\downarrow 1+\theta-\zeta} = 0$) fail to hold. Because $\rho \in (0, 1)$, it follows that $\rho > u'(r)$ if and only if $r < 1 + \theta - \zeta$. Since $u'(r)$ jumps discontinuously at $1 + \theta - \zeta$, the critical $\overline{r}$ at which the safe asset effect dominates the deposit pass-through effect equals the lower bound of the outside option. Hence, the safe asset effect can dominate the deposit pass-through effect for small values of r even without the continuity and convexity imposed by Assumption 1.[20]

What about the possibility that deposits themselves provide a convenience yield so that $u(r) < r$? Because the main results in the paper depend on the marginal costs and benefits of deposits versus reserve assets, allowing for a convenience yield on deposits such that $u(r) < r$ for $r > u^{-1}(\underline{u})$ would leave the results in Propositions 1–3 unaffected.[21]

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[20]The continuity and convexity assumptions ensure that $\overline{r} \geq u^{-1}(\underline{u})$ and that at $r = \overline{r}$ there is no discontinuity so deposit pass-through and safe asset effect are balanced at the margin.

[21]Changing the ordering between the outside option and the risk-free rate would, however, change the implications derived in Hypothesis 1. In this case, an exogenous increase in deposits would increase the banker's expected profit and therefore increase her incentives to monitor and lead her to issue more loans. Note, however, that $u(r) < r$ would allow the bank to make a risk-free profit from

The key element in Assumption 1 is the assumption that the outside option of depositors cannot fall below $\underline{u}$. Suppose we dispense with this assumption and set $u(r) = r$ for all values of r, which is a standard assumption in the corporate finance and banking literature, e.g., Dell'Ariccia, Laeven, and Marquez (2014) and Martinez-Miera and Repullo (2017). Because $\rho \in (0, 1)$ while $u'(r) = 1$, the deposit pass-through effect dominates the safe asset effect for all values of r and a lower interest rate always leads to an increase in monitoring, $\partial\hat{q}/\partial r < 0$. This mirrors the effect of r on the bank's risk-taking incentives for the case of sufficiently high leverage in Dell'Ariccia, Laeven, and Marquez (2014, Proposition 3). As a consequence, the loan risk channel always amplifies the portfolio adjustment effect and lower interest rates unambiguously lead to a lower loan rate and higher loan issuance. This argument shows that the lower bound on the depositors' outside option is a key condition for the weakening of monetary transmission via the loan risk channel.

5. Conclusion

This paper argues that the empirically observed correlation between weaker monetary transmission and higher risk-taking in an environment of low interest rates (e.g., Miller and Wanengkirtyo 2020 or Arce et al. 2021) can be viewed as the consequence of an agency friction between banks and their depositors.

The main contributions of our paper are two. First, we show that lower policy rates lead banks to increase risk-taking when the pass-through to deposit rates is too small to compensate for the reduction in the profitability of banks' safe assets. Higher risk-taking, in turn, leads to a weakening of the monetary transmission because it induces banks to optimally raise loan rates and issue fewer loans.

Second, our model complements Brunnermeier, Abadi, and Koby (2023) by showing an alternative mechanism by which a reversal of monetary transmission can arise. The existence of a reversal

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issuing deposits. To the extent that the bank could control the level of deposits (as in Section 4.2), the banker would issue as much deposits as possible.

rate depends on banks' characteristics (insured deposits, monitoring technology, leverage). Our model emphasizes that the reversal of monetary transmission is only an extreme manifestation of the more general phenomenon of weakened transmission due to higher risk-taking incentives in a low interest rate environment. This phenomenon should be of concern to central banks and may require them to devise policies that address the underlying causes of weaker transmission.

Our model suggests two policy implications that could help to alleviate the problem of weaker transmission. First, when operating in an environment with high excess reserves, central banks could implement reserve remuneration schemes that boost profits of banks holding excess reserves. While such schemes redistribute seigniorage revenues back to banks, they could nevertheless strengthen the transmission in an environment with protracted excess reserves and render monetary policy more effective. In this sense, our model provides a rationale for the two-tiered remuneration for excess reserves by the Eurosystem, which seeks to mitigate the effect of negative interest rates on bank profitability.[22]

Second, even though we abstracted from explicitly considering the effect of bank equity and capital regulation, our model can also speak to a recent debate on the importance of bank capitalization for monetary policy. In the context of our standard agency model, a capital requirement would weaken the link between loan rates and monitoring incentives. Put differently, an increase in loan risk would have a relatively smaller effect on the optimal loan rate if the bank must satisfy a larger capital requirement. As a consequence, a higher capital requirement would reduce the relative weight of the loan risk channel and strengthen monetary transmission via the portfolio adjustment channel. For banks with a smaller leverage, the reversal rate would be lower and the range of interest rates where transmission is unimpeded would be larger. Our model, therefore, echoes arguments by Gambacorta and Shin (2018) or Darracq Pariès, Kok, and Rottner (2020) who argue that bank capital matters not only for the central bank's financial stability but also for its monetary policy mandate and for the transmission of monetary policy.

