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Abstract

We investigate the relationship between monetary policy and banks' risk-taking behavior. We study a general equilibrium model in which a risk averse bank credits firms and also manages a portfolio consisting of a risky and a risk-free asset. When a bank signs up credit contracts with firms, it takes into account their solvency and potential gains from outside investment strategies. We show that the bank's asset/liability and risk management depend on the prevailing policy rate. However, low policy rates incentivizes a bank to search-for-yield by re-allocating their asset portfolios towards more risky exposures ultimately leads to under-capitalized positions. This renders the financial sector more vulnerable.

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1 Introduction

The excessive risk taking of financial intermediaries, and especially of the banking sector, is nowadays acknowledged to be one of the most important threats to macroeconomic stability. In this context, various studies such as Rajan (2006), Dell'Ariccia and Marquez (2006), Maddaloni and Peydró (2011), Delis and Kouretas (2011) and Adrian et al. (2019), among others, have established a link between the relatively low interest rates prevailing in the most industrialized countries over the last two decades, especially in the US and in Europe, and the excessive risk taking of the banking sector (see also Buch et al. (2014) for survey-based evidence on bank risk-taking). Indeed, as risk-free assets like sovereign bonds ceased to be relatively profitable investments, banks and other financial intermediaries turned to a *search-for-yield* behavior linked with an excessive risk-taking, which, in conjunction with weak banking supervision, led to a build-up of systemic financial risk and lastly to the Global Financial Crisis.

Three notable studies which focus in detail on the mechanisms behind the banks' *search-for-yield* behavior are Dell'Ariccia and Marquez (2006), Dell'Ariccia et al. (2014) and Martinez-Miera and Repullo (2017). In particular, Dell'Ariccia et al. (2014) set up a partial equilibrium model where risk-neutral banks raise deposits and invest them in a risky loan portfolio, which they monitor with a quadratic cost function. The authors show that this monitoring effect can be either negatively or positively related to the risk-free policy rate depending on the extent of the bank's capitalization. Similarly, in Martinez-Miera and Repullo (2017) risk-neutral (monitoring) banks maximize profits by using an optimal monitoring intensity which is not observable to investors. This creates a moral hazard problem which is the key friction of their approach: A reduction in the policy rate, induced e.g. by an increase in the supply of savings, lowers the loan rate spreads, but also increases the relative size of the non-monitoring banking system. This in turn decreases the monitoring intensity of traditional (monitoring) banks and thus favors their default probability.

In contrast to these studies, the present paper contributes to the existing literature on search-for-yield behavior by focusing on the risk aversion dimension of the decision making of financial intermediaries. More specifically, we develop a simple model of financial intermediation where a representative bank grants loans to firms in a traditional manner and, additionally, manages an asset portfolio consisting of risky and risk-free assets. In contrast to most of the existing literature, where lenders are often considered to be risk-neutral or to be able to diversify out risks perfectly, we assume following Greenwald and Stiglitz (1993) that both the firm that requests loans to finance its production costs and the bank are risk averse: the firm's managers fear the possibility of default, and the bank's managers, featuring a mean variance utility, are averse towards the higher risk exposure, which is associated with asset price risk volatility.

We show that under certain conditions, the bank managers' risk aversion may lead to credit rationing, represented by an inverse "C" shaped loan offer curve similar to the one in Jaffee and Stiglitz (1990), though emerging from different microfoundations. Accordingly, the loan offer curve is positively sloped over the range where the probability of default rises with the size of the credit, as higher lending rates compensate the bank for the higher probability of default on larger loans. At some point, the loan offer curve becomes backward-bending due to the convex penalties the bank managers face from expanding the loan supply. As a result, the borrower will be credit rationed since the bank is unwilling to expand the loan size independently from the level of the offered interest rate.

