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Monetary policy in a low interest rate environment: reversal rate and risk-taking

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Discussion papers

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Abstract

This paper develops a simple analytical framework to study the impact of central bank policy-rate changes on banks' credit supply and risk-taking incentives. Unobservable ex-post bank monitoring of loans creates an external-financing constraint, which determines bank leverage. Unobservable, costly ex-ante screening of borrowers determines the level of bank risk-taking. More risk-taking tightens the external-financing constraint. The policy rate affects the external-financing constraint because it affects both the return on outside investors' alternative investments and loan rates. In a low rate environment, a policy-rate cut reduces bank funding costs less because of a zero lower bound (ZLB) on retail deposit rates. Bank risk-taking is a necessary but not sufficient for a policy-rate cut to become contractionary ("reversal"). Reversal can occur even though banks' net-interest margins increase. Credit market competition plays an important role for the interplay of monetary policy and financing stability. When banks have market power, a policy-rate cut can increase lending and still lead to risk-taking. We use our analytical framework to discuss the literature on how monetary policy affects the credit supply of banks, with special emphasis on low and negative rates.

JEL codes: E44, E52, E58, G20, G21
Keywords: deposits, zero-lower bound, bank lending, equity multiplier.

Non-technical summary

In the aftermath of the global financial crisis, major central banks cut policy rates to close to zero or even to below zero. Generally, policy rate cuts are considered an effective tool to stimulate the real economy after severe downturns. However, following the introduction of negative rates, several voices in the academic and in the policy community have raised concerns about its limited effectiveness in stimulating lending and its potential adverse consequences for bank risk-taking and, more generally, for financial stability. In this paper, we contribute to the debate about the optimality of low and negative rates by clarifying through which channel(s) policy rate cuts affect bank credit supply and risk-taking.

Our conceptual framework is centred on an external financing constraint for banks, which is in the spirit of macro-models with financial frictions (e.g., Gertler and Kiyotaki, 2010; Gertler and Karadi, 2011; He and Krishnamurthy, 2012; Brunnermeier and Sannikov, 2014). Following Holmström and Tirole (1997), the constraint hinges on the existence of an *ex* post incentive problem for banks. Loans are risky. They need to be monitored *ex post* to reduce the probability of loan default. *Ex post* monitoring is necessary because outside investors would not provide funds otherwise, but it is costly as banks accrue a private benefit from shirking on monitoring. This implies that only a fraction of the loan return (pledgeable return) can be paid to outside investors and banks need to contribute with their own equity.

To analyse bank risk-taking, we also add an *ex ante* screening problem to the *ex post* monitoring problem. By exerting a privately costly screening effort, banks can increase borrower quality and increase the probability of loan repayment. Banks then take risk when they reduce their screening effort. Outside investors are willing to invest in banks that screen less as long as they receive a higher return on their investment.

Monetary policy affects bank credit supply via the external-financing constraint. By acting on both deposit and loan rates, a monetary policy cut generates two opposing effects. First, by reducing the required return for outside investors, a policy rate cut makes bank financing cheaper and so relaxes the bank's financing constraint. Second, by passing through to the loan rate, the reduction in the policy rate decreases banks' pledgeable return. This, in turn, implies an increase in the cost of external financing for banks, thus constraining their ability to raise external funding and ultimately reducing credit supply.

The strength of the pass-through of the policy rate to the cost of outside funding and to the pledgeable return, via loan rates, determines how bank credit supply reacts to monetary policy changes. In normal times, when rates are high, the pass-through to short-term rates (deposit rates) is stronger than that to long-term ones (loan rates). Hence, the external-financing constraint relaxes, and monetary policy is accommodative. In a low interest rate environment, the transmission to deposit rates is impaired because there is a zero-lower bound on retail deposit rates. A rate cut then still transmits to lower loan rates but less so to lower deposit rates. As result, the external-financing constraint relaxes less, and the effectiveness of the policy rate cut weakens up to a point, the so-called *reversal rate,* where the financing constraint tightens, and a rate cut becomes contractionary.

The effect of a policy rate cut on the external financing constraint also plays a central role for bank risk-taking. In this respect, our analysis shows that the contractionary effect of monetary policy on lending and bank risk-taking are closely intertwined.

Banks take more risk when the cost of prudent behaviour (e.g., costly screening) outweighs the benefit. The benefit of prudent behaviour is captured by the ability to lend and so accrue the intermediation rent. Prudent banks can attract more outside financing, lever up more and obtain larger profits. Hence, monetary policy affects risk-taking to the extent to which policy rate changes affect how lending reacts to changes in banks' screening effort.

When a policy rate cut makes it more difficult to expand lending, then banks find it less attractive to screen borrowers. This implies that when the policy rate falls below the reversal rate, a policy rate cut leads to increased risk-taking. However, monetary policy may also induce increased risk-taking when there is still a significant pass-through to deposit rates and it is still expansionary. This is more likely to occur when banks have market power since a change in the lending volume then reduces the loan rate, thus further reducing the benefit from screening.

We use our framework to discuss the literature on the various transmission channels and the related ample evidence, with a special focus on papers dealing with the peculiarities of a low and negative rate environment. The framework shows that there is close relationship between the effectiveness of monetary policy, financial stability, and credit market competition as all three affect the ability and profitability of bank intermediation.

1 Introduction

In the aftermath of the financial and sovereign debt crisis, central banks around the world significantly lowered their policy rates in the attempt to fight low growth and low inflation. Several central banks went as far as breaking through the zero lower bound (ZLB) and set negative policy rates. In June 2014, the European Central Bank (ECB) reduced the deposit facility (DF) rate from 0 to -0.10% and quickly followed up with another cut to -0.20% in September 2014.[1] Since then, this policy rate has been set at -0.50%. Other central banks, e.g, in Denmark, Switzerland, Sweden and Japan, have also implemented negative policy rates (Figure 1).

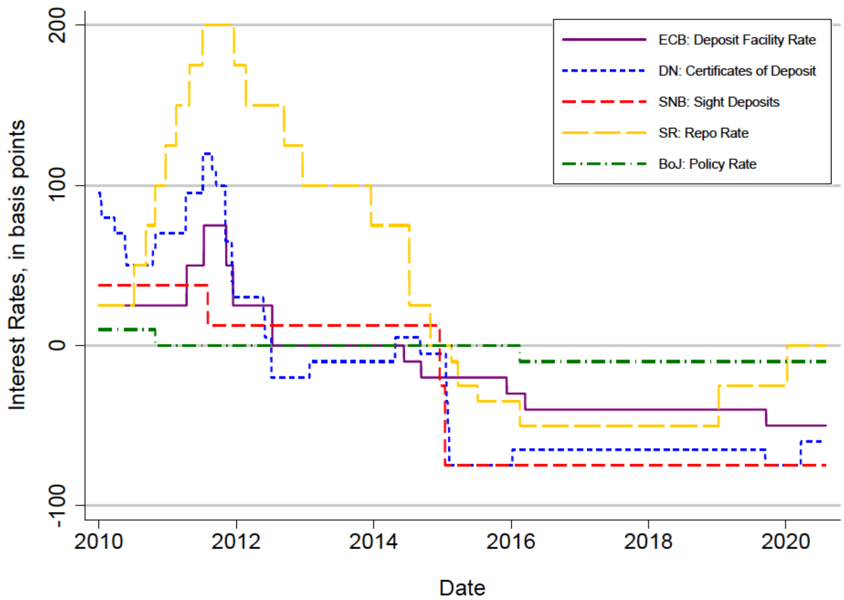


Figure 1: Falling and negative policy-rates in the euro area (ECB Deposit Facility), Denmark (DN Certificates of Deposits), Switzerland (SNB Sight Deposits), Sweden (SR Repo Rate) and Japan (BoJ Policy Rate). *Source:* Ulate (2021)

The currently ultra-low monetary policy rates reflect to some extent the falling equilibrium interest rate r^* in major economies (Figure 2). The equilibrium interest rate r^* is a model-based estimate of the level of the real short-term rate when the economy is at maximum employment and has stable inflation (Holston et al., 2017). When a central bank wants to stimulate the economy, it must achieve a short-term real interest rate below r^*. In the euro area, the point estimate of equilibrium rate became negative in 2010, well before the ECB decided to break

[1] In times of excess liquidity in the banking system, the rate on the ECB's deposit facility is the relevant policy rate for the economy, see for example Garcia-de-Andoain et al. (2016)

through the zero lower bound (ZLB) and set a negative policy rate.[2]

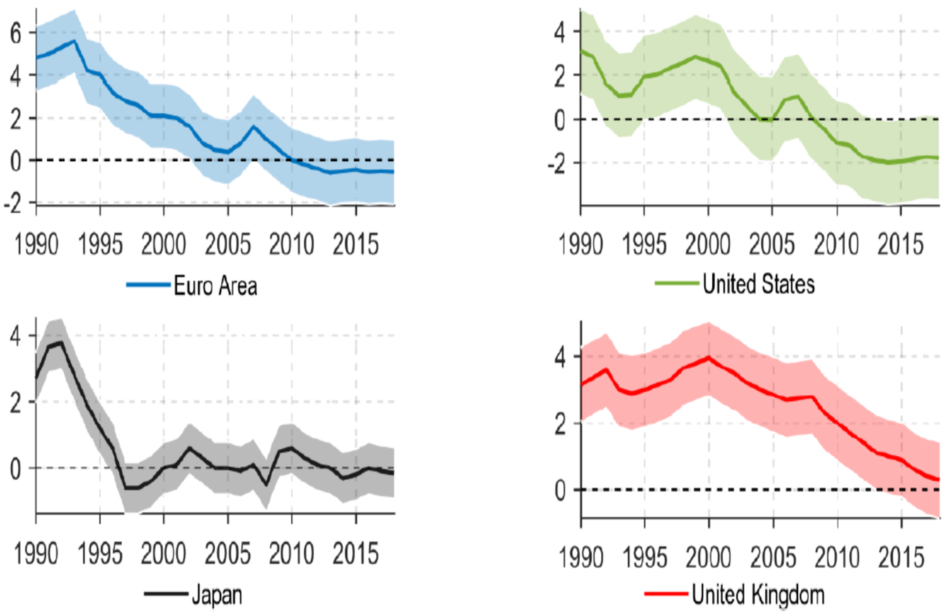
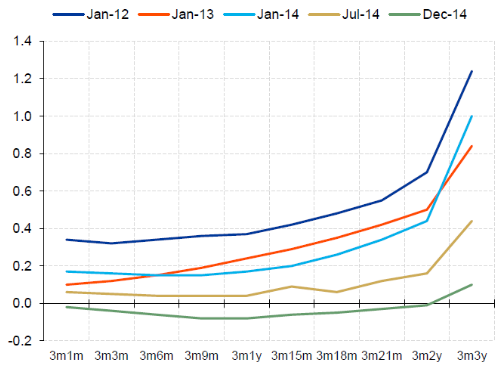


Figure 2: The figure provides model-based estimates of the natural rate: Euro Area, United States, Japan, UK (%). *Source:* ECB estimates.

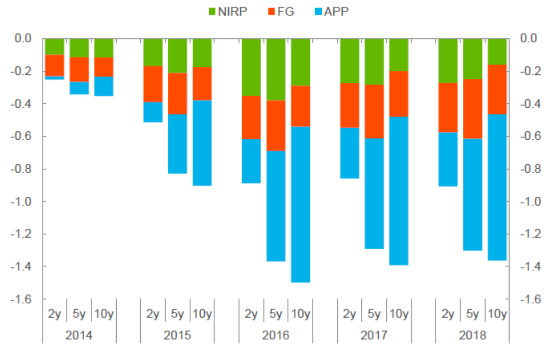
The ECB's decision to lower the policy beyond the ZLB is one of the most controversial unconventional monetary policies introduced in the last few years and has spurred an intense debate among both policy makers and academics.

On the one hand, and in line with the standard way of thinking about monetary policy transmission, a lower policy rate stimulates the economy. In fact, lowering the policy rate to below zero had a particularly strong impact on the yield curve. Whereas policy announcements by the ECB prior to mid-2014 had little impact on the yield curve, in particular on its long end, the announcement to break through the ZLB lowered long-term yields considerably (Figure 3a).

[2]For more information about the low interest rate environment and related macro-prudential issues, see ESRB (2021).



(a) Impact on Euribor forward curve (3-month Euribor rates). *Source:* Thomson Reuters.



(b) Impact of ECB's non-standard measures on the euro area sovereign yield curve (percentage points p.a.). *Source*: Rostagno et al. (2019).

Figure 3: The negative policy rate had a strong impact on government bond yields.

Before the ECB's decision, markets considered the ZLB as a hard lower bound, which biases expectations about future policy rates in the direction of rate increases. Once the policy rate breaks through the ZLB, expectations shift towards possible future rate cuts, which are then priced into lower long-term interest rates. The introduction of a negative policy rate was part of a policy package that included the introduction of the ECB's Public Sector Purchase Programme (PSPP) in March 2015 and a reinforcement of forward guidance. The combination of these three policies lowered the euro area sovereign yield curve considerably (Figure 3b) and contributed to the rebound of loan growth in the euro area as of 2014 (Figure 4).

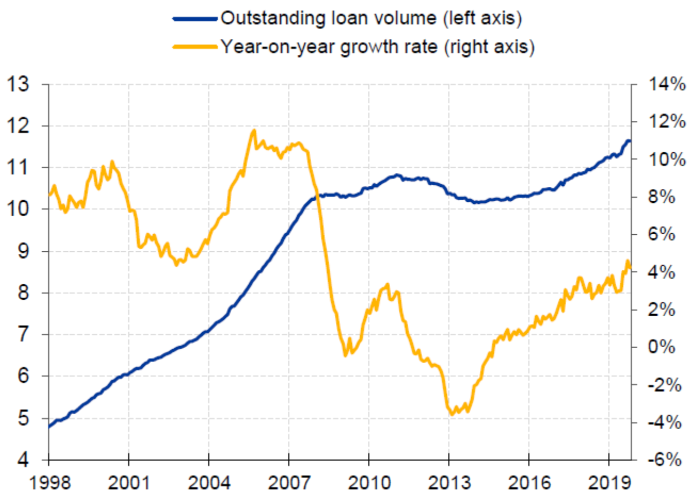


Figure 4: The figure highlights a steady increase in the growth rate of loans after the introduction of negative rates. *Source:* ECB Data Warehouse.

On the other hand, there are concerns about the potential side effects of low and negative rates on the banking sector. These concerns mostly refer to the impact of low, and especially of negative rates, on bank profitability and capital and, in turn, to their implications for bank credit supply and risk-taking (Borio and Zhu, 2012; Rajan, 2005). Reflecting those concerns, even though the policy and equilibrium rates in the U.K. and the U.S. have come down too, neither the Bank of England nor the Federal Reserve set negative policy rates.[3] Some even call negative rates "black-hole economics" (Summers, 2019).

Concerns about a less effective monetary policy and bank risk-taking in low rate environments are present in the academic literature. Although not specific to negative rates, Brunnermeier and Koby (2018) show the possibility of a "reversal rate". A reversal rate exists when a policy-rate cut reduces banks' net-worth and leads to a contraction in lending to avoid violations of banks' regulatory and external-financing constraints. A reduction in bank net-worth may also induce banks to lower their underwriting standards (see e.g., Dell' Ariccia et al., 2014) and to engage in a "search for yield" behaviour (see e.g., Martinez-Miera and Repullo, 2017). When rates are low and interest margins are small, banks may screen and monitor loans less, as well as invest in higher-yielding assets despite the higher risk of future losses.