[22]https://www.ecb.europa.eu/mopo/two-tier/html/index.en.html.

Appendix

A.1 Proofs

Proof of Lemma 1. Maximizing expected profits for a given deposit rate r_D with respect to q yields the first-order condition

$$r_L L - r_D D + rR - \kappa q = 0.$$

By substituting r_D from the participation constraint, we can obtain $\hat{q}$ as the solution to the following implicitly defined function:

$$\phi(q, r_L, r) \equiv r_L L - \frac{u(r)D - rR}{q} - \kappa q = 0.$$

The latter is quadratic in q. Following Allen, Carletti, and Marquez (2015), we take the larger of the two roots, such that

$$\frac{\partial \phi}{\partial q} = \frac{u(r)D - rR}{q^2} - \kappa < 0.$$

Moreover, we have

$$\frac{\partial \phi}{\partial r} = \frac{R - u'(r)D}{q}$$

and, using the fact that $R = D - L(r_L)$,

$$\frac{\partial \phi}{\partial r_L} = r_L L'(r_L) + L(r_L) - \frac{r}{q} L'(r_L).$$

An application of the implicit function theorem yields the expressions for $\partial \hat{q}/\partial r_L$ and $\partial \hat{q}/\partial r$.

Proof of Proposition 1. From Equation (7), the first-order condition for the optimal loan rate is given by

$$\begin{aligned} \frac{d\Pi}{dr_L} = \; & \hat{q}(r_L, r)\left(r_L L'(r_L) + L(r_L)\right) - rL'(r_L) \\ & + \frac{\partial \hat{q}}{\partial r_L} \underbrace{\left(r_L L(r_L) - \kappa \hat{q}\right)}_{=(u(r)D - rR)/q} = 0 \end{aligned}$$

$$= \hat{q}(r_L, r)\left(r_L L'(r_L) + L(r_L) - \frac{r}{\hat{q}(r_L, r)}L'(r_L)\right)$$
$$\times \left(1 - \frac{u(r)D - rR}{u(r)D - rR - \hat{q}^2\kappa}\right) = 0.$$

$\hat{q}$ and the second bracket are positive, so that the optimal r_L^* satisfies condition (8) in the text.

The second-order condition, evaluated at the critical point r_L^*, becomes[23]

$$r_L L''(r_L^*) + 2L'(r_L^*) - \frac{r}{\hat{q}}L''(r_L^*) = -\frac{L''(r_L^*)L(r_L^*)}{L'(r_L^*)} + 2L'(r_L^*) < 0,$$

which is satisfied since $L(\cdot)$ is a decreasing and concave function. Thus, r_L^* maximizes the bank's profits.

Applying the implicit function theorem to the first-order condition evaluated at r_L^* yields

$$\frac{dr_L^*}{dr} = \frac{\partial r_L^*}{\partial r} + \frac{\partial r_L^*}{\partial q}\frac{d\hat{q}}{dr}$$
$$= -\frac{-\frac{L'(r_L^*)}{\hat{q}} + \frac{r}{\hat{q}^2}L'(r_L^*)\frac{\partial \hat{q}}{\partial r}}{-\frac{L''(r_L^*)L(r_L^*)}{L'(r_L^*)} + 2L'(r_L^*)} \gtrless 0 \Leftrightarrow -\frac{L'(r_L^*)}{\hat{q}}\left(1 - \frac{\partial \hat{q}}{\partial r}\frac{r}{\hat{q}}\right) \gtrless 0, \tag{A.1}$$

where we replaced $\frac{d\hat{q}}{dr}$ with $\frac{\partial \hat{q}}{\partial r}$ because $\frac{\partial \hat{q}}{\partial r_L} = 0$ when evaluated at $r_L = r_L^*$.

Equation (A.1) implies that the loan risk channel weakens the portfolio channel whenever $\partial\hat{q}/\partial r > 0$, which is equivalent to $u'(r) < \rho$ (cf. Lemma 1).