We then use our model to investigate how the bank chooses the riskiness of its asset portfolio for different levels of the bank's funding rate (the rate of return on risk-free asset), assumed to be equal to the policy rate. We obtain the following main results: *First*, loose monetary policy, i.e. a lower policy rate leads to a reduction of the loan interest rate charged by the bank, and thus to "cheaper" credit similarly to Dell'Ariccia et al. (2014), with the exception that we do not have a risk-shifting effect since the bank's funding costs are supposed to be exogenous. *Second*, a reduction in the policy rate generates an incentive for a *search-for-yield* behavior by the bank, as it induces the bank to re-allocate its asset portfolio towards more risky assets. This is due to the increasing opportunity costs and the positive interest rate pass-through effect that amplifies the reallocation of the assets in the bank's financial portfolio in equilibrium. Although the bank is assumed to be risk averse, it gradually substitutes out risk-free by risky assets when the reference (risk-free) interest rate declines, as it is standard in portfolio choice models. And *third*, we show that the bank's financial position, which we define here as the Tier 1 capital ratio according to the guidelines of the Basel III accord (Basel Committe on Banking Supervision (BCBS), 2017*a*, p. 140), is weakened by decreasing policy rates, as the bank shifts from a well-capitalized to a poor-capitalized position in response to lower relative profitability of the risk-free asset. Consequently, since the bank is willing to take more risk in low interest rate regimes in order to maintain stable profits, the bank's financial position reaches the minimum capital requirements as the policy rate approaches zero.

The remainder of this paper is organized as follows: Section 2 introduces the model and examines its equilibrium. Section 3 studies through comparative statics the impact of monetary policy on the model's equilibrium, as well as the asset re-allocation effects resulting from a variation in the risk-free interest rate. In that section we also examine the bank's risk-taking behavior by relating it to a measure of the bank's capital ratio. Section 4 draws some concluding remarks from this study.

2 The Model

2.1 The Firm

The firm's behavior is based on the model from Greenwald and Stiglitz (1990, 1993). Accordingly, we assume a representative, profit maximizing firm which sells its goods at a price P determined according to

$$P = u\bar{P}, \tag{1}$$

where $\bar{P}$ denotes the average market price and u is the firm specific relative price, which is a randomly distributed variable with $u \sim NID(\mu_u, \sigma_u^2)$.[1] Without a loss of generality, we normalize the average market price $\bar{P}$ and expected relative price $E(u)$ to $\bar{P} = E(u) = \mu_u = 1$. We denote the probability density and cumulative distribution functions (CDF) of u as $f(\cdot)$ and $F(\cdot)$, respectively.[2]

The firm's production costs are financed by the firm's equity or net worth and by loans obtained from the commercial bank. Accordingly, the loan incurred by the firm is equal to

$$B = g(Y) - W, \tag{2}$$

where B represents the loan amount, $g(Y)$ the production cost function and $W = W^n/\bar{P}$ is

[1] As a robustness exercise, we have also derived the model under the assumption that relative prices are distributed uniformly with $u \sim U(0, 2)$. This specification led to qualitatively similar results. We decided to report the model based on the normal distribution, since it is more realistic and does not exhibit heavy tails.

[2] The original strand of the literature on credit rationing (see e.g. the seminal work by Greenwald and Stiglitz, 1993) treated the relative price u in a general fashion, without specifying its distribution. Our model is related to work by Gatti et al. (2005), who implemented the microfoundations of Greenwald and Stiglitz (1993) into an ABM framework by considering a uniformly distributed random variable.

the firm's real net worth, which under the normalization of $\bar{P} = 1$ coincides with the firm's nominal net worth W^n. We further assume that the firm's production function is

$$Y = \phi K^{\frac{1}{2}} \quad \text{with} \quad \phi > 0,$$

where the term K represents a composite of the input factors required by the production process. Hence, the firm's total production costs are

$$g(Y) = p_k K = \psi Y^2 \tag{3}$$

for $\psi \equiv p_k/\phi^2$, where p_k represents the total price of the composite of input factors. As the production costs are convex in Y (and the production function is concave in K), it holds that

$$\frac{\partial g(Y)}{\partial Y} > 0, \quad \frac{\partial^2 g(Y)}{\partial Y \partial Y} > 0, \quad \frac{\partial Y}{\partial K} > 0 \quad \text{and} \quad \frac{\partial^2 Y}{\partial K \partial K} < 0.$$