At the heart of the controversy about monetary policy in a low rate environment is the zero lower bound (ZLB) on interest rates (e.g., Coibion et al., 2012). A zero lower bound does not apply universally. First of all, real interest rates have often become negative in the past.[4] Second, and more importantly, negative nominal rates are now widespread. Short-term market rates follow central bank policy rates closely. For example, the 3-month Euribor rate follows the ECB's policy rate closely and has become negative at the beginning of September 2014. Many government bonds, including those with longer maturities, now offer negative yields.[5]

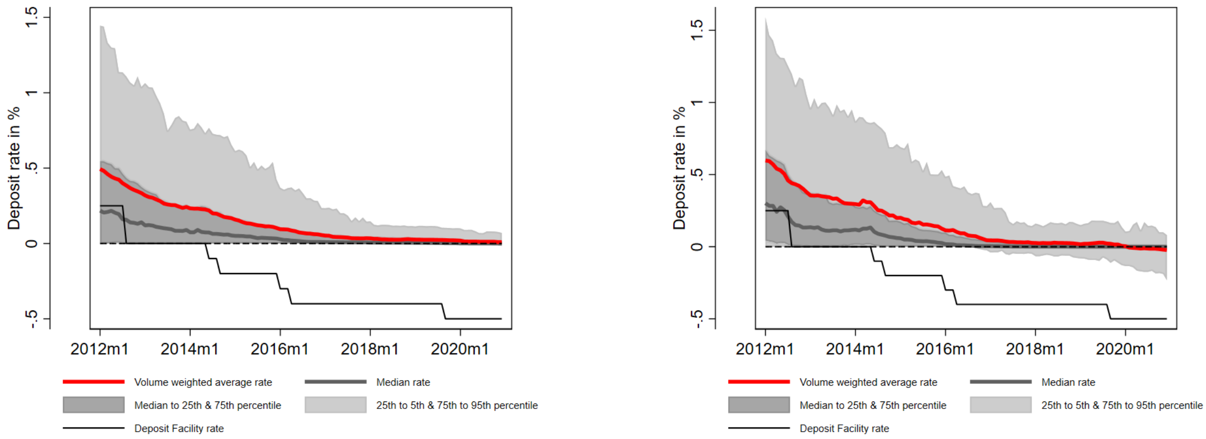
There is, however, a hard zero lower bound on deposit rates, especially for retail deposits held by households (Figure 5a). Not only do the average and the median household deposit rate not become negative even though the policy rate (the DF rate) becomes negative, the *distribution* of household deposit rates is truncated at zero. For deposits held by non-financial corporations, the truncation is slightly weaker (Figure 5b). Most corporate deposit rates do not cross the ZLB

[3]For concerns of these two central banks, see, e.g., https://www.bankofengland.co.uk/-/media/boe/files/inflation-report/2016/press-conference-transcript-august-2016.pdf, and https://www.stlouisfed.org/on-the-economy/2016/may/negative-interest-rates-tax-sheep-clothing.

[4]See for example, https://www.bundesbank.de/en/tasks/topics/nothing-new-about-negative-real-interest-rates-on-deposits-666512.

[5]In August 2019, The Economist writes that "Creditors holding $15trn-worth of securities will make a loss if they hold them to maturity (https://www.economist.com/finance-and-economics/2019/08/08/as-yields-turn-negative-investors-are-having-to-pay-for-safety).

and those rates between the 25th and the 75th percentile get squeezed at zero.



(a) Distribution of rates on overnight deposits held by households. *Source:* ECB Statistical Data Warehouse.

(b) Distribution of rates on overnight deposits held by non-financial corporations. *Source:* ECB Statistical Data Warehouse.

Figure 5: Hard zero lower bound on household deposit rates and most corporate deposit rates.

The exact reasons for why banks are reluctant to charge negative deposit rates are still unclear. There could be competitive, behavioural, and legal reasons. The slight pass-through of negative policy rates to corporate deposits but not to household deposits suggests the size of individual deposits matters. While household deposits are small and, hence, can be easily moved across banks, corporate deposits are large and less mobile.[6]

In this paper we connect the notions of low/negative interest rates, a ZLB on banks' main source of funding (deposits), bank risk-taking, and the effectiveness of monetary policy. We develop a simple conceptual framework, which serves three purposes. First, the model takes a stand on which friction is responsible for changes in the monetary policy rate to lead to changes in banks' credit supply. Second, the model allows to structure the discussion of the literature. We can relate different papers to our modelling assumptions and, hence, clarify how they drive the different results in the literature. Third, the model makes clear how bank risk-taking matters for the transmission of policy-rate changes to banks' credit supply. For example, we show that risk-taking is a necessary but not sufficient condition for reversal to occur.

The model centers on an external-financing constraint for banks, which is in the spirit of macro-models with financial frictions (e.g., Gertler and Kiyotaki, 2010; Gertler and Karadi, 2011; He and Krishnamurthy, 2012; Brunnermeier and Sannikov, 2014). We micro-found the external-

[6]For further analysis of household vs. corporate deposits, see Heider et al. (2019); Albertazzi et al. (2020); Altavilla et al. (2021).

financing constraint as in Holmström and Tirole (1997). Bank loans are not self-financing, i.e., they require bank equity in addition to outside funding, as only a fraction of the loan return (pledgeable return) can be paid to outside investors. Outside financing is costly because the bank earns a rent given by the difference between the physical loan return and the pledgeable return to outsiders. The rent compensates the banker for retaining the illiquid portion of the loan return, while outsiders receive the remaining liquid portion. The extent to which loans are not self-financing gives rise to an equity multiplier. The multiplier determines bank leverage, i.e., how much credit banks supply given their equity.

Monetary policy affects bank credit supply by changing banks' equity multiplier. There are two effects. First, a policy-rate cut makes outside funding cheaper. This decreases the extent to which loans are not self-financing, relaxes the external-financing constraint and increases the equity multiplier. Second, a policy-rate cut reduces loan rates and, hence, decreases the pledgeable return. This increases the extent to which loans are not self-financing, tightens the external-financing constraint and decreases the equity multiplier. The strength of these two opposing effects determines how much, if at all, a policy-rate cut is accommodative and increases bank credit supply (and vice versa for a rate hike).

The key factor in our model of transmission is the strength of the pass-through of the policy rate to the cost of outside funding and to the pledgeable return via loan rates. The strength of the pass-through determines how the extent to which loans are not self-financing, and therefore also the equity multiplier and bank leverage, react to a change in the policy rate.

In normal times, when interest rates are high, the pass-through of a lower policy rate to the cost of funding is stronger than the pass-through to loan rates. This is intuitive because banks perform intermediation between short-term funding and long-term loans. In our model, such difference in the strength of pass-through is the condition under which a policy-rate cut increases bank credit supply.

Instead, in a low interest-rate environment, possibly with negative policy rates, the opposite occurs. The ZLB on retail deposit rates weakens the pass-through of a lower policy rate to the cost of funding for banks so that it is weaker than the pass-through to loan rates. When this happens, a policy-rate cut increases bank credit supply less. When the pass-through to banks' cost of funding is sufficiently weak, then reversal occurs – a policy-rate cut then *decreases* bank credit supply.

A possible contractionary effect of a lower policy rate can occur even though banks' net-interest margin still increases. Because of the external-financing constraint, the relevant earning margin is the extent to which loans are not self-financing, i.e., the difference between the required rate for outside investors and the fraction of the loan rate that can be pledged to them. This margin is different from (but, of course, related to) the net-interest margin, which is the difference between the required rate for outside investors and the rate on loans.

In our framework the effect of a policy-rate cut on bank lending operates via banks' external-financing constraint. In our survey of the literature on monetary policy transmission via banks (including reversal) we discuss the relevance of this particular form of market imperfection and relate it to other sources of frictions, e.g., capital regulation.

The external-financing constraint also plays an important role for how monetary policy affects banks' risk-taking incentives. In our conceptual framework, loans are risky and banks engage in costly screening in order to improve the success probability of their loans. The model therefore has two incentive problems for banks. First, a bank needs to screen loans ex-ante in order to improve their success probability. Second, a banks needs to monitor the loans ex-post in order to avoid their failure. The ex-post problem creates a wedge between the physical loan return and the pledgeable return, and makes outside financing costly. The ex-ante problem captures bank risk-taking, i.e., offering credit to riskier borrowers when there is less screening.

The optimal level of screening trades-off the marginal cost and the marginal benefit. The marginal cost increases in the screening intensity and represents the costly infrastructure of screening borrowers such as hiring loans officers and investing in information technologies. The marginal benefit is given by the per-loan rent times the sensitivity of lending with respect to screening. The sensitivity of lending with respect to screening in turn is positive. More screening increases the expected pledgeable return and makes it easier to attract outside funding.

Risk-taking incentives and the effect of a change in the policy rate on credit supply are closely linked in our framework. This is a new insight. A change in the policy rate affects bank risk-taking because the policy rate affects the external-financing constraint and, hence, changes the sensitivity of lending with respect to screening. The policy rate does not change the per-loan rent the bank earns. The rent compensates the bank for retaining an illiquid loan, i.e., once the loan has been made, and retention of loans does not depend on the policy rate.

A policy-rate cut increases risk-taking in a low-rate environment because monetary policy has less accommodative or even contractionary effects on lending. In a low-rate environment, banks take more risk and, as a consequence, the banking sector becomes more fragile. Given the partial-equilibrium nature of our analysis, risk-taking and financial stability are synonymous in our framework. To complement our analysis, we also review contributions in the literature that focus on the financial stability implications of low and negative rates. These contributions explore other sources of instability beyond risk-taking, e.g., bank runs and multiple equilibria, or account for the changes in macro-economic conditions and borrowers' creditworthiness in a general-equilibrium approach.

The structure of the paper is as follows. In Section 2, we introduce the conceptual framework and explain the key role of banks' external-financing constraint. We also characterize bank credit supply and discuss some basic comparative statics, e.g., of bank lending with respect to bank risk or competition in the loan market, to illustrate the underlying mechanism. The external-financing constraint creates a wedge between the internal rate of return on equity and the external market rate – an increase in a bank's net-interest margin does not necessarily imply an increase in bank profits. Section 3 characterizes the effect of a policy-rate cut on lending. Section 4 solves for banks' risk-taking decisions and disentangles the channels through which they are affected by the central bank's policy rate. Section 5 concludes by tracing out policy implications. The formal details of the conceptual framework and all proofs are in the appendix.

2 A simple conceptual framework

In order to review the main issues in the academic and policy debate on the impact of monetary policy on bank lending and risk-taking, it is useful to think in terms of a stylized economy in which banks intermediate funds between investors and firms, as illustrated in Figure 6.[7]

[7]The formal description of the economy is in Appendix A. Appendix B derives the main results of the paper, and Appendix C reports the functional forms for the numerical example we use to derive the figures throughout the main text.

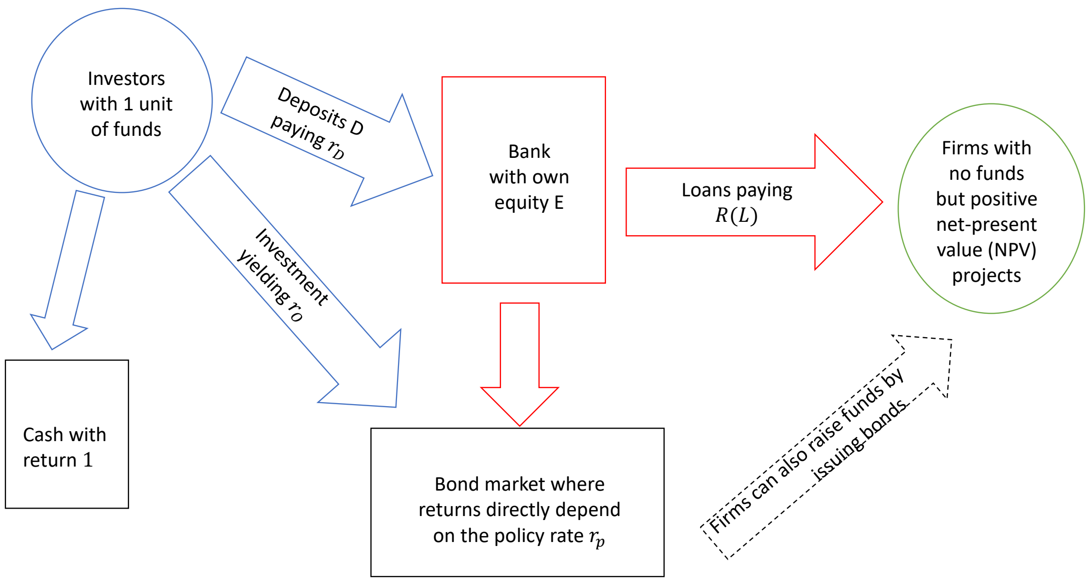


Figure 6: The economy.

In our stylized economy, investors deposit their funds into a bank as long as the deposit rate compensates them for the risk of bank failure and pays more than alternative investment opportunities, like cash and bonds (for the substitutability of bank liabilities and government bonds see, e.g., Krishnamurthy and Vissing-Jorgensen, 2015). Banks use their own equity and the debt raised from investors to provide loans to firms. The loan rate depends on the degree of competition in the loan market. The loan rate decreases in the loan volume, and more when banks have more market power. Like investors, banks also have access to alternative investment opportunities, e.g., bonds.[8]

The ability of banks and investors to buy bonds creates a link between deposit rates and loan rates on one hand, and the policy rate on the other hand. The policy rate impacts bond rates (Gertler and Karadi, 2015), which in turn passes through to deposit and loan rates. The ability of investors to hold cash instead of bank deposits creates a hard ZLB on retail deposit rates (Figure 5a).[9] There is an extensive literature on the pass-through of central bank policy rates to other rates in the economy (e.g., Berger and Udell, 1992; Mojon, 2000; Gambacorta et al., 2014; Altavilla et al., 2020) and, more recently, on how the pass-through to deposit rates becomes weaker closer to the ZLB (Eggertsson et al., 2019; Heider et al., 2019; Wang, 2020; Ulate, 2021).

Bank loans are risky and bank intermediation features two incentive problems. Ex-ante –

[8]Loan and bond market returns are intertwined also because firms can raise funds by issuing bonds as alternative or in addition to bank loans (e.g., Bolton and Freixas, 2006).

[9]Banks do not hold cash in our model because, in line with the empirical evidence, loans always carry a positive return, even when the policy rate is negative.

before raising external funding − banks need to screen loans in order to improve loan quality. Screening is costly, but increases the probability of loan repayment. Hence, as standard in the literature (e.g., Dell' Ariccia and Marquez, 2006; Allen et al., 2011; Martinez-Miera and Repullo, 2017), a lack of screening can be interpreted as a form of bank risk-taking. Ex-post − after external funds have been collected and loans are made − banks need to monitor loans in order to maintain loan quality (i.e., not to jeopardize the repayment probability). Bank monitoring is also costly as banks' obtain a private benefit from shirking on monitoring. This ex-post incentive problem is a convenient way to micro-found costly external financing, which we describe next.

2.1 Banks' financing constraint

The ex-post incentive problem between banks and their depositors introduces an external-financing constraint for the banks as in Holmström and Tirole (1997). Loans are not self-financing as only a fraction of the per-loan return can be pledged to outside investors. We refer to such fraction as pledgeable return. The incentive problem makes raising outside funding costly and requires banks to contribute equity. The measure of how much lending L can be done by raising outside financing with a given amount of equity E is captured by the equity multiplier k. Formally (for details see Appendix A), the constraint on lending is

$$L \leq kE. \tag{1}$$

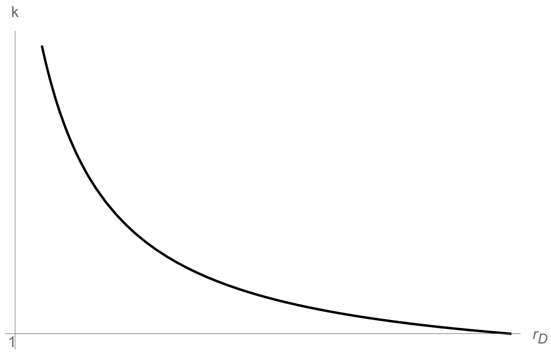
The equity multiplier can be interpreted as a measure of bank leverage. When $k = 1$, banks cannot raise outside funding and the amount of credit they provide is equal to the amount of equity. As k increases, banks start to lever up on their equity by raising external funding and, as a result, expand credit.