Next, we show the existence of a value $\overline{r}$ such that for all $r < \overline{r}$, we must have $u'(r) < \rho$. Note that by Assumption 3, for all $r < u^{-1}(\underline{u})$ we have $\rho = R/D = 1 - L(r_L^*(r))/D > 0 = u'(r)$. If r becomes sufficiently large, R converges to a positive and finite value, while $u'(r)$ diverges (because of the strict convexity of $u(\cdot)$ for $r > u^{-1}(\underline{u})$) so that we have $u'(r) > \rho$ for sufficiently large r. Thus, there exists a smallest value $\overline{r}$ such that $u'(\overline{r}) = \rho$. For all $r < \overline{r}$, we have $u'(r) < \rho$.

[23]Note that the partial effect of r_L on $\hat{q}$ is irrelevant for determining the sign of the second-order condition since $\partial\hat{q}/\partial r_L = 0$ when evaluated at r_L^*.

Thus, for $r < \overline{r}$, we have $u'(r) < \rho$ and, as a consequence of Lemma 1, $\partial\hat{q}/\partial r > 0$. From Equation (A.1) follows that the loan risk channel weakens the transmission via the portfolio channel for $r < \overline{r}$.

Proof of Proposition 2. The proof follows immediately from Equation (A.1):

$$\frac{dr_L^*}{dr} < 0 \;\Leftrightarrow\; 1 < \frac{\partial\hat{q}}{\partial r}\frac{r}{\hat{q}}.$$

Proof of Proposition 3. We show the existence of $\hat{r}$ that satisfies

$$1 = \frac{\partial\hat{q}(r_L^*, \hat{r})}{\partial r}\frac{\hat{r}}{\hat{q}(r_L^*, \hat{r})}.$$

From the proof of Lemma 1 it follows that

$$\frac{\partial\hat{q}}{\partial r}\frac{r}{\hat{q}} = \frac{(u'(r)D - R)r}{u(r)D - rR - \hat{q}^2\kappa} \geq 1 \;\Leftrightarrow\; (u(r) - u'(r)r)D \geq \kappa\hat{q}^2.$$

The last inequality requires that $u'(r)D \leq R$ since $u(r)D - rR < \kappa\hat{q}^2$ (cf. Lemma 1). Therefore, consider $u'(r) < \rho$. Since $u''(r) > 0$, the left-hand side of the above inequality is strictly decreasing in r. Since $u'(r) = 0$ for $r < u^{-1}(\underline{u})$, we have $\text{argmax}_r\{u(r) - u'(r)r\} = u^{-1}(\underline{u})$. Thus, a necessary and sufficient condition for the existence of a reversal rate is that κ satisfies $\kappa\hat{q}^2 \leq \underline{u}D$. Note further that

$$\frac{d\kappa\hat{q}(\kappa)^2}{d\kappa} = \frac{\hat{q}^2}{u(r)D - rR - \hat{q}^2\kappa}\left(u(r)D - rR + \kappa\hat{q}^2\right) < 0.$$

Thus, we can find a value $\underline{\kappa}$ such that $\underline{\kappa}\hat{q}(\underline{\kappa})^2 = \underline{u}D$ and where $\underline{\kappa}$ also satisfies the condition for $\partial\phi/\partial q < 0$ in the proof of Lemma 1. Since $(u(r) - u'(r)\hat{r})D - \kappa\hat{q}^2$ is strictly decreasing in r for $r \leq \overline{r}$, there exists $\hat{r} < \overline{r}$ such that for $\kappa \geq \underline{\kappa}$

$$(u(\hat{r}) - u'(\hat{r})\hat{r})D - \kappa\hat{q}^2 = 0. \tag{A.2}$$

For $r < \hat{r}$, we have

$$(u(r) - u'(r)r)D > \kappa\hat{q}^2 \;\Leftrightarrow\; \frac{\partial\hat{q}}{\partial r}\frac{r}{\hat{q}} > 1.$$

Proof of Hypothesis 1. We consider an exogenous increase in the deposit volume and show that this leads to an increase in excess reserves, a higher reserves-deposit ratio, and less lending.

The equilibrium effect of an increased D follows by applying the implicit function theorem to the two equilibrium conditions

$$r_L L(r_L) - \frac{u(r)D - r(D - L(r_L))}{q} - \kappa q = 0,$$
$$r_L L'(r_L) + L(r_L) - \frac{rL'(r_L)}{q} = 0.$$

Let J^* denote the Jacobian of the above system of two equations evaluated at the optimum. From the proofs of Lemma 1 and Proposition 1 follows that $J^* < 0$ (when the variable vector is (r_L, q)). Note further that the second equation is independent of D. Thus, by the implicit function theorem

$$\frac{dq^*}{dD} \propto -\frac{u(r) - r}{q^*} < 0 \quad \text{and} \quad \frac{dr_L^*}{dD} \propto \frac{u(r) - r}{q^*} > 0.$$