As the firm is assumed to determine its production level before the relative price shock u is realized, it may be forced to default on its debt if the firm's debt obligations exceed its realized sales revenues, i.e. if $PY - R^b B < 0$, where R^b and B denote the loan rate and loan volume upon which the firm and commercial bank agreed, respectively. By (2), the firm remains thus solvent when the stochastic relative price u is above a threshold given by

$$u \geqslant R^b \left(\frac{g(Y) - W}{Y} \right) \equiv \bar{u}. \tag{4}$$

Based on this default threshold $\bar{u}$, we can now derive the firm's default probability as the CDF of the underlying distribution of the random variable u evaluated at the critical relative price $\bar{u}$:[3]

$$Pr\left[u < R^b \left(\frac{g(Y) - w}{Y} \right) \right] = \int_0^{\bar{u}} f(u) du = F(u). \tag{5}$$

Following Greenwald and Stiglitz (1993) we assume that the firm managers are rewarded for maximizing the firm's expected (real) profit, but are also penalized for debt funding due to shareholders' aversion towards a possible bankruptcy. Hence, the managers' problem is given

[3] To ensure that the firm possesses a certain resilience against disadvantageous random price shocks, we further assume that the parameters of the firm's production function and the relative price's distribution are such that the firm hit by the average shock is solvent in the equilibrium, namely that $\mu_u > \widehat{\bar{u}}$.

by

$$\max_{Y} E\left\{PY - R^b(g(Y) - W) - \Upsilon(Y)F(u)\right\}, \tag{6}$$

where $\Upsilon(Y)$ is a bankruptcy cost function, weighted by the probability of default (5). These bankruptcy costs increases proportionally with the level of the firm's output, formally:

$$\Upsilon(Y) = \chi Y \tag{7}$$

where $\chi > 0$ is a scaling parameter.[4] As the firm is assumed to be a price-taker in the market for loans, the firm treats the contractual credit rate R^b as an "exogenous" variable set by the bank (c.f. Gale and Hellwig, 1985). In other words, the bank defines its optimal loan supply, i.e. the pair of loan quantity and price (the loan rate), and the firm chooses the point along the bank's loan supply curve which maximizes its expected profits, as it will be discussed below.

The first-order condition of the firm's optimization problem in equation (6) is

$$\begin{aligned} 1 - \psi 2YR^b - \chi\left[F(u) + Yf(\bar{u})\frac{\partial \bar{u}}{\partial Y}\right] &= 0, \\ 1 - \psi 2YR^b &= \rho, \end{aligned} \tag{8}$$

where $\rho = \chi\left[F(u) + Yf(\bar{u})\frac{\partial \bar{u}}{\partial Y}\right]$ are the marginal bankruptcy costs with $\frac{\partial \bar{u}}{\partial Y} = R^b\left(\psi - \frac{W}{Y^2}\right)$.

In absence of the marginal bankruptcy costs ρ, the first-order condition in equation (8) suggests that the average market price (which is normalized at unity) coincides with the marginal costs $\psi 2YR^b$ in the optimum, which is a standard result. If instead the firm acts in a risk averse manner, the marginal bankruptcy costs ρ increase rapidly and in a nonlinear manner that implies that there is a permanent mismatch between price and marginal costs. Accordingly, the average market price exceeds the firm's marginal costs depending on its production level Y, its financial wealth W, the contractually determined loan rate R^b and the degree of uncertainty regarding the firm's (post-contractual) relative price, i.e. the dis-

[4]We use this specification of the bankruptcy costs for the sake of analytical tractability. Greenwald and Stiglitz (1993) justify it by arguing that bankruptcy afflicts larger firms more, because they hire relatively more managers, who in turn fear that their position, power and income would be impaired in the event of bankruptcy. In comparison, Gatti et al. (2005) assume a quadratic cost function. Other approaches are mostly related to the "costly state verification" (CSV) problem of asymmetric information which goes back to the works of Townsend (1979) and Bernanke et al. (1999). Accordingly, entrepreneurs are funded by banks that cannot fully observe the entrepreneur's effort. The bank is thus engaged in costly monitoring which in turn reduces credit risk due to a reduction of the lender's default probability. Both approaches, the bankruptcy and the monitoring costs, deliver similar results as long as the respective costs are sufficiently convex in Y.