The equity multiplier is given by:

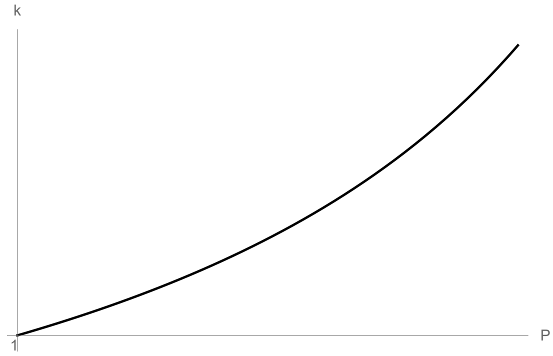
$$k = \frac{r_D}{r_D - \mathcal{P}}$$

where r_D is the deposit rate and $\mathcal{P}$ is the pledgeable return.

The equity multiplier decreases with the deposit rate (Figure 7a). It becomes harder for banks to raise external financing when outside investors (depositors) receive a higher return. The equity multiplier increases with the pledgeable return (Figure 7b). It becomes easier for banks to raise external financing when more can be promised to outside investors (without undermining the incentive to monitor).



(a) Effect of a change in the deposit rate r_D on the equity multiplier k.



(b) Effect of a change in the pledgeable return $\mathcal{P}$ on the equity multiplier k.

Figure 7: Comparative statics of the equity multiplier k.

The pledgeable return and the deposit rate directly depend on various parameters of interest. The pledgeable return $\mathcal{P}$ to outsiders increases with the loan rate R obtained from borrowers. The bank intermediates and monitors the loans. For this intermediation the bank earns a per-loan rent. This rent is the difference between the expected loan return qR and the pledgeable return $\mathcal{P}$. The rent increases if shirking on monitoring becomes more attractive. The pledgeable return therefore decreases with the private benefit b. Finally, when loans are safer, outsiders are repaid more often and, hence, the pledgeable return increases with the probability of loan repayment q.

Formally, we have

$$\frac{\partial \mathcal{P}}{\partial R} > 0; \quad \frac{\partial \mathcal{P}}{\partial b} < 0; \quad \frac{\partial \mathcal{P}}{\partial q} > 0.$$

The deposit rate decreases with the probability of loan repayment q. When loans and, hence, the bank become less risky, outside investors (depositors) require a lower repayment. The deposit rate increases with the policy rate. A higher policy rate increases the rate on outside investors' alternative investment opportunities, e.g., government bonds. To be still able to attract external financing, banks then need to increase the deposit rate. Conversely, when the policy rate falls, banks can afford to lower deposit rates until the point where outside investors would prefer to hold cash instead of bank deposits. Beyond this ZLB, the deposit rate no longer responds to changes in the policy rate.

Formally, we have

$$\frac{\partial r_D}{\partial q} < 0; \quad \frac{\partial r_D}{\partial r_p} \geq 0.$$

Changes in the policy rate r_p affect bank credit supply by inducing a change in the equity multiplier k. The policy rate affects both deposit rates (short-term rates), as well as loan rates (long-term rates). Given the opposite effects of the deposit rate and the pledgeable return on the equity multiplier, the strength of the pass-through of the policy rate to short-term and long-term rates determines the sign of the effect of monetary policy on lending, as we illustrate in the next section.

2.2 Optimal lending

The existence of the agency problem vis á vis the outside investors combined with the inability of banks to change their equity at short notice, implies that banks' credit supply is constrained by their level of capitalization.[10] At the optimum, banks maximize profits and the external-financing constraint (1) binds. One unit of equity capital allows banks to lend $k > 1$ unit more by attracting more outside deposit financing.

> Banks lend as much as their external-financing constraint allows, i.e.,
>
> $$L^* = kE. \tag{2}$$

Empirically, banks' capitalization matters for their credit supply (see e.g., Peek and Rosengren, 1997, 2000). When banks lend more, then the extra lending coincides with more bank debt and not with more bank equity (Gambacorta and Shin, 2018).[11] In other words, banks' external-financing constraint (1) tends to be binding in the real world and banks' lending volumes depend on how they can lever up on their own funds, as measured by the equity multiplier. This implies that banks with different equity multipliers may provide different lending volumes, despite having the same level of equity.

Bank risk plays an important role for bank lending. Both the pledgeable return $\mathcal{P}$ and the deposit rate r_D, which determine the equity multiplier k, depend on the probability of loan repayment q. A higher probability of repayment increases the pledgeable return and decreases

[10] In this section, we study the direct impact of a policy-rate cut on bank lending, taking the screening effort as given. In Section 4, we study the overall effect, including the indirect effect via bank risk-taking.

[11] For banks with abundant equity, the external-financing constraint does not bind. Given their high level of capitalization, those banks can in principle raise more external-financing than what it would be needed to finance their preferred level of lending. This would imply that the optimal credit supply is independent of banks' net worth. This type of banks predominantly features in Monti-Klein models, providing an industrial organization approach to banking. In these frameworks, banks choose their lending trading-off the marginal benefits in terms of a higher profits with the marginal costs in terms of lower per unit loan interest rate (see e.g., Chapter 3.2 in Freixas and Rochet, 2008).

the deposit rate. Both lead to an increase in the equity multiplier and so make it easier to obtain external financing and to lend (Figure 8).

Safer banks lend more than riskier ones.

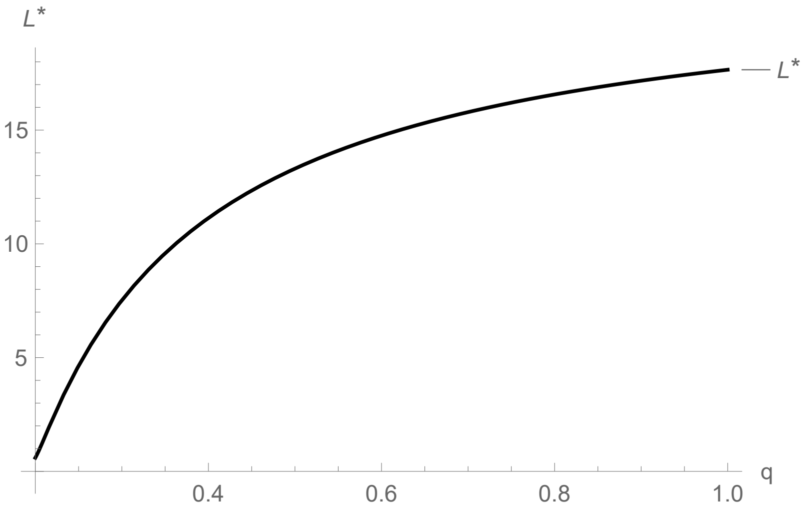


Figure 8: Lending L and bank screening q.

The degree of credit market competition also plays an important role for bank lending (for a recent empirical paper on the impact of competition on banking, as well as for many references, see Carlson et al., 2021). In our framework, competition affects bank lending via the equity multiplier. In a more competitive market, the loan rate is less sensitive to changes in the loan volume. Banks can increase lending with less of a corresponding decrease in the loan rate. The lower negative sensitivity of the loan rate to changes in the loan volume translates into a lower negative sensitivity of the pledgeable return and, hence, leads to a higher lending volume by relaxing the external-financing constraint (Figure 9).

Banks operating in more competitive credit markets lend more.

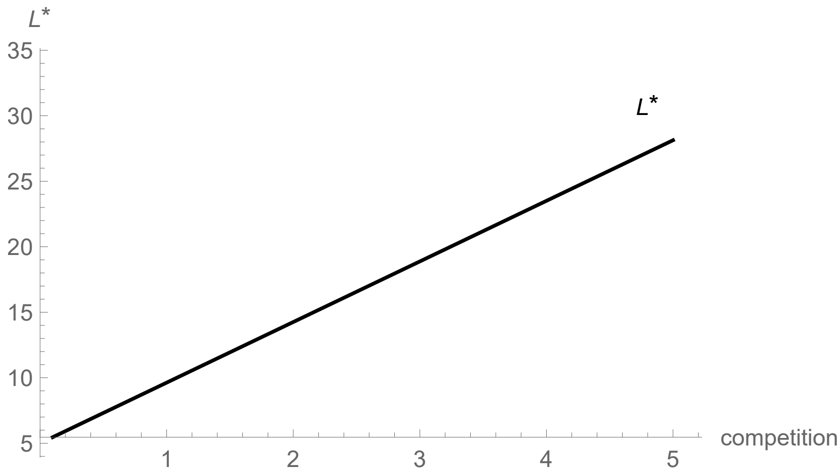


Figure 9: Lending as a function of the degree of loan competition.

2.3 Bank profits, bank value, and the net-interest margin

The existence of an external-financing constraint creates a wedge between the internal rate of return on equity capital and the external market rate. Maximized bank profits (gross of the cost of ex-ante screening) in our framework can be written as follows:

$$V = \rho k E \tag{3}$$

where ρ denotes the per-loan rent for the banker to ensure monitoring (see Appendix A). Bank profits are given by the per-loan rent times the equity multiplier times the equity. The return of bank equity is larger than the external market rate of funding, $\rho k > r_D$ because bank lending adds value and cannot be done by the market, i.e., outside investors cannot lend to firms and monitor them.

To understand bank behaviour in response to monetary-policy changes, one needs to understand the impact of such changes on bank profits. Several contributions in the literature, therefore, examine the impact of low and negative interest rates on bank profits and net-interest margins (Claessens et al., 2018; Molyneux et al., 2019; Lopez et al., 2020; Urbschat, 2018). The net-interest margin is the difference between the loan rate and the deposit rate. The argument in the literature is that bank profits suffer when the net-interest margin shrinks, e.g., because banks are no longer able to set lower deposit rates in response to lower policy rates at the ZLB.

The argument on shrinking net-interest margins and, hence, shrinking bank profits ignores, however, how the net-interest margin is split between the bank and outside investors when there is an external-financing constraint. The bank receives compensation for its intermediation service in the form of the per-loan rent ρ and, hence, wants to maximize the lending volume. If the bank received the entire net-interest margin as a rent then it could not raise any outside financing and would not maximize the lending volume. It is, therefore, optimal for the bank to retain only the illiquid (non-pledgeable) part of the net-interest margin (the rent) and to transfer the liquid (pledgeable) part to outside investors (the net-interest margin minus the rent).

The split of the net-interest margin into an illiquid part retained by the bank and a liquid part transferred to outside investors means that the net-interest margin overstates the benefit from lending. One can therefore have a situation where bank profits decrease with the policy rate even though the net-interest margin still increases (Figure 10).

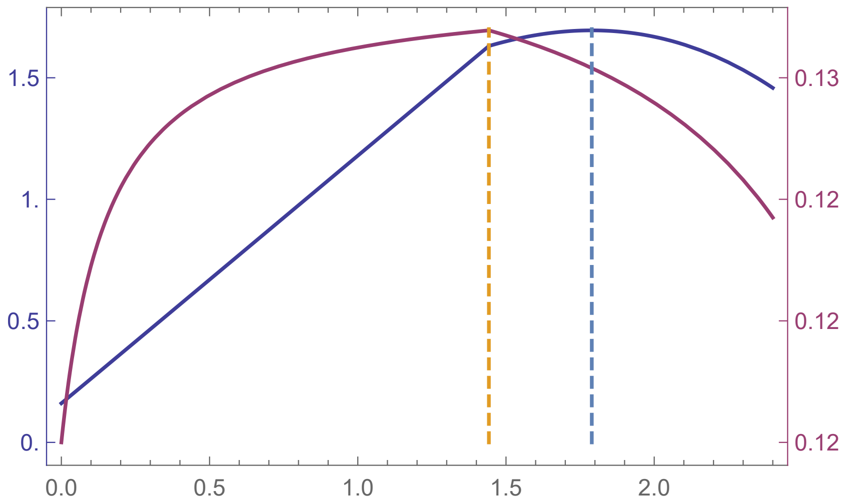


Figure 10: The figure illustrates how banks' profits (blue line) and interest rate margin $R - r_D$ (purple line) vary with the policy rate r_p. The two dashed lines identify the point where profits (blue line) and interest margin (yellow line) are maximal.

A better measure than the net-interest margin to understand bank profits is the return on equity ρk. This is the same as the Tobin's q of a bank. Tobin's q is the franchise value of the bank V divided by its net worth E (assets minus liabilities), i.e., the levered rent ρk. There is a long history of estimating Tobin's q for non-financial firms using stock-market information. Accordingly, several papers examine how banks' stock prices react to monetary-policy announcements. Away from the ZLB, a lower policy rate tends to increase banks' return on equity, while close to the ZLB, the opposite holds (Flannery and James, 1984; English et al., 2018; Hong and Kandrac, 2018; Ampudia and Van den Heuvel, 2018; Eggertsson et al., 2019).

2.4 The external funding constraint in the macro literature

The external-financing constraint (1) is closely related to the financing constraint found in many macro-finance papers (e.g. Gertler and Kiyotaki, 2010; Gertler and Karadi, 2011; He and Krishnamurthy, 2012, 2013; Brunnermeier and Sannikov, 2014; Gertler and Kiyotaki, 2015). For example, in Gertler and Kiyotaki (2010) a bank can divert a fraction θ of assets. To make sure the bank does not divert funds, in which case the bank defaults, the maximized value of the bank when not diverting funds, V must be larger than the gain from diverting funds:

$$V \geq \theta L. \tag{4}$$

Using the expression for bank profits (gross of the cost of ex-ante screening) (3), we can write the external funding constraint as

$$V \geq \rho L \tag{5}$$

and hence the diversion parameter θ in (4) corresponds to the per-loan rent ρ in our framework.

In He and Krishnamurthy (2012, 2013), the constraint has a slightly different interpretation. There L corresponds to the amount households invest in bank equity and V corresponds to the amount specialists invest in bank equity. The parameter θ describes how much households invest in banks per unit of wealth invested by specialists in banks. The constraint determines the "scale" of intermediation L and the parameter θ captures the agency problem between (inside) specialists who run banks, and (outside) households who finance them.[12]

Box 1: A financing constraint based on regulation

The notion that bank equity matters for the transmission of monetary policy via bank credit supply, the so-called bank-capital channel, appears first in Van den Heuvel (2002). The prior literature on the transmission of monetary policy via bank credit supply largely ignores the role of bank equity and instead focuses on banks' reserve requirements.[a]

To bring bank equity into the picture, Van den Heuvel (2002), as well as Bolton and Freixas (2006), consider capital regulation. A constraint based on capital regulation forces

[12] In Brunnermeier and Sannikov (2014), (inside) experts cannot issue any equity to (outside) households because of an agency problem. This can be interpreted as $\theta = 0$ - the scale of intermediation depends solely on the net worth of experts.

a bank to hold more equity relative to assets than a regulatory minimum μ:

$$\frac{E}{L} \geq \mu. \tag{6}$$

The denominator L can denote risk-weighted assets or just assets, in which case (6) is a leverage constraint.