Since r_L increases in D, a higher D leads to less lending and higher excess reserves

$$\frac{dL^*}{dD} = L'(r_L^*)\frac{dr_L^*}{dD} < 0 \quad \text{and} \quad dR = dD - L'(r_L^*)\frac{dr_L^*}{dD} > 0.$$

Finally, note that the latter implies also a higher reserves-deposit ratio ρ because $\rho < 1$ and $L'(r_L^*)\frac{dr_L^*}{dD} < 0$ such that we obtain

$$\frac{d\rho}{dD} = \frac{1}{D}\left(1 - \rho - L'(r_L^*)\frac{dr_L^*}{dD}\right) > 0.$$

Proof of Hypothesis 2. Applying the implicit function theorem to Equation (A.2) yields

$$\frac{\partial \hat{r}}{\partial \kappa} = \frac{\frac{d\kappa \hat{q}^2}{d\kappa}}{-ru''(r)D - 2\kappa\hat{q}\frac{\partial \hat{q}}{\partial r}} > 0 \quad \text{and}$$

$$\frac{\partial \hat{r}}{\partial D} = \frac{-(u(r) - u'(r)r) + 2\hat{q}\kappa \frac{\partial \hat{q}}{\partial D}}{-ru''(r)D - 2\kappa\hat{q}\frac{\partial \hat{q}}{\partial r}} > 0.$$

Proof of Proposition 4. $\hat{q}$ is given by the solution to the following implicit function:

$$\phi(q, r_L, \delta, r) \equiv r_L L(r_L) - \left(\delta + \frac{1-\delta}{q}\right)(u(r)D - rR) - \kappa q = 0,$$

with

$$\frac{\partial \phi}{\partial q} = \frac{1-\delta}{q^2}(u(r)D - rR) - \kappa < 0,$$

$$\frac{\partial \phi}{\partial r} = \frac{(R - u'(r)D)(q\delta + (1-\delta))}{q^2} > 0 \Leftrightarrow \rho > u'(r),$$

$$\frac{\partial \phi}{\partial r_L} = r_L L'(r_L) + L(r_L) - \frac{\delta q + (1-\delta)}{q} r L'(r_L),$$

and

$$\frac{\partial \phi}{\partial \delta} = \frac{1-q}{q}(u(r)D - rR) > 0.$$

Given $\hat{q}$, the first-order condition for the banker's optimal loan rate is given by

$$\hat{q}\left(r_L L'(r_L) + L(r_L) - \frac{\delta q + (1-\delta}{q} r L'(r_L)\right) \times \left(1 - \frac{(\hat{q}\delta + (1-\delta))(u(r)D - rR)}{(1-\delta)(u(r)D - rR) - \kappa\hat{q}^2}\right) = 0.$$

Since the second bracket is strictly positive, the optimal loan rate satisfies

$$r_L L'(r_L) + L(r_L) - \frac{\delta q + (1-\delta)}{q} r L'(r_L) = 0.$$

Application of the implicit function theorem yields

$$\frac{dr_L^*}{dr} \propto -(1-\delta)L'(r_L)\left(1 + \frac{\delta\hat{q}}{1-\delta} - \frac{\partial \hat{q}}{\partial r}\frac{r}{\hat{q}}\right).$$

Thus, $\frac{dr_L^*}{dr} < 0$ if and only if $1 + \frac{\delta\hat{q}}{1-\delta} < \frac{\partial \hat{q}}{\partial r}\frac{r}{\hat{q}}$.

Proof of Hypothesis 3. From the proof of Proposition 4 it follows that the reversal rate $\hat{r}(\delta)$ is given by the solution to

$$\frac{\partial \hat{q}}{\partial r}\frac{r}{\hat{q}} - 1 - \frac{\delta \hat{q}}{1-\delta} = 0.$$

Using the expressions for $\partial \hat{q}/\partial r$, we can rewrite the latter as

$$u(r)D - \delta r R - (1-\delta)u'(r)rD - \kappa \hat{q}^2 = 0. \tag{A.3}$$

For $\delta = 0$, the above condition is equal to Equation (A.2), implying that $\hat{r}(\delta)$ converges to the value of the reversal rate in Proposition 3. Another application of the implicit function theorem to Equation (A.3), taking into account that for $r = \hat{r}$ we have $u'(r) < \rho$ and $\partial R/\partial r = 0$, implies $\frac{\partial \hat{r}}{\partial \delta} < 0$.

Note further that for $\delta \to 1$, Equation (A.3) cannot be satisfied since $\hat{q}$ is the larger root, which implies that $\kappa \hat{q}^2 - u(r)D + rR > 0$. Hence, for $\delta \to 1$, the reversal rate ceases to exist.