The constraint (6) appears to have the same structure as the financing constraint (1), with the capital ratio μ taking the place of the inverse of the equity multiplier k. A model with a regulatory constraint such as (6), however, requires a different mechanism for monetary policy to affect lending. With a binding external-financing constraint as in (1), monetary policy affects bank intermediation L via the equity multiplier k. With a binding regulatory constraint, this is not possible as the capital ratio μ does not depend on monetary policy. Models with a regulatory constraint therefore typically allow bank equity E to vary at a cost. For example, in Van den Heuvel (2002), a bank can retain earnings to accumulate equity, but this is costly because of the tax advantage of debt. In Bolton and Freixas (2006), a bank can issue more equity to outsiders, and because outsiders have less information about the quality of the banks, this issuance has a dilution cost. Ulate (2021) has a target level, say $1/\mu$, for banks loan-to-equity ratio L/E and a quadratic cost when a bank deviates from it. The constraint therefore is, in spirit, close to a regulatory constraint and, as in Van den Heuvel (2002), banks accumulate equity through retained earnings.

In Brunnermeier and Koby (2018) the constraint of bank capital has the following form,

$$\mu L \leq V, \tag{7}$$

where μ is a regulatory risk-weight. In their words, the constraint combines "economic and regulatory factors". According to Repullo (2020), the constraint (7), however, "does not correspond to either a standard collateral constraint or a standard capital requirement." The constraint (7) is not a capital requirement because the constraint uses the bank's maximized value V as in (3) instead of bank equity E as in (6). The constraint (7) is also not a standard collateral constraint as in (5) because it uses a risk-weight (or regulatory minimum) μ instead of the per-unit rent ρ (or, equivalently, the diversion parameter θ in (4)). Repullo (2020) then proposes a model with a regulatory capital constraint (6) and endogenous costly equity in order to generate an impact of monetary policy on lending as discussed above. In such a set-up, however, there is no reversal rate. The banker prefers to shut down the bank when the policy rate becomes too low instead of lending less.

[a] For a discussion of the bank-capital channel and its relation to the prior literature on the substitutability between reserves on non-reservable bank liabilities, see Van den Heuvel (2002). For a model of monetary policy transmission via the substitution of reserves with non-reservable liabilities, see Stein (1998).

3 Does a policy-rate cut always stimulate lending?

After the Great Recession, central banks have started operating in a low or zero interest rate environment. This has raised concerns among both academics and policy makers about whether policy-rate cuts are still effective in stimulating lending in such circumstance (Summers, 2019). The main argument in the debate hinges on the idea that when rates are low or negative, banks can no longer pass the reduction in the policy rate onto depositors. In this circumstance, banks may be reluctant or unable to increase lending because their net worth is lower, thus tightening their financing constraint (see e.g., Box 1).

The discussion about whether a looser monetary policy becomes less effective at stimulating the economy in a low or zero interest rate environment can be framed around the existence of a reversal rate. The concept of a reversal rate is introduced by Brunnermeier and Koby (2018) and refers to the cutoff level for the policy rate below which a further rate becomes *contractionary*, i.e., the cut reduces bank credit supply. In the context of our conceptual framework and equation (2), the reversal rate represents the level of policy rate below which the equity multiplier starts to decrease with the policy rate.

A policy-rate cut decreases lending when it lowers the equity multiplier. Formally, this occurs when

$$\frac{k}{k-1}\frac{\partial R(.)}{\partial r_p} - \frac{\partial r_D(.)}{\partial r_p} > 0 \tag{8}$$

holds.

The effect of a policy-rate cut on the equity multiplier is twofold. First, a policy-rate cut leads to a reduction in the deposit rate. The bank can offer a lower deposit rate because the lower policy rate reduces the rate on the alternative investment for outside investors, e.g., bonds (unless we are close to the ZLB). A lower deposit rate in turn increases the equity multiplier

(Figure 7a). Second, a policy-rate cut reduces the loan rate and hence, reduces the pledgeable return, which decreases the equity multiplier (Figure 7b).

The overall effect of monetary policy on bank lending depends on which of these two effects, pass-through via deposit rates or via loan rates, dominates. In particular, a contractionary effect of monetary policy on lending emerges when the effect of a policy-rate cut on lower loan rates dominates the effect on lower deposit rates. As shown in (8), reversal is possible when the pass-through of the policy rate to deposit rates is sufficiently weak, which is what occurs at the ZLB (Figures 5a and 5b).

Condition (8) can be re-arranged in terms of semi-elasticities, which yields a simple condition for the reversal rate. At the reversal rate, a one basis point decrease in the policy rate translates into the same percentage decrease of the deposit rate and of the pledgeable return. A policy-rate cut reduces bank credit supply whenever the semi-elasticity of the deposit rate is smaller than the semi-elasticity of the pledgeable return (Figure 11).

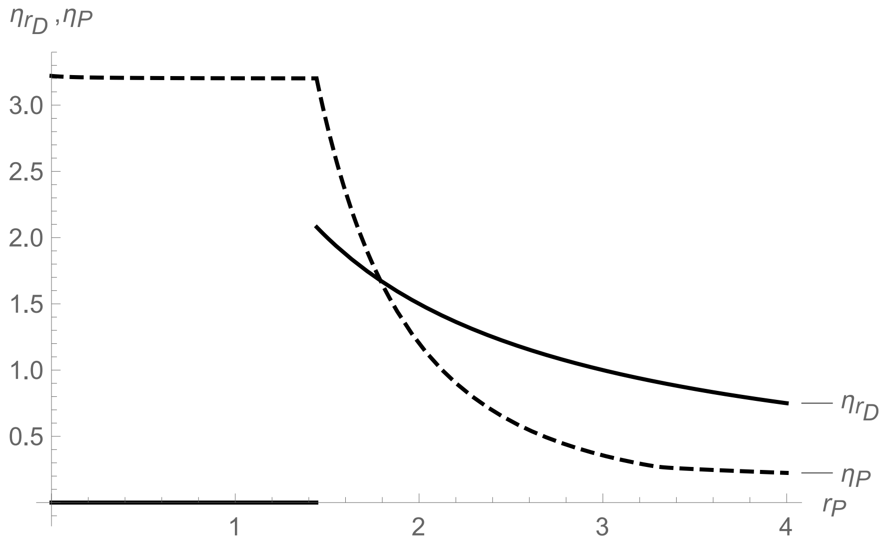


Figure 11: The figure shows the semi-elasticity of deposit rate to the policy rate (solid line) and that of the pledgeable return (dashed line).

Figure 11 illustrates why the impact of a policy-rate cut on bank credit supply in high-rate and a low-rate environment is different. In normal times, when rates are high, a policy-rate cut is expansionary because the elasticity of the pledgeable return is smaller than the elasticity of the deposit rate. This relaxes the bank's external-financing constraint and the equity multiplier increases after a policy-rate cut. In normal times, this difference in elasticities occurs because the pass-through to deposit rates is intact. The pass-through to rates of long-term assets such as loans is more sluggish than the pass-through to short-term assets such as withdrawable deposits.

In a low interest rate environment, the strength of the pass-through to deposit rate weakens relative to that to the loan rate because of the ZLB. Close to the ZLB, the pass-through of the policy rate to deposit rate weakens and becomes smaller than the pass-through to loan rates. When the policy rate falls below the reversal rate, the elasticity of the deposit rate (to the policy rate) is below the elasticity of the loan rate. When this happens, the external-financing constraint tightens and the equity multiplier shrinks in reaction to a policy-rate cut.

The condition on when a policy-rate cut is expansionary (i.e., (8) with the opposite inequality) is more stringent than the requirement on an increase of banks' net-interest margins (i.e., $\frac{\partial R(.)}{\partial r_p} - \frac{\partial r_D(.)}{\partial r_p} < 0$), which is common in the literature. An increase in banks' net-interest rate margin after a policy-rate cut is not enough to stimulate lending. As shown in Section 2.3, the net-interest margin overstates the benefit from lending because it ignores the cost of attracting outside financing (see also Figure 10). To obtain the funding for lending, the bank must transfer part of the net-interest margin (the liquid part) to outside investors (depositors).

In Brunnermeier and Koby (2018), whether a policy-rate cut has a contractionary or accommodative effect on lending depends on how it affects banks' profitability. Like us, there is an external-financing constraint for banks. The nature of the constraint is, however, different as it relies on regulatory constraints on banks' capital (see also (7) and the discussion in Box 1). In Brunnermeier and Koby (2018) two effects are at play following a policy-rate cut. First, a reduction in the policy rate decreases banks' net-interest income. Second, it induces revaluation gains on banks' fixed-income assets like bonds. When the former dominates the latter, monetary policy stimulus becomes contractionary. They calibrate their model using euro area data and show that the reversal rate is negative and around -1 percent.

A similar mechanism is at play in Darracq et al. (2020). They develop a non-linear general equilibrium model in which banks' market power in the deposit market dissipates when rates hit the zero lower bound and when banks hold low-risk sovereign bonds on their balance sheet for regulatory purposes. These features capture the differential co-movement of market and deposit rates with the policy rate close to the ZLB. In a low-rate environment, monetary policy has a modest impact on deposit rates, while it still lowers the return on sovereign bonds significantly. This then has a detrimental effects on banks' profitability and tightens their regulatory constraint, which reduces banks' ability to lend.

Ulate (2021) builds a DSGE model in which the reduced bank profitability, following a policy-rate cut, hinges on the existence of a hard zero lower bound on retail deposits. The different pass-through of a policy-rate cut to loan and to deposit rates in high-rate and low-rate environments explains differences in the effectiveness of monetary policy. The model predicts a 60 percent to 90 percent efficacy of monetary policy when the interest rate is below 50 basis points relative to an interest rate above 50 basis points.

In Ulate (2021), the standard lending channel of monetary policy, whereby the reduction in loan rates stimulates lending, is dominated by a net-worth channel at the ZLB. In the net-worth channel, an erosion of profitability, brought about by a decline in the loan-deposit spread, leads to a reduction in the value of bank equity. To counter the reduction, banks increase loan rates and decrease lending volumes. In Ulate (2021), it is costly for banks to deviate from a target level of the loan-to-equity-ratio. As in Brunnermeier and Koby (2018), the fall in banks' profit margins together with a financing constraint based on capital requirements leads to the reduced impact of a lower policy rate on the economy.

Ampudia and Van den Heuvel (2018) document a different effect of policy-rate changes on bank net-worth in a high-rate and a low-rate environment. Considering only the changes in short-term market rates around the ECB's press release, they identify policy rate surprises and show that the coefficient of regressing banks' stock prices on a policy rate surprises is negative in the high-rate environment before September 2008 ("normal times") and is positive in the low-rate environment since July 2012. Moreover, the positive coefficient is larger for banks with a higher deposit-to asset ratio, which is in line with the hard ZLB on deposit rates (Figures 5a and 5b) and its adverse effect on bank funding costs.

The existence of a hard zero lower bound on deposit rates and its negative implications for bank lending has been also documented in Heider et al. (2019). They show that when the ECB set a negative policy rate in mid-2014, banks with more deposit funding expanded lending less.

Bittner et al. (2020) provide evidence of the heterogeneous effect of the mid-2014 policy-rate cut between the core and the periphery of the euro area. Using confidential credit registry data from Germany and Portugal, they show that the rate cut expanded lending in Portugal but less so in Germany. This core-periphery difference hinges on the ability of Portuguese banks, but not of German banks, to pass through the lower policy rate to deposits. In Portugal, interest rates were relatively high and far away from the ZLB in mid-2014, while in Germany interest rate were already close to the ZLB at that time. Thus, the results in the paper further highlight the importance of the pass-through of policy rates to bank funding costs (deposit rates) for the effectiveness of an accommodative monetary policy.

In a recent paper, using a vector autoregressions (VAR) model with euro area macroeconomic and banking data, Mendicino et al. (2021) show that banks currently pass on policy rate shocks to both depositors and firms so that the impact of a policy-rate cut has quantitatively similar effects both in positive and negative rate territory (see Box 2).

Box 2: Policy Rate Shocks in Negative Territory: Real and Financial Stability Implications[a]

Are policy-rate cuts in negative territories still effective in stimulate lending and the real economy? Do they have adverse implications for financial stability?

Mendicino et al. (2021) provide evidence on the real and financial stability implications of policy rate shocks both in positive and negative territory. The analysis relies on the use of a suit of vector autoregressions (VAR) models and identification strategies. The results are based on macroeconomic aggregates and confidential banking data for the euro area.

The transmission of policy-rate cuts over time is analyzed by means of a time-varying coefficients VAR model with stochastic volatility (TV-VAR) as in Cogley and Sargent (2005) and Primiceri (2005). This approach allows to explore the effects of policy rate shocks in positive, zero and negative territory. Overall, the results show that policy-rate cuts have quantitatively similar effects on economic and banking activity both in positive and negative territory.

Real Activity. Figure A12 reports the effect of a 1 percentage point shock to the ECB deposit facility rate. The different lines capture the average responses of GDP and inflation to the shock the over four periods: pre-Global Financial Crisis (pre-GFC, 2000Q1-2007Q3), Financial and Sovereign Debt Crisis (Crisis, 2007Q4-2012Q2), Zero Lower Bound (ZLB, 2012Q3-2014Q2), Negative Interest Rate Policies (NIRP, 2014Q3-2019Q4). No relevant differences can be detected in the response of GDP and Inflation across the different periods. In particular, the results show no signs of a weakening in the effectiveness of policy-rate cuts at zero or even in negative territory.

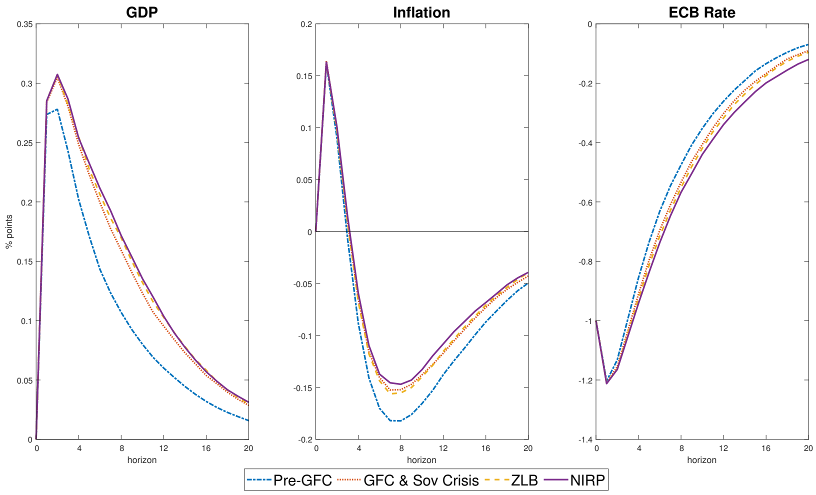


Figure A12: **Time Varying Impulse Response Functions to a Monetary Policy shock.** Notes: Recursive Identification: log change of real GDP (GDP), log change of the Harmonised Index of Consumer Prices (Inflation) and the ECB Deposit Facility Rate (ECB Rate). Source: Mendicino et al. (2021)

Financial Stability Risks. Figure A13 augments the VAR with information from the confidential Bank Lending Survey (BLS) regarding the lending standards that banks apply to (non-financial) loan applicants. Following a policy-rate cut, banks' lending standards generally decline. At the same time, the demand for loans by non-financial corporations, as observed and reported by banks, increases. This is also in line with the overall increase in bank-intermediated credit to non-financial corporations shown in Mendicino et al. (2021). The relaxation of lending standards in response to policy-rate cuts is in line with previous evidence on policy-rate cuts in positive territory (Maddaloni and Peydró, 2011; Ciccarelli et al., 2015) and suggests an important role for the credit channel of monetary policy Bernanke and Gertler (1995) also in negative territory.

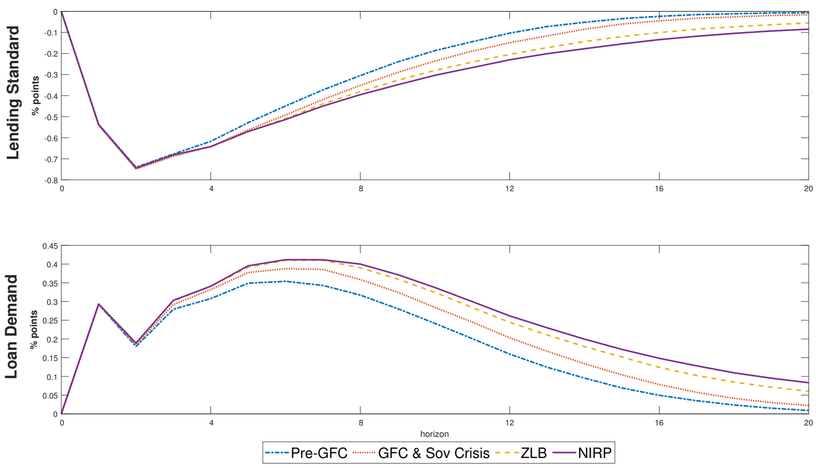


Figure A13: **Time Varying Impulse Response Functions to a Monetary Policy shock.** Notes: Recursive Identification: log change of real GDP (GDP), log change of the Harmonised Index of Consumer Prices (Inflation), Lending Standards, Loan Demand and the ECB Deposit Facility Rate (ECB Rate). Source: Mendicino et al. (2021)

The loosening of lending standards by banks in response to policy-rate cuts is often associated to an accumulation of risk, hence raising concerns regarding possible implications for financial stability. Figure B20, however, shows that policy-rate cuts generally decrease the probability of default (Moody's expected default frequency) of both banks and firms. Importantly, firm and bank default probabilities respond in similar ways throughout the whole sample period.

Mendicino et al. (2021) also show that policy-rate cuts generally decrease overall systemic risk, as measured by SRISK (Brownlees and Engle, 2017), supporting the idea that the impact of the policy-rate cut on macroeconomic conditions and credit worthiness of borrowers has a positive effect on banks' balance sheets and their credit riskiness both in positive and negative territory.

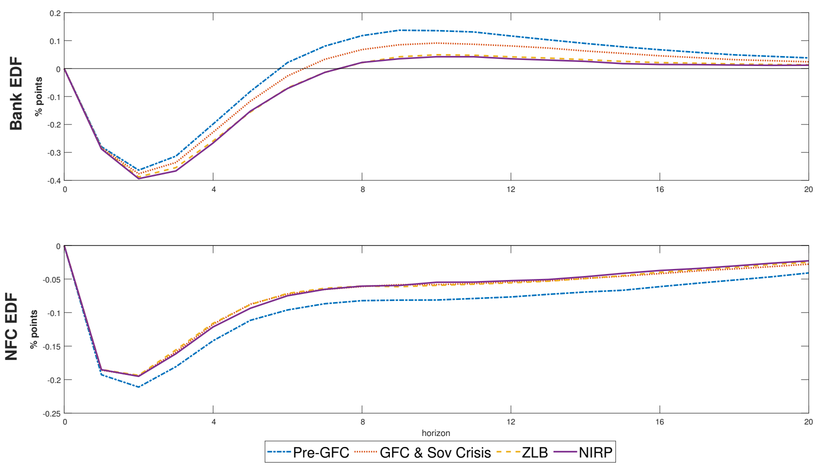


Figure A14: **Time Varying Impulse Response Functions to a Monetary Policy shock.** Notes: Recursive Identification: log change of real GDP (GDP), log change of the Harmonised Index of Consumer Prices (Inflation), Bank EDF, Firm EDF and the ECB Deposit Facility Rate(ECB Rate). Source: Mendicino et al. (2021)

Heterogeneity. Overall, the results presented suggests that policy-rate cuts in negative territory still work as "central bank business as usual" (Rogoff, 2016) in terms of their real and financial implications. Substantial heterogeneity is, however, documented in the pass-through of negative policy rate shocks to lending rates. Mendicino et al. (2021) shows that banks with (ex-ante) lower levels of retail deposit rates are on average less responsive to policy rate shocks in negative territory compared to banks with (ex-ante) higher retail deposit rates. This result warrant some concerns regarding the possibility that a larger number of banks reaches the effective lower bound as we move further in negative territory, hence, reducing the effectiveness of policy-rate cuts going forward.

[a]This box was prepared by Caterina Mendicino and it is based on Mendicino et al. (2021).

One important insight in Mendicino et al. (2021) is the heterogeneity in banks' responses to a policy-rate cut. In line with this findings, our conceptual framework also highlights the importance of bank characteristics for the effect of monetary policy on lending.

First, the strength of monetary policy transmission depends on bank leverage.

Banks with lower leverage lend less than those with higher leverage and a policy-rate cut is more likely to be expansionary the higher bank's leverage is.

Figure 15 shows that banks with a lower leverage (i.e., banks with a higher benefit b of not monitoring) lend less than those with higher leverage. For a bank fully relying on its own equity, i.e., with $k = 1$ and zero leverage, a change in the central bank's rate policy has no effect on lending, as bank equity E is fixed. For a levered bank, i.e., with $k > 1$, instead, a policy-rate cut is more expansionary the higher bank leverage is. This can be immediately see from (8) since the fraction $\frac{k}{k-1}$ decreases with k. Higher leverage makes the condition on the strength of the pass-through to funding rates less tight. The role of leverage is intuitive as more leverage means a higher ability to attract outside financing, which leads to more intermediation. Empirically, banks with more leverage (a lower equity-to-asset ratio) tend to react stronger to policy-rate changes (Jayaratne and Morgan, 2000; Kishan and Opiela, 2000; Gambacorta and Shin, 2018).

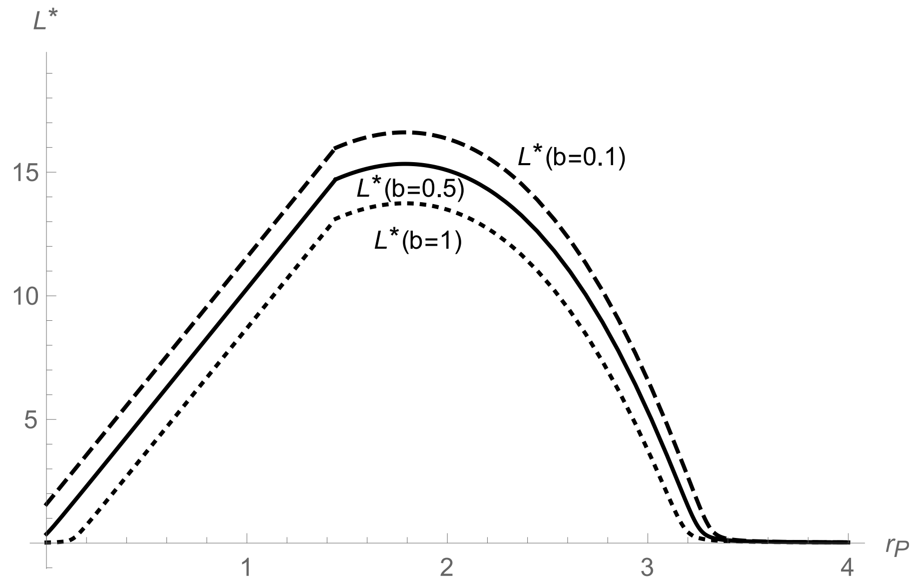


Figure 15: The figure plots bank lending as a function of the policy rate for different values of bank leverage, i.e., low leverage ($b = 1$), medium leverage ($b = 0.5$) and high leverage ($b = 0.1$).

Second, the strength of the pass-through depends on the risk of banks, as measured by their screening effort q. This implies that risky and safe banks differ in terms of lending volumes (Figure 16) and reversal rate (Figure 17). Riskier banks lend less than safer ones for any level of the policy rate and their credit supply responds differently to changes in the interest rate.

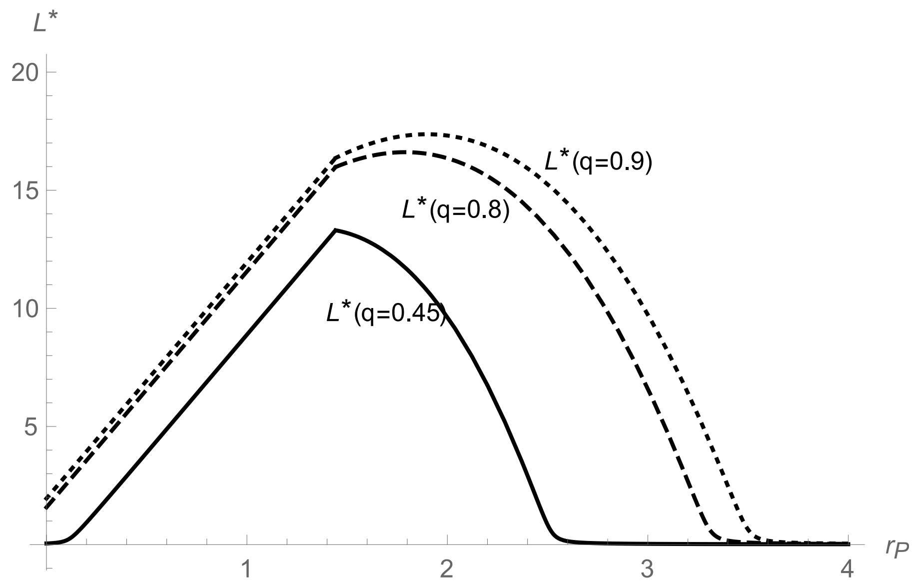


Figure 16: The figure illustrates how lending changes with the policy rate for different levels of banks' screening effort, i.e., low screening (q=0.45); medium screening (q=0.8) and high screening (q=0.9).

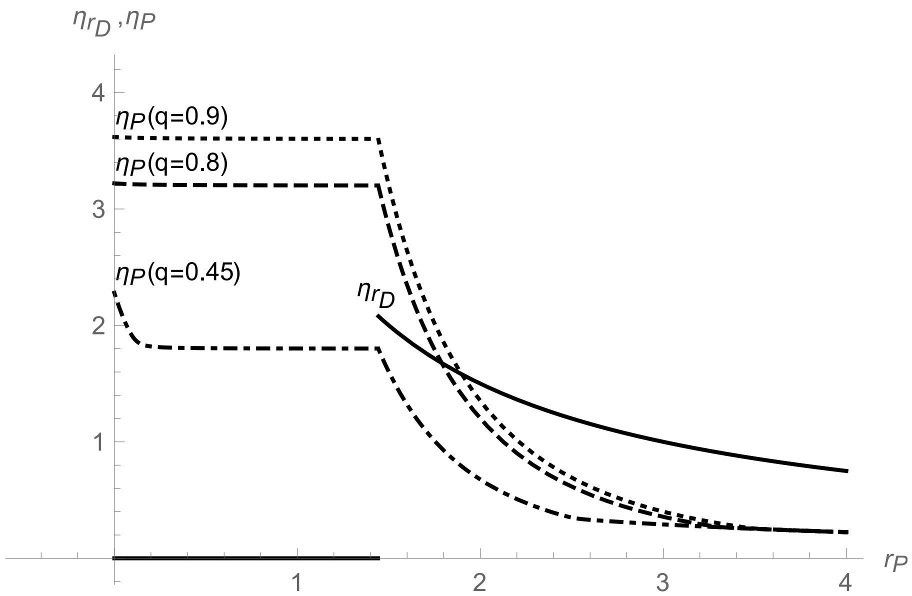


Figure 17: The figure plots the semi-elasticity of deposit rate (solid line) and that of the pledgeable return (dotted lines) for different levels of banks' screening effort, i.e., low screening (q=0.45); medium screening (q=0.8) and high screening (q=0.9).

Interestingly, the reversal rate is higher for safer banks than for riskier ones (Figure 17). For risky banks, i.e., those that screen their loans little, the contractionary effect of a policy-rate cut only emerges when the deposit rate hits its lower bound. For safer banks the sensitivity of the pledgeable return to changes in the policy rate is higher, which translates into a higher semi-elasticity and pushes the reversal rate to the right. The reason is that safer banks can expand more, which, given a downward-sloping demand for credit, reduces loan rates more.

The results show that the effect of policy-rate changes on bank lending depends on bank risk, which itself could respond to the policy rate. In the next section, we therefore consider endogenous bank risk and examine the joint reaction of bank lending and bank risk-taking to monetary policy.

4 Monetary policy and bank risk-taking

So far, the literature on the reversal rate and the literature on bank risk-taking have moved independently.[13] A number of theoretical and empirical papers investigate the role of monetary policy for banks' risk-taking, the so-called "risk-taking channel" of monetary policy (e.g., Borio and Zhu, 2012; Jiménez et al., 2014). Low rates hurt bank profitability and may induce banks

[13] An exception is Koenig and Schliephake (2020). They investigate the interaction of the reversal rate and bank risk-taking using a Monti-Klein-type of model. In their framework, a policy-rate cut either reduces credit or increases risk-taking, they never occur simultaneously.

to take more risk. There are two possibilities. First, banks may engage in a search for yield behavior, i.e., substitute low-yield safe assets with riskier high-yield ones in order to make up for the decline in profitability (Martinez-Miera and Repullo, 2017).[14] Second, the lower profitability and hence, lower charter values make prudent but costly behavior less attractive (Dell' Ariccia et al., 2014).[15]

In the existing literature on risk-taking, a reduction in banks' profitability is necessary to induce an increase in risk. In this respect, the contractionary effect of monetary policy on lending, which is also related to lower profitability, and bank risk-taking appear to be connected.

Our conceptual framework clarifies the natural connection between reversal and risk-taking. Banks behave less prudently when the cost of prudent behavior (e.g., costly screening) outweighs the benefit. The benefit of prudent behavior is the ability to lend and capture the intermediation rent. Prudent banks can attract more outside financing, lever up more, and engage in more profitable intermediation. If monetary policy reduces the benefit of intermediation, risk-taking ensues.

Banks choose the level of screening effort q so to maximize expected profits. In doing this, banks trade-off the marginal cost of screening with the marginal benefit in terms of credit expansion. As shown previously (Figure 8), safer banks lend more than risky ones. By increasing their screening effort, banks relax the external-financing constraint and increase the equity multiplier. As a result, banks can lend more and increase profits.

In our framework, banks operating in more competitive markets tend to be more prudent and screen their loans more (Figure 18). This result is at odds with a literature following Keeley (1990) on the detrimental effect of credit market competition on bank risk-taking or, more broadly, on bank stability. In that literature, more intense competition reduces the loan interest rate and hence, undermines banks' franchise value. This, in turn, induces banks to take on more risk.[16]

[14] Angeloni et al. (2015) propose another channel. A policy-rate cut increases bank risk because banks substitute more stable funding sources with deposits, which are a cheaper but make banks more prone to the risk of a run.

[15] Using the same argument on banks' borrowers, a reduction in loan rates would lead to an increase in borrowers' profitability and so to a decrease in their risk-taking incentives. Overall this mechanism, which resembles the one in Boyd and De Nicoló (2005), would lead to safer banks.

[16] Using the same argument but moving the focus of the analysis from banks to banks' borrowers, Boyd and De Nicoló (2005) show that more competition is beneficial for bank stability as the lower interest rates induce banks' borrowers to take less risk.