Proof of Lemma 2 and Proposition 5. The adjusted profit function becomes

$$\Pi = q\left(r_L L(r_L) + r\int_{-1}^{z}(R + x\,D)\,dF(x) - r_D D\right) - \frac{\kappa q^2}{2}.$$

Because $E[x] = 0$, we can simplify to the same profit function as in our baseline model,

$$\Pi = q\,(r_L L(r_L) + r\,R - r_D D) - \frac{\kappa q^2}{2}.$$

Inserting the participation constraint into the first-order condition for q implicitly defines the function $\hat{q}(r_L, D, r)$

$$\phi(r_L, D, r) = r_L L(r_L) + r\,R - \frac{u(r)D - (1-q)r\int_{-1}^{-\rho}(R + xD)\,dF(x)}{q} - \kappa q = 0.$$

Taking the larger of the two roots, we obtain

$$\begin{aligned}\frac{\partial \phi}{\partial r} &= qR - u^{'}D + (1-q)\int_{-\rho}^{z}(R + xD)\,dF(x) \\ &= R - (1-q)\int_{-1}^{-\rho}(R + xD)\,dF(x) - u^{'}D\end{aligned}$$

and

$$\begin{aligned}\frac{\partial \phi}{\partial r_L} &= q((r_L - r)L^{'} + L) - (1-q)rL^{'}\int_{-\rho}^{z} dF(x) \\ &= q(r_L L^{'} + L) - rL^{'} + (1-q)rL^{'}\int_{-1}^{-\rho} dF(x),\end{aligned}$$

as well as

$$\begin{aligned}\frac{\partial \phi}{\partial D} &= qr - u(r) + (1-q)r\int_{-\rho}^{z}(1+x)\,dF(x) \\ &= r - u(r) - (1-q)r\int_{-1}^{-\rho}(1+x)\,dF(x) < 0,\end{aligned}$$

which is unambiguously negative for $r \leq u(r)$.

The first-stage profit function, given the required return for the expected equilibrium monitoring choice, becomes

$$\begin{aligned}\Pi(r_L, D; r) = \hat{q}(r_L L(r_L) + r\,R) - u(r)D \\ - (1-q)r\int_{-1}^{-\rho}(R + xD)\,dF(x) - \kappa\frac{\hat{q}^2}{2}.\end{aligned}$$

Differentiating with respect to D and r_L yields the first-order conditions for a profit maximum. As the bank optimally minimizes deposit costs, we evaluate the first-order condition at $D^* = (1-\sigma)L^*(r_L)$ and $R^* = -\sigma L^*(r_L)$, such that $\rho = -\frac{\sigma}{1-\sigma}$.

Using the implicit function theorem we obtain

$$\frac{dr_L}{dr} = -\frac{\begin{aligned}-L' + (1-\hat{q})L'\textstyle\int_{-1}^{\frac{\sigma}{1-\sigma}} dF(x)) \\ + \left(r_L L' + L - rL'\textstyle\int_{-1}^{\frac{\sigma}{1-\sigma}} dF(x)\right)\frac{\partial \hat{q}}{\partial r}\end{aligned}}{\frac{\partial^2 \Pi}{\partial r_L^2}}.$$

For r_L^* to be the optimal loan rate in equilibrium, we must have $\frac{\partial^2 \Pi}{\partial r_L^2} < 0$. Therefore, $\frac{dr_L}{dr} < 0$ if and only if the numerator is negative. Using the first-order condition $\frac{\partial \Pi}{\partial r_L} = 0$, we can simplify to

$$\frac{r}{\hat{q}}\left(1 - \int_{-1}^{\frac{\sigma}{1-\sigma}} dF(x)\right)\frac{\partial \hat{q}}{\partial r} > 1 - (1-\hat{q})\int_{-1}^{\frac{\sigma}{1-\sigma}} dF(x) \Leftrightarrow \frac{r}{\hat{q}}\frac{\partial \hat{q}}{\partial r} > \frac{1 - (1-\hat{q})\int_{-1}^{\frac{\sigma}{1-\sigma}} dF(x)}{\left(1 - \int_{-1}^{\frac{\sigma}{1-\sigma}} dF(x)\right)},$$

which corresponds to the condition in Proposition 5. Note that as $\sigma \to 1$, the left-hand side approaches zero and the right-hand side $\hat{q}$ such that the condition can never be fulfilled. If the bank can fund all loans by borrowing from the central bank, reversal rate cannot exist.