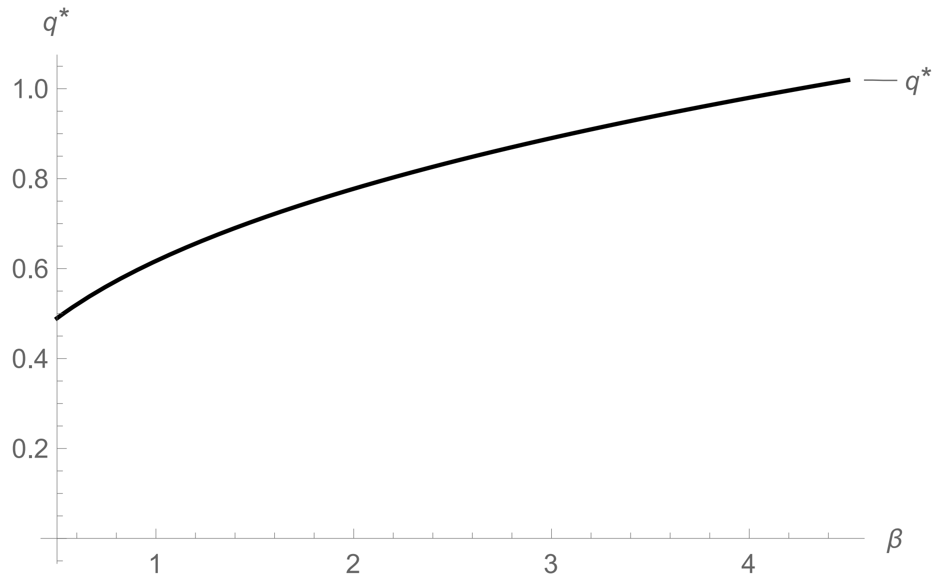


Figure 18: The figure shows that bank screening effort q increases with the degree of credit market competition β.

More competition leads to less risk-taking because it changes the sensitivity of the credit supply to changes in the screening effort. More competition reduces the loan rate and the pleadgeble return. Lending more becomes less profitable ceteris paribus. In order to be able to continue to expand profitable lending, banks engage in more costly screening, which relaxes the external-financing constraint.

The sensitivity of the loan volume to changes in the screening effort is the channel through which a change in the policy rate affects risk-taking.

> A policy-rate cut increases risk-taking when it decreases the sensitivity of loan volume to changes in banks' screening effort, i.e., when $\frac{dL^*}{dq}$ increases with r_p.

A policy-rate cut affects bank risk-taking because the rate cut directly affects the impact of costly screening on lending, i.e., $\frac{dL^*}{dq}$. Banks perform costly screening because it allow to perform more profitable intermediation. When a cut in the policy rate becomes less expansionary (e.g., as shown in Section 3) and makes it more difficult to expand lending, then screening borrowers becomes less attractive.

There is an additional indirect effect operating through the degree of competition. By changing the lending volume, a policy-rate cut affects the loan return, which further changes the benefit of screening (see Figure 18). While the direct effect is always present, the indirect effect manifests itself when banks have market power. Hence, the effect of a policy-rate cut on risk-taking depends on the degree of credit market competition.

> In competitive credit markets, a policy-rate cut increases risk-taking when it leads to a reduction in lending. When banks have market power, increased risk-taking also manifests itself when the policy-rate cut has an expansionary effect on lending.

In our conceptual framework, the effect of a policy-rate cut on risk-taking is intertwined with the effect that it has on lending. Hence, the occurrence of risk-taking may be different in a high-rate and a low-rate environment and, as just explained, this difference depends on the degree of credit market competition.

As with the effect of monetary policy on lending, there are two opposing effects at play. First, a lower policy rate reduces the required rate for depositors and this makes outside financing cheaper. With cheaper outside financing, the incentive to exert costly screening effort increases. Second, a lower policy rate reduces the pledgeable return and this makes outside financing more costly. With more costly outside financing, the incentive to exert effort decreases. The latter effect dominates in a low rate environment where the pass-through to deposits rates is weaker, while is it dominated in normal times so that a policy-rate cut then tends to reduce risk-taking.

In a competitive credit market, where the loan rate does not react to changes in the loan volume, a lower policy rate always induces banks to take more risk in a low rate environment. Moreover, we know that in a low rate environment, a rate cut can be contractionary.

When banks have market power and the loan rate responds to changes in the loan volume, there can be risk-taking in response to a lower policy rate even in normal times when rates are high and monetary policy is expansionary (Figure 19). When banks have market power, more lending leads to lower loan rates and, hence, to a lower pledgeable return. This indirect effect comes on top of the direct effect of a lower policy rate on loan rates. Risk-taking can therefore occur even when there is still considerable pass-through to deposit rates.

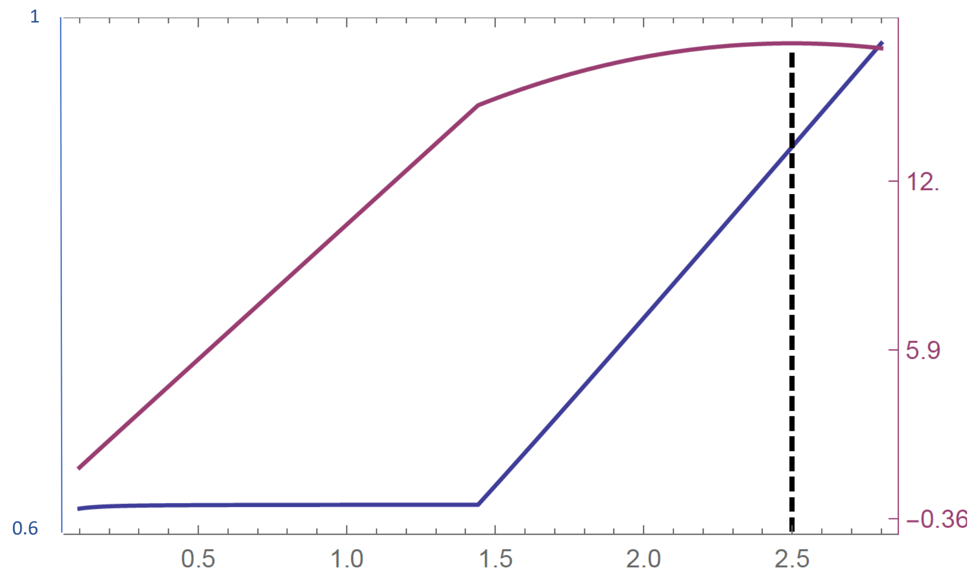


Figure 19: The figure illustrates how the optimal level of screening (blue line) and lending (purple line) change with the policy rate.

The analysis above highlights the close relationship between risk-taking and the contractionary effect of monetary policy on bank lending. In particular, it shows that, in a competitive credit market, increased risk-taking is a necessary, but not sufficient condition, to observe a contraction in lending following a policy-rate cut. The two phenomena are related, but not identical, because changes in the policy rate affect banks' external-financing constraint and hence, the ability to perform profitable intermediation.

In the theory literature, a few recent contributions consider the implications of monetary policy on banks' attitude towards risk. Similarly to us, they are partial-equilibrium models focusing primarily on banks' risk-taking decisions on the asset side.

Dell' Ariccia et al. (2014) develop a model in which banks engage in costly monitoring of their loans to increase the probability of success. In their framework, a change in the policy rate affects both the loan rate and banks' cost of funding positively and translates into movements of banks' profit margins. They show that two opposite mechanisms are at play. On top of the standard charter value mechanism, whereby the policy-rate cut induces banks to take more risk as they have less to gain from behaving prudently, a risk-shifting arguments also applies. By reducing banks' cost of funding, a policy-rate cut leads to an increase banks' (net) interest margin. This increases banks' incentives to take less risk since banks have little room to transfer the losses associated with increased risk-taking to depositors. The strength of the latter effect crucially depends on bank leverage: the more levered the bank, the stronger is the risk-shifting channel.

The analysis in Dell' Ariccia et al. (2014) highlights the role of bank leverage in determining the effect of policy-rate cut on banks' risk-taking. They show that a policy-rate cut leads to less risk-taking when banks have high leverage. The opposite is true for banks with low leverage as the risk-shifting effect associated with a policy-rate cut is small.

In Martinez-Miera and Repullo (2017), the driving force behind banks' risk-taking incentives is also the change in banks' profit margin, i.e., a reduction in the interest rate margin, either via a reduction in the loan rate or an increase in the funding cost, leads to a reduction in banks' monitoring effort. This occur because the benefits banks accrue from exerting effort, as measured by the (net) interest rate margin, decreases, while the cost of monitoring does not.

Bank risk-taking in a low-rate environment is well documented empirically. Maddaloni and Peydró (2011) show that low short-term rates lead to looser credit standards for households and corporate loans. In Jiménez et al. (2014) low rates are shown to induce poorly capitalized banks to grant more credit to riskier borrowers and with fewer collateral requirements. Their evidence highlights the dangers of a (long) period of low interest rates. Using Bolivian credit registry data, Ioannidou et al. (2015) provide evidence of an increased risk appetite of banks following a reduction in the policy rate. Specifically, they show that banks grant new loans to ex-ante less creditworthy borrowers and with a higher ex-post default rate. Ioannidou et al. (2015) focuses on ex-ante measures of risk-taking. A similar approach is taken by Dell' Ariccia et al. (2017). They use confidential data on US banks' loan ratings and show that when interest rates fall, banks become more prone to grant loans to businesses with lower credit ratings.

More recently and with a particular focus on negative rates, Heider et al. (2019) show that accommodative monetary policy leads to increased risk-taking when rates become negative. When rates fall into negative territory, banks' profitability falls since they are constrained in their ability to pass on negative rates to depositors. This effect is particularly strong for banks with a larger deposit base and causes them to lend to riskier borrowers.

A similar mechanism is also at play in Whited et al. (2021). They show that the interaction of monetary policy and bank market power leads to increased risk-taking incentives when the deposit rate approaches zero. Specifically, using micro-level data Whited et al. (2021) quantify the detrimental effect on risk-taking to be equal to 3.2 percent of a bank's balance sheet, or over 10 percent of its newly issued loans.

Evidence supporting the detrimental effect of negative rates on banks' risk-taking is also provided by Bubeck et al. (2020). Using data on security holdings, they show that the introduction of negative rates leads to a reach-for-yield behaviour in the security portfolios of banks. This effect is particularly strong for high-deposits banks.

The contributions described above point to a detrimental effect of accommodative monetary policy on banks' risk-taking incentives. While more risk-taking leads to an increase in banks' ex-post default probability, the existing literature does not explicit explore the implications of an accommodative monetary policy for overall financial stability, with a few exceptions.

The analysis in Mendicino et al. (2021) takes a general-equilibrium view. They consider the effects of a policy-rate cut on both banks' risk-taking incentives and the creditworthiness of their borrowers. In line with the papers above, they show that policy-rate cuts lead to a relaxation of bank credit standards. However, Mendicino et al. (2021) provide evidence that this does not translate into an increase in financial fragility. The reason is that the lower underwriting standards are compensated by an overall improvement in macroeconomic conditions and borrower creditworthiness.

Within a DSGE framework, Afanasyeva and Güntner (2020) reach a different conclusion. They show that in response to a policy-rate cut, banks tend to lend more against a given amount of collateral. This increases the leverage of bank borrowers and reduces their creditworthiness.

A common feature of the above mentioned papers is the focus on risk-taking on the asset side of banks. However, risks can also arise on the liability side because of maturity mismatch and the role of banks as liquidity providers. Several papers in the banking and in the macro-economics literature (e.g., Diamond and Dybvig, 1983; Gertler and Karadi, 2011) investigate the sources of bank risk on the liability side, for example, banks' exposure to runs. [17]

Porcellacchia (2020) also focuses on banks' liability side and on their exposure to fundamental-driven runs in the tradition of Allen and Gale (1998). In his framework, banks' primary function is to offer liquidity to risk-adverse depositors. The associated maturity mismatch exposes them to the risk of a run. Monetary policy determines banks' exposure to runs by affecting banks' profitability and hence, their ability to meet early withdrawals. The analysis in Porcellacchia (2020) characterizes the existence of a cutoff value of the interest rate below which runs emerge (see Box 3).

Still related to the role of banks as liquidity providers, Stein (2012) shows how tighter mon-

[17] Bank run papers (e.g., Diamond and Dybvig, 1983; Goldstein and Pauzner, 2005) are rarely used to study the implication of monetary policy changes. However, in these contributions an increase in the short-term interest rates always leads to more fragility. This hinges on the fact that higher short-term rates increase the strategic complementarity in depositors' withdrawal decisions and so their incentive to run. Hence, a policy-rate cut would reduce banks' exposure to runs in this class of models.

etary policy can be used to induce banks to internalize the detrimental effects of private money creation (i.e., issuance of short-term debt) on systemic crises.

Box 3: What is the tipping point? Low rates and financial stability[a]

Firms and households demand liquid assets, which they can access on demand. Banks supply these, while funding long-term projects. This arrangement is known as maturity transformation. It is efficient, because it allows long-term investment to take place even as firms and households hold liquid assets. However, it is a fragile arrangement, because banks do not have enough resources to redeem all their outstanding liabilities at any point in time.

Fragility is exacerbated if bank profitability falls. This motivates the concern expressed in academic and policy circles that low interest rates, by harming bank profits, may undermine bank stability. To address this concern, I develop a model of financial crises that features the two main channels whereby interest rates affect bank profitability: the revaluation effect and interest-margin compression. In the model, lower bank profits make a crisis more likely by increasing the gap between the resources available to banks at any given point in time and their liabilities.

A reduction in interest rates leads to capital gains on long-term assets, since they have a higher interest rate locked in. This is the revaluation effect. On the other hand, a reduction in interest rates also leads to a compression in the interest-rate margin earned by banks, since cash becomes a more attractive substitute for deposits. At levels of interest rates that are normal by historical standard, there is evidence that the former effect dominates and a cut in interest rates boosts bank profits (English et al., 2018). However, as the level of interest rates falls, interest-margin compression becomes stronger (Maddaloni and Peydró, 2011; Heider et al., 2019).

The main output of the model is a critical level of the policy rate, called the tipping-point rate. If the monetary authority lowers its policy rate below the tipping-point rate, then it induces a negative net effect on bank profitability. This heightens the risk of a financial crisis. The key variable that captures the strength of interest-margin compression, and thus co-determines the tipping-point rate, is the elasticity of banks' deposit franchise (i.e., the present discounted value of bank profits associated with deposits) with respect to the policy rate. This elasticity is known as the effective duration of deposits (Hutchison and Pennacchi, 1996). Importantly, this elasticity increases as the policy rate falls. It is highest when the deposit rate hits zero, because in this case the bank cannot respond to the policy-rate cut by reducing the deposit rate.

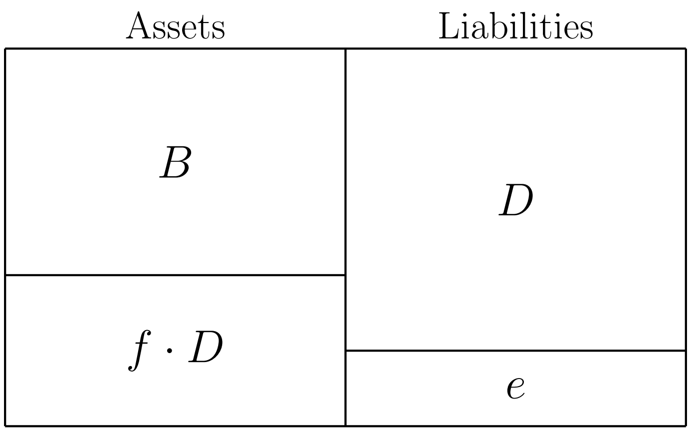


Figure B20: **Bank balance sheet.** Notes: Variable B is the current value of bank assets and D the bank's outstanding liabilities. The deposit franchise is f and e is the equity value of the bank. The revaluation effect of a policy-rate cut increases B and the interest-margin compression reduces f. The net effect on e, and thus on bank stability, depends on the level of the policy rate.