Proof of Hypothesis 4. The reversal rate $\hat{r}$ is implicitly defined by

$$\psi(\hat{r}, \sigma) \equiv \frac{\hat{r}}{\hat{q}}\frac{\partial \hat{q}}{\partial r} - 1 - \hat{q}\left(\frac{F(\frac{\sigma}{1-\sigma})}{1 - F(\frac{\sigma}{1-\sigma})}\right) = 0.$$

By the implicit function theorem, $\frac{\partial \hat{r}}{\partial \sigma} = \frac{\partial \psi/\partial \sigma}{\partial \psi/\partial r} < 0$, because $\frac{F(\frac{\sigma}{1-\sigma})}{1-F(\frac{\sigma}{1-\sigma})}$ strictly increases in σ as the distribution function $F(\cdot)$, is an increasing function and at $r = \hat{r}$, we have $\partial \psi/\partial r < 0$.

Proof of Proposition 6. The banker's optimal monitoring choice is the same as in the benchmark model, i.e., $\hat{q}$ is given by the implicitly defined function $\hat{q}(r_L, r)$. Substituting $\hat{q}$ and the deposit rate into the expected profits yields

$$\Pi = \hat{q} r_L L(r_L) - \left(\frac{u(r) - \rho r}{1-\rho}\right) L(r_L) - \frac{\kappa \hat{q}^2}{2}.$$

The first-order condition determining the bank's loan issuance is given by

$$\left(\hat{q} r_L - \frac{(u(r) - \rho r)}{1-\rho}\right) L'(r_L) + \hat{q} L(r_L) + \frac{(u(r) - \rho r) L(r_L)}{\hat{q}} \frac{\partial \hat{q}}{\partial r_L} = 0.$$

Using the expression for $\partial\hat{q}/\partial r_L$ implies that the optimal loan rate r_L^* must satisfy

$$\left(r_L^* - \frac{(u(r)-\rho r)}{\hat{q}(1-\rho)}\right) L'(r_L^*) + L(r_L^*) = 0.$$

The second-order sufficient condition is satisfied when evaluated at r_L^*. Totally differentiating the first-order condition yields

$$\frac{dr_L^*}{dr} = \frac{\frac{L'(r_L)}{\hat{q}}\left(1 + \frac{(u(r)-\rho r)L(r_L)}{\hat{q}\left(\kappa - \frac{(u(r)-\rho r)L(r_L)}{\hat{q}^2}\right)}\right)}{\frac{\partial^2 \Pi}{\partial r_L^*}} \cdot \left(\frac{u'(r)-\rho}{1-\rho}\right).$$

Since the term multiplying $(u'(r)-\rho)/(1-\rho)$ is strictly positive, it follows immediately that

$$\frac{dr_L^*}{dr} \gtrless 0 \Leftrightarrow u'(r) \gtrless \rho \Leftrightarrow r \gtrless \bar{r},$$

where $\bar{r}$ solves $u(r) = \rho$.

A.2 Proportional Monitoring Cost

This section shows that the key result in Proposition 2, i.e., that

$$\frac{dr_L}{dr} < 0 \Leftrightarrow \frac{\partial\hat{q}(r_L^*, r)}{\partial r}\frac{r}{\hat{q}(r_L^*, r)} > 1$$

remains unchanged if monitoring costs are proportional to loan issuance, i.e.,

$$c(q, r_L) = \frac{\kappa}{2} q^2 L(r_L).$$

To show this, we derive the first-order condition determining the bank's optimal monitoring effort:

$$r_L L(r_L) - r_D D + r(D - L(r_L)) - cqL(r_L) = 0.$$

The optimal monitoring effort $q(r, r_L)$ is implicitly defined by the first-order condition after substituting for r_D:

$$r_L L(r_L) - cqL(r_L) - \frac{u(r)D - r(D - L(r_L))}{q} = 0.$$

Application of the implicit function theorem yields

$$\frac{\partial \hat{q}(r_L, r)}{\partial r_L} = \frac{r_L L'(r_L) + L(r_L) - \frac{r}{q} L'(r_L) - cqL'(r_L)}{cL(r_L) - \frac{u(r)D - rR}{q^2}} \gtrless 0,$$

and

$$\frac{\partial \hat{q}(r_L, r)}{\partial r} = \frac{R - u'(r)D}{cL(r_L) - \frac{u(r)D - rR}{q^2}} \gtrless 0.$$

Given $\hat{q}(r_L, r)$, the bank maximizes its profits by choosing the loan rate r_L. The profit function is given by

$$\hat{q}(r_L, r) r_L L(r_L) + r(D - L(r_L)) - u(r)D - \frac{c}{2}\hat{q}(r_L, r)^2 L(r_L).$$

Differentiating with respect to r_L yields the first-order condition that pins down r_L^*:

$$q(r_L, r)\left(r_L L'(r_L) + L(r_L) - \frac{r}{q(r_L, r)} L'(r_L) - \frac{c}{2} q(r_L, r) L'(r_L)\right) + (r_L L(r_L) - cq(r_L, r)L(r_L))\frac{\partial q(r_L, r)}{\partial r_L} = 0.$$

Dividing the latter equation by $\hat{q}$ and adding and subtracting $c\hat{q}L'/2$, we obtain

$$\left(r_L L'(r_L) + L(r_L) - \frac{r}{q(r_L, r)} L'(r_L) - cq(r_L, r) L'(r_L)\right) + (r_L L(r_L) - cq(r_L, r)L(r_L))\frac{\partial q(r_L, r)}{\partial r_L}\frac{1}{\hat{q} r_L, r)} + \frac{c}{2} q(r_L, r) L'(r_L) = 0.$$

Using the first-order condition for monitoring to replace $r_L L(r_L) - c\hat{q}$, we obtain

$$\left(r_L L'(r_L) + L(r_L) - \frac{r}{q(r_L, r)} L'(r_L) - cq(r_L, r) L'(r_L)\right) + \frac{u(r)D - r(D - L(r_L))}{q(r_L, r)^2}\frac{\partial \hat{q}(r_L, r)}{\partial r_L} + \frac{c}{2} q(r_L, r) L'(r_L) = 0.$$

Substituting the expression for $\partial\hat{q}/\partial r_L$ and collecting terms, we finally obtain

$$cL(r_L)\left(r_L L'(r_L) + L(r_L) - \frac{r}{q}L'(r_L) - cq(r_l, r)L'(r_L)\right)$$
$$+ \frac{c}{2}q(r_L, r)L'(r_L)\left(cL(r_L) - \frac{u(r)D - r(D - L(r_L))}{q(r_L, r)^2}\right) = 0.$$

The second-order condition is strictly negative when evaluated at the critical point r_L^* that satisfies the latter equation. Thus, from the implicit function theorem follows that the sign of dr_L^*/dr is equal to the sign of the derivative of the first-order condition with respect to r, i.e., we have (for simplicity, we have dropped the arguments from functions $\hat{q}$ and L):

$$\begin{aligned}
\frac{dr_L^*}{dr} \propto& -\frac{cLL'}{\hat{q}} - \frac{cL'}{2}\frac{u'(r)D - (D - L)}{\hat{q}} \\
&+ \left(\frac{cLL'r}{\hat{q}^2} - \frac{c^2LL'}{2} + \frac{cL'}{2}\frac{u(r)D - r(D - L)}{\hat{q}^2}\right)\frac{\partial\hat{q}}{\partial r} \\
=& -\frac{cLL'}{\hat{q}} - \frac{cL'}{2}\left(cL - \frac{u(r)D - r(D - L)}{\hat{q}^2}\right)\frac{\partial\hat{q}}{\partial r} \\
&+ \left(\frac{cLL'r}{\hat{q}^2} - \frac{c^2LL'}{2} + \frac{cL'}{2}\frac{u(r)D - r(D - L)}{\hat{q}^2}\right)\frac{\partial\hat{q}}{\partial r} \\
=& -\frac{c}{\hat{q}}LL'\left(1 - \frac{\partial\hat{q}}{\partial r}\frac{r}{\hat{q}}\right),
\end{aligned}$$

where the second line follows from using the expression for $\frac{\partial\hat{q}}{\partial r}$ from above. Since $-cL(r_L)L'(r_L)/\hat{q}(r_L, r) > 0$, it follows that

$$\frac{dr_L^*}{dr} < 0 \Leftrightarrow \frac{\partial\hat{q}}{\partial r}\frac{r}{\hat{q}} > 1,$$

which is the same condition as in Proposition 2 where monitoring costs are independent of $L(r_L)$.

Note, while the condition for the marginal effect of r on r_L^* remains unchanged, a comparison of the respective first-order conditions shows that if the monitoring costs are proportional to loan issuance, the bank issues fewer loans (sets a higher loan rate) to reduce the monitoring costs.

A.3 Different Outside Options for Insured Depositors

In the main text, we assume that uninsured and insured depositors have the same outside option $u(r)$. Here, we show that Proposition 4 and Hypothesis 3 remain unchanged even if insured depositors have a different outside option. To this end, let $u_I I(r)$ denote the outside option of insured depositors. The outside option of the uninsured depositors remains denoted by $u(r)$.