Using findings from the empirical literature, I quantify the effective duration of deposits at 6, once the deposit rate is at its lower bound. Consider a bank that only invests in reserves, so that there is no revaluation effect. This quantification implies that, once the deposit rate is zero, a one-percentage-point permanent policy-rate cut reduces the equity value of such bank by 6%. Finally, I carry out a quantitative application of the model. I study how far the Federal Reserve could have cut its policy rate on the eve of the Great Recession in September 2007 without eroding bank profitability through the channels considered in this model. I find that a cut from the initial 5.25% down to 0.75% is neutral for bank profitability. Below 0.75% the net effect on bank profitability turns negative.

[a]This box was prepared by Davide Porcellacchia and it is based on Porcellacchia (2020).

5 Concluding remarks

This paper investigates the effect of monetary policy-rate cuts on bank lending and risk-taking. We develop a simple conceptual framework to explain how the policy rate affects banks. The aim is to bring together the, so far separate, bank-lending (or bank-capital) channel and the risk-taking channel of monetary policy, and to build a comprehensive view of monetary policy transmission using the ample empirical evidence on the various channels.

The central element of our conceptual framework, which we share with the literature on macro-economics with financial frictions, is an external-financing constraint for banks. To this we add the ex-ante costly screening of borrowers. The constraint arises because of an agency problem between banks and their outside investors. The agency problem creates a wedge between the internal rate on capital and the market rate so that banks' net-interest margins overstate the profitability of bank intermediation.

The external-financing constraint determines bank leverage via an equity multiplier, which changes with the policy rate. When a policy-rate cut changes the equity multiplier, this changes the marginal benefit of screening. This is how we can obtain risk-taking (less screening) in our framework.

The key friction in a low rate environment is the zero lower bound (ZLB) on retail deposit rates. The ZLB makes it more difficult for banks to benefit from a lower cost of funding when the policy rate falls.

Our conceptual framework shows how a contraction in lending and increased risk-taking appear when a central bank cuts the policy rate when the economy is close to the ZLB. Both phenomena are linked through the external-financing constraint, as it determines banks' ability to perform intermediation, which, in turn, shapes the benefit of banks' prudent behavior.

The framework shows a tight connection between the ability of monetary policy to stimulate the economy, financial stability, and competition, as more lending by banks with market power reduces loan rates and further reduces intermediation margins.

Our results imply that it is important for central banks to take financial stability considerations into account when deciding on monetary policy, and that there may be conflicts over the longer run between price stability and financial stability objectives. Moreover, our modeling framework suggests that the competitive nature of lending and deposit markets need to be taken into account when assessing these trade-offs.

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Appendix A

Consider an economy populated by a representative bank and a large number of investors endowed with 1 unit of funds.

At date 0, the bank screens potential borrowers. At $t = 1$ the bank lends a total amount L to firms. At $= 2$ the per-unit loan return is R if firms are able to repay the loans, which happens with probability q, and zero if firms default on their loans. As in Holmström and Tirole (1997), loans are perfectly correlated across borrowers.

We model the screening at $t = 0$ as follows. If the bank exerts a greater costly screening effort, it lends to safer borrowers and loans are repaid more often. For simplicity, we model the screening effort as q, the success probability, and the cost of screening as $\frac{cq^2}{2}$, with $c > 0$. The screening cost can be interpreted as the investment the bank needs to make in setting up a screening team or technology. The cost is independent of the lending volume and is sunk after $t = 0$. Note that outsiders cannot observe q but they will form an expectation about it and this expectations will be correct in equilibrium.

At $t = 1$, when a bank offers a loan supply L^s, it faces a downward-sloping loan-demand curve of the form

$$L^d = \alpha - \beta R. \tag{A.1}$$

An increase in α shifts the demand function, while an increase in β makes demand more sensitive to changes in the lending rate and can therefore be interpreted as an increase in the intensity of competition in the market.

With market clearing $L^s = L^d \equiv L$, and from (A.1) we obtain the loan rate as a function of the equilibrium lending volume:

$$R = \frac{\alpha - L}{\beta}, \tag{A.2}$$

i.e., more lending reduces the loan rate. In addition, we assume that the loan rate is an increasing function of the policy rate r_p. We do not model this direct impact of the policy rate on the loan rate explicitly. Such a direct impact can be justified in a number of ways. For example, by considering the possibility for banks to invest in interest-bearing reserves or more generally, in securities whose return is linked to the policy rate, e.g., interbank loans or government bonds (as in e.g., Brunnermeier and Koby, 2018; Repullo, 2020; Ulate, 2021). In that case, R describes the return on total bank assets. Alternatively, one could consider a dependence of the loan rate on the policy rate because of the loan demand. For example, firms could also borrow in the bond market where the supplier of funds can also invests in governement bonds as in Bolton and Freixas (2006). Alternatively, firms could have an explicit demand for money as in Rocheteau et al. (2018).

To sum up, the loan rate $R(r_p, L)$ increases with the policy rate r_p and decreases with the amount of lending L, i.e., $\frac{\partial R(r_p,L)}{\partial r_p} > 0$ and $\frac{\partial R(r_p,L)}{\partial L} < 0$. Furthermore, consistent with (A.2), we have $\frac{\partial^2 R(r_p,L)}{\partial r_p \partial L} = \frac{\partial^2 R(r_p,L)}{\partial L \partial r_p} = 0$ and $\frac{\partial^2 R(r_p,L)}{\partial L^2} = 0$.

The bank finances loans L with its own equity E and with funds raised as deposits from outsiders, $D = L - E$. We assume equity is fixed because it is costly to issue new equity, especially in the short run (e.g., as a reaction to monetary-policy changes).

Depositors have access to an outside investment opportunity, whose return $r_O(r_p)$ depends positively on the policy rate r_p, i.e., $\frac{\partial r_O(r_p)}{\partial r_p} > 0$. For example, they could hold government bonds instead of bank deposits. Krishnamurthy and Vissing-Jorgensen (2015) and Li et al. (2020) examine government bonds as an alternative to bank liabilities.

Depositors also have the option to store their funds as cash, which yields a (gross) per unit return equal to 1. Hence, the (gross) interest rate r_D promised by banks to depositors must satisfy

$$q r_D \geq \max\{r_O(r_p), 1\}. \tag{A.3}$$

We refer to (A.3) as depositors' participation constraint. It is easy to see that the interest rate r_D is weakly increasing in the policy rate r_p and that a lower bound for the deposit rate exists: The deposit rate r_D never falls below $\frac{1}{q} \geq 1$, otherwise depositors would prefer to hold cash instead of bank deposits. Depositors' participation constraint also shows that the deposit rate r_D decreases with the screening effort q. In other words, safer banks−those with a higher q− need to offer a lower deposit rate, ceteris paribus, than riskier ones. We, thus, denote the deposit rate as $r_D(r_p, q)$ and it holds that $\frac{\partial r_D(r_p,q)}{\partial r_p} \geq 0$ and $\frac{\partial r_D(r_p,q)}{\partial q} < 0$. In equilibrium, depositors' participation constraint is always binding and the interest rate promised to depositors $r_D(r_p, q)$ solves (A.3) with equality.

The ability of the bank to raise external funding is disciplined by an external-financing constraint in the spirit of Holmström and Tirole (1997). Such constraint arises because of the existence of an agency problem between the bank and depositors. At date 0, after the external funds have been collected and loans have been granted, the bank chooses whether to monitor the loans. If the bank shirks on monitoring, a loan only returns $R(r_p, L)$ with probability δq, with $\delta \in (0,1)$, but the bank gains a private benefit $b > 0$ per loan. Hence, the bank monitors its loans only if the following incentive compatibility constraint holds:

$$q\left[R\left(r_p, L\right) L - r_D\left(r_p\right)\left(L - E\right)\right] \geq q\delta\left[R\left(r_p, L\right) L - r_D\left(r_p\right)\left(L - E\right)\right] + bL,$$

which can be rearranged as:

$$\left[R\left(r_p, L\right) - \frac{b}{q\left(1-\delta\right)}\right] L \geq r_D\left(r_p, q\right)\left(L - E\right). \tag{A.4}$$

We denote $R\left(r_p, L\right) - \frac{b}{q(1-\delta)} \equiv \widehat{P}\left(r_p, L\right)$ as the pledgeable return, i.e., the amount per loan the bank can promise to debt-holders without jeopardizing incentives to monitor borrowers. Similarly, we denote $q\widehat{P}\left(r_p, L\right) = qR\left(r_p, L\right) - \frac{b}{(1-\delta)} \equiv P\left(r_p, L\right)$ as the expected pledgeable return. Using these definitions and (A.3), multiplying both sides of the inequality in (A.4) by q we can rearrange it as follows:

$$\max\left\{r_O\left(r_p\right), 1\right\}\left(L - E\right) - P\left(L, r_p\right) L \leq 0, \tag{A.5}$$

thus, finally obtaining

$$\frac{\max\left\{r_O\left(r_p\right), 1\right\}}{\max\left\{r_O\left(r_p\right), 1\right\} - P\left(L, r_p\right)} E \geq L. \tag{A.6}$$

The fraction on the LHS of the inequality identifies the equity multiplier, which we denote as

$$k \equiv \frac{\max\left\{r_O\left(r_p\right), 1\right\}}{\max\left\{r_O\left(r_p\right), 1\right\} - P\left(L, r_p\right)}. \tag{A.7}$$

The equity multiplier is given by the ratio of the expected cost of outside funding relative to the extent to which the expected pledgeable return falls short of the expected cost. Hence, it describes the extent to which the project is not self-financing and requires equity (or balance sheet space) and, so provides a measure of bank leverage. In this respect, as it clearly emerges from condition (A.6), bank's equity (or net worth) limits lending, but the exact limit depends on the size of the equity multiplier. A bank with a higher equity multiplier can rise a large amount of outside funding for each unit of internal funds E, which implies that it ends up with a large debt to equity ratio, i.e., leverage.

The bank chooses first the monitoring effort q and then the amount of lending L so to maximize its expected profits, as given by

$$\max_{L} \Pi(L) = q\left[R(r_p, L)L - r_D(r_p, q)D\right]$$

subject to the resource constraint $L = E + D$, the incentive constraint (A.6) and depositors' participation constraint (A.3). Hence, the bank's problem simplifies to:

$$\max_{L} \Pi(L) = q\left[R(r_p, L)L - r_D(r_p, q)(L - E)\right]$$

subject to

$$L \leq kE,$$

and

$$r_D(r_p, q) = \frac{\max\{r_O(r_p), 1\}}{q}.$$

When in equilibrium (A.6) is binding, so that the optimal level of lending is given by

$$L^* = kE,$$

the bank's maximized profits can be written as follows:

$$\Pi = (L) = \frac{b}{1-\delta}L^* + (P(r_p, L^*) - \max\{r_O(r_p), 1\})kE + \max\{r_O(r_p), 1\})kE.$$

This further simplifies to

$$\Pi = \frac{b}{1-\delta}kE,$$

where we denote $\rho \equiv \frac{b}{1-\delta}$ as the per-loan rent for the bank to ensure monitoring.

Appendix B

Proposition 1. *The optimal level of lending L^* corresponds to the solution to:*

$$\frac{\partial R\left(r_p, L\right)}{\partial L} L+\left[R\left(r_p, L\right)-r_D\left(r_p, q\right)\right]=0 \tag{A.8}$$

for a bank with abundant equity (unconstrained bank), and

$$L^*=k E . \tag{A.9}$$

for a bank with limited equity (constrained bank).

Proof of Proposition 1: The bank chooses L^* to maximize expected profits

$$q\left[R\left(r_p, L\right) L-r_D\left(r_p, q\right)(L-E)\right]$$

subject to $L \leq k E$. The Lagrangian for the bank's problem is given by

$$\mathcal{L}=q\left[R\left(r_p, L\right) L-r_D\left(r_p, q\right)(L-E)\right]-\lambda[L-k E] .$$

Consider first the case when $\lambda=0$. Then, (A.6) is slack and L^* is the solution to

$$\frac{\partial R\left(r_p, L\right)}{\partial L} L+\left[R\left(r_p, L\right)-r_D\left(r_p, q\right)\right]=0 .$$

Consider now the case when $\lambda>0$, then L^* is the solution to (A.6) holding with equality, that is

$$L^*=k E .$$

In this case, the Lagrangian multiplier λ is the solution to

$$q \frac{\partial R\left(r_p, L\right)}{\partial L} L+q R\left(r_p, L\right)-q r_D\left(r_p, q\right)-\lambda\left[1-\frac{\partial k}{\partial L} E\right]=0,$$

where $\frac{\partial k}{\partial L}=\frac{k}{\max \left\{r_O\left(r_p\right), 1\right\}-P\left(r_p, L\right)} \frac{\partial P\left(r_p, L\right)}{\partial L}$, which gives

$$\lambda=q \frac{\frac{\partial R\left(r_p, L\right)}{\partial L} L+R\left(r_p, L\right)-r_D\left(r_p, q\right)}{1-\frac{k}{\max \left\{r_O\left(r_p\right), 1\right\}-P\left(r_p, L\right)} \frac{\partial P\left(r_p, L\right)}{\partial L} E} .$$

The denominator is positive since $\frac{\partial P\left(r_p, L\right)}{\partial L}=q \frac{\partial R\left(r_p, L\right)}{\partial L}<0$. Hence, in order for $\lambda>0$, the numerator must be positive, i.e., $\frac{\partial R\left(r_p, L\right)}{\partial L} L+R\left(r_p, L\right)-r_D\left(r_p, q\right)>0$ and the proposition follows. □

Corollary A.1. *A safe bank lends more than a risky one, i.e.,* $\frac{d L^*}{d q}>0$.

Proof of Corollary A.1: The derivative $\frac{dL^*}{dq}$ is computed using the implicit function theorem, we have:

$$\frac{dL^*}{dq} = \frac{\frac{\partial k}{\partial q} E}{1 - \frac{\partial k}{\partial L} E}.$$

The denominator is positive since $\frac{\partial k}{\partial L} = k \frac{\frac{\partial P(L,r_p)}{\partial L}}{\max\{r_O(r_p),1\} - P(L,r_p)} = k \frac{q \frac{\partial P(L,r_p)}{\partial L}}{\max\{r_O(r_p),1\} - P(L,r_p)} < 0$.