The first-order condition for the banker's monitoring choice is given by

$$r_L(L(r_L) + rR - (\delta u^I(r) + (1-\delta)r_D)D - \kappa q = 0,$$

where r_D denotes the interest rate on uninsured debt. Substituting Equation (5) for r_D into the first-order condition yields the implicit function for $\hat{q}(r_L, r)$:

$$\begin{aligned}\phi(\hat{q}, r_L, r) \equiv\ & r_L(L(r_L)) \\ & - \frac{(\delta\hat{q}u_I I(r) + (1-\delta)u(r))D - (\hat{q} + (1-\delta)(1-\hat{q}))rR}{\hat{q}} \\ & - \kappa\hat{q} = 0.\end{aligned}$$

Again, choosing the larger root for $\hat{q}$, we have $\frac{\partial\phi}{\partial\hat{q}} \equiv \phi_{\hat{q}} < 0$ and

$$\frac{\partial\phi}{\partial r_L} \equiv \phi_{r_L} = r_L L'(r_L + L(r_L) - (\hat{q} + (1-\delta)(1-\hat{q}))\frac{r}{\hat{q}}L'(r_L).$$

Given the implicitly defined function $\hat{q}(r_L, r)$, we next turn to the banker's optimal choice of r_L. Substituting the uninsured deposit rate and $\hat{q}$ into the profit function, we obtain

$$\begin{aligned}\pi(r_L) = & \hat{q}r_L L(r_L) + (\hat{q} + (1-\hat{q})(1-\delta))rR \\ & - (\delta u_I(r) + (1-\delta)u(r))D - \frac{\kappa}{2}\hat{q}^2.\end{aligned}$$

The first-order condition for r_L is given by

$$\begin{aligned}\pi'(r_L) = & \hat{q}\left(r_L L' + L - (\hat{q} + (1-\delta)(1-\hat{q}))\frac{r}{\hat{q}}L'\right) \\ & + (r_L L + \delta(rR - u_I(r)D) - \kappa q)\frac{\partial\hat{q}}{\partial r_L} = 0.\end{aligned}$$

Substituting from the first-order condition for effort choice,

$$r_L L - \kappa\hat{q} = \frac{(\delta\hat{q}u_I(r) + (1-\delta)u(r))D - (\hat{q} + (1-\delta)(1-\hat{q}))rR}{\hat{q}},$$

and the expression for $\partial\hat{q}/\partial r_L$, it follows that the optimal loan rate r_L^* must solve

$$r_L L'(r_L) + L(r_L) - (\hat{q} + (1-\delta)(1-\hat{q}))\frac{r}{\hat{q}}L'(r_L) = 0.$$

As the second-order condition for a profit maximum must be negative, it follows from the implicit function theorem that

$$\begin{aligned}\frac{dr_L^*}{dr} < 0 \;\Leftrightarrow\; & -\frac{(\hat{q} + (1-\delta)(1-\hat{q}))}{\hat{q}}L'(r_L) \\ & + \left(-\frac{r}{\hat{q}}L'(r_L) + \frac{(\hat{q} + (1-\delta)(1-\hat{q}))r}{\hat{q}^2}L'(r_L)\right)\frac{\partial\hat{q}}{\partial r} < 0.\end{aligned}$$

Rewriting the latter equation yields

$$\begin{aligned}\frac{dr_L^*}{dr} < 0 \;\Leftrightarrow\; & -\frac{(1-\delta)}{\hat{q}}L'(r_L)\left(\frac{r}{\hat{q}}\frac{\partial\hat{q}}{\partial r} - \left(1 + \frac{\hat{q}\delta}{1-\delta}\right)\right) \\ < 0 \;\Leftrightarrow\; & \frac{r}{\hat{q}}\frac{\partial\hat{q}}{\partial r} > 1 + \frac{\delta\hat{q}}{1-\delta},\end{aligned}$$

which is the same condition as in Proposition 4.

However, note that while the above condition is the same as in the main text, the magnitude of the thresholds $\bar{r}$ and $\hat{r}$ changes compared to the model with identical outside options. To see this, consider the sign of

$$\frac{\partial\hat{q}}{\partial r} > 0 \;\Leftrightarrow\; \rho > \frac{\left(\delta\hat{q}\frac{u_I'(r)}{u'(r)} + (1-\delta)\right)u'(r)}{\delta\hat{q} + (1-\delta)}.$$

It follows that the relative deposit pass-through, i.e., $u_I'(r)/u'(r)$, determines whether or not the threshold rates $\bar{r}$ and $\hat{r}$ change compared to the baseline model. Whenever the interest rate pass-through to insured and uninsured depositors is the same, $u_I'(r) = u'(r)$, then $\bar{r}$ and $\hat{r}$ remain unchanged. Otherwise, if, say, $u_I'(r) < u(r)$, then the threshold $\bar{r}$ becomes larger, i.e., the range of risk-free rates where the bank's risk-taking incentives increase following a marginal increase in r.

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