The sign of the numerator is equal to the sign of $\frac{\partial k}{\partial q}$, which is given by:

$$\begin{aligned}
\frac{\partial k}{\partial q} &= k \frac{\frac{\partial P(L,r_p)}{\partial q}}{\max\{r_O(r_p),1\} - P(L,r_p)} \\
&= k \frac{R(L,r_p)}{\max\{r_O(r_p),1\} - P(L,r_p)} > 0.
\end{aligned}$$

Hence, being both $1 - \frac{\partial k}{\partial L} E > 0$, and $\frac{\partial k}{\partial q} > 0$, it follows that $\frac{dL^*}{dq} > 0$. This completes the proof of the corollary. □

Proposition 2. *Denote as η_{r_D} and $\eta_{P(r_p,L^*)}$ the semi-elasticity of the deposit rate and of the pledgeable return to the policy rate, respectively. A policy-rate cut increases lending when $\eta_{r_D} > \eta_{P(r_p,L^*)}$ and decreases it otherwise.*

Proof of Proposition 2: We compute the effect of r_p on L^* using the implicit function theorem. Using (A.9), we obtain that

$$\frac{dL^*}{dr_p} = E \frac{\frac{\partial k}{\partial r_p}}{1 - \frac{\partial k}{\partial L} E}. \tag{A.10}$$

Given the definition of the equity multiplier k in (A.7) and $r_D(q,r_p) = \frac{\max\{r_O(r_p),1\}}{q}$, we obtain:

$$\frac{\partial k}{\partial L} = \frac{k}{\max\{r_O(r_p,1)\} - P(r_p,L^*)} \frac{\partial P(r_p,L^*)}{\partial L} < 0,$$

since from $P(r_p,L^*) = qR(r_p,L) - \frac{b}{1-\delta}$, it follows that $\frac{\partial P(r_p,L^*)}{\partial L} \equiv q \frac{\partial R(r_p,L^*)}{\partial L} < 0$. The expression for $\frac{\partial k}{\partial r_p}$ can be found as follows:

$$\frac{\partial k}{\partial r_p} = \frac{q \frac{\partial r_D(r_p,q)}{\partial r_p}(1-k) + k \frac{\partial P(r_p,L^*)}{\partial r_p}}{\max\{r_O(r_p,1)\} - P(r_p,L^*)}.$$

Since $\frac{\partial k}{\partial L} < 0$ and, as a result, the denominator in (A.10) is positive, the sign of $\frac{dL^*}{dr_p}$ is equal to the sign of $\frac{\partial k}{\partial r_p}$.

We can rearrange the numerator of $\frac{\partial k}{\partial r_p}$ as follows:

$$\frac{k}{k-1} \frac{\partial P(r_p,L)}{\partial r_p} - q \frac{\partial r_D(r_p,q)}{\partial r_p}.$$

Substituting k from (A.7), the expression above can be rewritten as follows:

$$qr_D(r_p,q)\left[\frac{1}{P(r_p,L^*)}\frac{\partial P\left(r_p,L^*\right)}{\partial r_p}-\frac{1}{r_D(r_p,q)}\frac{\partial r_D\left(r_p,q\right)}{\partial r_p}\right].$$

The term $\frac{1}{P(r_p,L^*)}\frac{\partial P(r_p,L^*)}{\partial r_p}$ represents the semi-elasticity of the expected pledgeable return to changes in the policy rate and we denote it as $\eta_{P(r_p,L^*)}$. Similarly, the term $\frac{1}{r_D(r_p,q)}\frac{\partial r_D(r_p,q)}{\partial r_p}$ is the semi-elasticity of the deposit rate to changes in the policy rate and we denote it as η_{r_D}. The expression above can be rewritten as follows:

$$qr_D(r_p,q)\left[\eta_{P(r_p,L^*)}-\eta_{r_D}\right].$$

It follow that $\frac{dL^*}{dr_p}<0$ when $\eta_{P(r_p,L^*)}<\eta_{r_D}$, and $\frac{dL^*}{dr_p}>0$ when $\eta_{P(r_p,L^*)}>\eta_{r_D}$. Hence, the proposition follows.

Lemma 1. *The optimal level of screening q^* is given by the solution to*

$$-cq+\frac{b}{1-\delta}\frac{dL^*}{dq}=0. \tag{A.11}$$

Proof of Lemma 1: Using $L^*=kE$ and $qr_D\left(r_p,q\right)=\max\left\{r_O\left(r_p\right),1\right\}$, we can write a constrained bank's profits as follows:

$$\Pi(L^*)=\frac{b}{1-\delta}L^*-c\frac{q^2}{2}, \tag{A.12}$$

since $P\left(L^*,r_p\right)=qR\left(L^*,r_p\right)-\frac{b}{1-\delta}$. Differentiating (A.12) with respect to q, we obtain the expression as in (A.11) and the lemma follows.

Lemma 2. *The effect of a policy change on risk-taking is given by the sign of $\frac{d^2L^*}{dqdr_p}$.*

Proof of Lemma 2: To compute the effect of a policy-rate cut on risk-taking, we use the implicit function theorem as follows:

$$\frac{dq^*}{dr_p}=-\frac{\frac{\partial FOC}{\partial r_p}}{\frac{\partial FOC}{\partial q}},$$

where FOC is given by (A.11). The denominator $\frac{\partial FOC}{\partial q}$ is negative since a high c guarantees that q^* is an interior solution. Hence, the sign of $\frac{dq^*}{dr_p}$ is equal to the sign of $\frac{\partial FOC}{\partial r_p}$, which is given by

$$\frac{\partial FOC}{\partial r_p}=\frac{b}{1-\delta}\frac{d^2L^*}{dqdr_p},$$

and the Lemma follows.

Proposition 3. *When* $\frac{\partial R(r_p,L^*)}{\partial L} = 0$, *a policy-rate cut increases risk-taking in a low interest rate environment when monetary policy has a contractionary effect on lending, i.e.,* $\frac{dq^*}{dr_p} > 0$ *when* $\eta_{r_p} < \eta_P$. *When* $\frac{\partial R(r_p,L^*)}{\partial L} < 0$, *the effect that of a policy-rate cut has on risk-taking is weakened both in a low interest rate environment and in normal times.*

Proof of Proposition 3: From Corollary A.1, we have that

$$\begin{aligned}
\frac{dL^*}{dq} &= E\frac{k}{1-k\frac{\frac{\partial P(r_p,L^*)}{\partial L}}{\max\{r_O(r_p),1\}-P(r_p,L^*)}E}\frac{R(r_p,L^*)}{\max\{r_O(r_p),1\}-P(L^*,r_p)} \\
&= E\frac{kR(r_p,L^*)}{[\max\{r_O(r_p),1\}-P(r_p,L^*)]\left[1-k\frac{\frac{\partial P(r_p,L^*)}{\partial L}}{\max\{r_O(r_p),1\}-P(r_p,L^*)}E\right]} \\
&= E\frac{kR(r_p,L^*)}{\max\{r_O(r_p),1\}-P(r_p,L^*)-k\frac{\partial P(r_p,L^*)}{\partial L}}.
\end{aligned}$$

Differentiating the expression above with respect to r_p, we can compute $\frac{d^2L}{dqdr_p}$ as follows:

$$\begin{aligned}
\frac{d^2L^*}{dqdr_p} &= E\frac{\left[\frac{\partial k}{\partial r_p}+\frac{\partial k}{\partial L}\frac{dL^*}{dr_p}\right]R(r_p,L^*)+k\frac{\partial R(r_p,L^*)}{\partial r_p}+k\frac{\partial R(r_p,L^*)}{\partial L}\frac{dL^*}{dr_p}}{\max\{r_O(r_p),1\}-P(r_p,L^*)-k\frac{\partial P(r_p,L^*)}{\partial L}} \\
&\quad -\frac{dL^*}{dq}\frac{\left[\frac{\partial\max\{r_O(r_p),1\}}{\partial r_p}-\frac{\partial P(r_p,L^*)}{\partial r_p}-\frac{\partial P(r_p,L^*)}{\partial L}\frac{dL^*}{dr_p}\right]}{\max\{r_O(r_p),1\}-P(r_p,L^*)-k\frac{\partial P(r_p,L^*)}{\partial L}} \\
&\quad +\frac{dL^*}{dq}\frac{\frac{\partial P(r_p,L^*)}{\partial L}\left[\frac{\partial k}{\partial r_p}+\frac{\partial k}{\partial L}\frac{dL^*}{dr_p}\right]}{\max\{r_O(r_p),1\}-P(r_p,L^*)-k\frac{\partial P(r_p,L^*)}{\partial L}},
\end{aligned} \tag{A.13}$$

since $\frac{\partial^2 P(r_p,L^*)}{\partial L\partial r_p} = 0$.

Set $\frac{\partial R(r_p,L^*)}{\partial L} = 0$. This also implies that $\frac{\partial P(r_p,L^*)}{\partial L} = 0$ and, as a result, the expression in (A.13) simplifies to

$$\frac{d^2L^*}{dqdr_p} = E\frac{\frac{\partial k}{\partial r_p}R(r_p,L^*)+k\frac{\partial R(r_p,L^*)}{\partial r_p}}{[\max\{r_O(r_p),1\}-P(r_p,L^*)]} - \frac{dL^*}{dq}\frac{\left[\frac{\partial\max\{r_O(r_p),1\}}{\partial r_p}-\frac{\partial P(r_p,L^*)}{\partial r_p}\right]}{[\max\{r_O(r_p),1\}-P(r_p,L^*)]}$$

where

$$\frac{\partial k}{\partial r_p} = \frac{\frac{\partial\max\{r_O(r_p),1\}}{\partial r_p}(1-k)+kq\frac{\partial R(r_p,L^*)}{\partial r_p}}{\max\{r_O(r_p),1\}-P(r_p,L^*)},$$

and

$$\left.\frac{dL^*}{dq}\right|_{\frac{\partial R(r_p,L^*)}{\partial L}=0} = kR(r_p,L^*)\frac{E}{\max\{r_O(r_p),1\}-P(r_p,L)}.$$

Hence, we can rewrite

$$\frac{d^2L}{dqdr_p} = \frac{ER\left(r_p,L^*\right)}{\left[\max\left\{r_O\left(r_p\right),1\right\}-P\left(L^*,r_p\right)\right]}\frac{\frac{\partial\max\{r_O(r_p),1\}}{\partial r_p}(1-k)+kq\frac{\partial R(r_p,L^*)}{\partial r_p}}{\max\left\{r_O\left(r_p\right),1\right\}-P\left(r_p,L^*\right)} \tag{A.14}$$
$$+\frac{E}{\left[\max\left\{r_O\left(r_p\right),1\right\}-P\left(r_p,L^*\right)\right]}k\frac{\partial R\left(r_p,L^*\right)}{\partial r_p}$$
$$+\frac{ER(r_p,L^*)}{\max\left\{r_O\left(r_p\right),1\right\}-P\left(r_p,L^*\right)}k\frac{\left(q\frac{\partial R(r_p,L^*)}{\partial r_p}-\frac{\partial\max\{r_O(r_p),1\}}{\partial r_p}\right)}{\left[\max\left\{r_O\left(r_p\right),1\right\}-P\left(r_p,L^*\right)\right]}.$$

The second term in (A.15) is positive, we can sum up the first and last term obtaining the following:

$$\frac{ER(r_p,L^*)}{\max\left\{r_O\left(r_p\right),1\right\}-P\left(r_p,L^*\right)}\frac{2kq\frac{\partial R(r_p,L^*)}{\partial r_p}-(2k-1)\frac{\partial\max\{r_O(r_p),1\}}{\partial r_p}}{\left[\max\left\{r_O\left(r_p\right),1\right\}-P\left(r_p,L^*\right)\right]},$$

which is greater than zero when

$$q\frac{2k}{2k-1}\frac{\partial R\left(r_p,L^*\right)}{\partial r_p}>\frac{\partial\max\left\{r_O\left(r_p\right),1\right\}}{\partial r_p}$$

From the proof of Proposition 2, we know that a policy-rate cut becomes contractionary when

$$\frac{k}{k-1}\frac{\partial P\left(r_p,L\right)}{\partial r_p}-q\frac{\partial r_D\left(r_p,q\right)}{\partial r_p},$$

which is equivalent to

$$q\frac{k}{k-1}\frac{\partial R\left(r_p,L^*\right)}{\partial r_p}>\frac{\partial\max\left\{r_O\left(r_p\right),1\right\}}{\partial r_p}.$$

Furthermore, following the same steps in the proof of Proposition 2, can be rearranged using the semi-elasticities as follows:

$$\eta_{r_D}<\eta_{P(r_p,L^*)}.$$

Since $\frac{2k}{2k-1}<\frac{k}{k-1}$, the first and last term in (A.15) sum up to a positive one when the policy-rate cut is contractionary. As a consequence, when (5) holds, the expression in (A.15) is greater than zero, which also implies that $\frac{dq^*}{dr_p}>0$.

Consider now the case in which $\frac{\partial R(r_p,L^*)}{\partial L}<0$. As shown above, the sign of $\frac{dL^*}{dqdr_p}$ depends on the sign of the numerator, since the denominator $\left[\max\left\{r_O\left(r_p\right),1\right\}-P\left(r_p,L^*\right)-\frac{\partial P(r_p,L^*)}{\partial L}\right]$ is always positive. Then, the additional terms we need to consider on top of those already included in the expression for $\left.\frac{d^2L}{dqdr_p}\right|_{\frac{\partial R(r_p,L^*)}{\partial L}=0}$ are given by

$$\Delta = E\frac{dL^*}{dr_p}\left[\frac{\partial k}{\partial L}R\left(r_p,L^*\right)+k\frac{\partial R\left(r_p,L^*\right)}{\partial L}\right]+\frac{dL^*}{dq}\frac{dL^*}{dr_p}\frac{\partial P\left(r_p,L^*\right)}{\partial L} \tag{A.15}$$
$$+\frac{dL^*}{dq}\frac{\partial P\left(r_p,L^*\right)}{\partial L}\left[\frac{\partial k}{\partial r_p}+\frac{\partial k}{\partial L}\frac{dL^*}{dr_p}\right].$$

The sign of the terms in the first line in the expression for Δ are equal to the opposite sign of

$\frac{dL^*}{dr_p}$. The sign of the last term $\frac{dL^*}{dq}\frac{\partial P(r_p,L^*)}{\partial L}\left[\frac{\partial k}{\partial r_p}+\frac{\partial k}{\partial L}\frac{dL^*}{dr_p}\right]$ depends crucially on the overall effect that a change in the policy rate has on the equity multiplier k, i.e., the term $\frac{\partial k}{\partial r_p}+\frac{\partial k}{\partial L}\frac{dL^*}{dr_p}$. This can be rewritten as follows:

$$\begin{aligned} & \frac{\frac{\partial \max\{r_O(r_p),1\}}{\partial r_p}(1-k)+k\frac{\partial P(r_p,L^*)}{\partial r_p}+k\frac{\partial P(r_p,L^*)}{\partial L}\frac{dL^*}{dr_p}}{\max\left\{r_O\left(r_p\right),1\right\}-P\left(r_p,L^*\right)} \\ = & \frac{q\frac{\partial r_D(r_p,q)}{\partial r_p}(1-k)+kq\frac{\partial R(r_p,L^*)}{\partial r_p}+kq\frac{\partial R(r_p,L^*)}{\partial L}\frac{dL^*}{dr_p}}{\max\left\{r_O\left(r_p\right),1\right\}-P\left(r_p,L^*\right)}, \end{aligned}$$

using $r_D\left(r_p,q\right)=\frac{\max\{r_O(r_p),1\}}{q}$. It easy to see that when $\frac{\partial r_D(r_p,q)}{\partial r_p}<\frac{k}{k-1}\frac{\partial R(r_p,L^*)}{\partial r_p}$, which implies $\frac{dL^*}{dr_p}>0$, $\frac{\partial k}{\partial r_p}+\frac{\partial k}{\partial L}\frac{dL^*}{dr_p}>0$ and so also the sign of the last term in (A.15) is equal to the opposite sign of $\frac{dL^*}{dr_p}$. Hence, the proposition follows.

Appendix C

We illustrate the results of the analysis in Appendix B through a simple numerical example. The figures included in the main text are also drawn using the numerical example. Specifically, we assume the following. Banks face a downward sloped demand function of the form:

$$R(L)=\gamma r_p+\frac{\alpha-L}{\beta}.$$

Depositors obtain the return

$$r_O(r_p)=\frac{r_p^3}{3}$$

from investing their funds into an alternative investment opportunity. The numerical example throughout the text is derived for the current parameter space: $\gamma=4;\alpha=5;\delta=0.02;b=0.1;\beta=2.5;E=0.01$ and $r_p=1.7$, unless otherwise specified. All returns are gross.

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