tribution functions $F(\,\cdot\,)$ and $f(\,\cdot\,)$. Together with the financing condition (2), this solution can be transformed to firm's optimal credit demand function

$$B^D = \arg\max_B E\left\{PY - R^b(\psi Y^2 - W) - \chi(Y)F(u) \mid Y = \sqrt{(1/\psi)(B+W)}\right\}$$
$$\equiv m(R^b, W). \tag{9}$$

From equation (9) we derive the following proposition:

Proposition 1 *Let the random sales price be uniformly distributed with any arbitrarily chosen support, i.e.* $u \sim U[\underline{x}, \overline{x}]$ *with* $0 \geqslant \underline{x} < \overline{x}$*, then the loan-demand curve is negatively sloped and convexly shaped in the lending rate* R^b*. It follows that* $m'_{R^b} = \partial m(R^b, W)/\partial R^b < 0$ *and* $m''_{R^b} = \partial^2 m(R^b, W)/\partial R^{b^2} > 0$ *hold.*

The analytical proof of Proposition 1 can be found in Appendix B. As an analytical discussion of the curvature of the loan-offer curve for a normally distributed random sales price is quite unwieldy, we provide a graphical illustration in Figure 1 for different values of the bankruptcy costs parameter χ, based on the parameter values reported in Table 1 in Appendix A.[5]

Figure 1 clearly shows that the firm's optimal loan demand is sufficiently convex even in the case of a normal distributed random variable u and low values of χ. This demand is declining in χ, *ceteris paribus*, while its curvature becomes more pronounced for increasing values. Note that the convexity of the loan demand function does not arise exclusively from to the nonlinear bankruptcy costs – in fact it emerges even in case when the marginal bankruptcy costs in equation (8) are zero, i.e. $\rho = 0$. We will tackle this issue with the help of the following lemma:

Lemma 1 *In absence of marginal bankruptcy costs* ($\rho = 0$) *the credit demand curve is uniquely defined and convex in the loan rate* R^b*.*

Proof can be found in Appendix C.

2.2 Bank Behavior and Asset Management

The bank is considered to act as a financial intermediary with no liquidity constraints. For the sake of simplicity, we assume that it raises its funds D from outside investors, subject to

[5] The analytical proof for the convexity of this loan demand function in the loan rate R^b for the case of a normally distributed random variable u can be found in Appendix C.

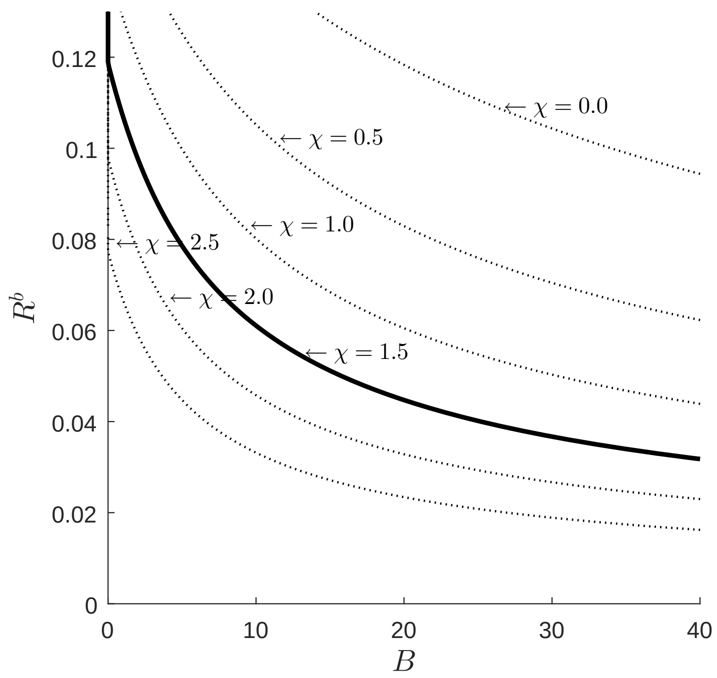


Figure 1: The firm's optimal loan demand (equation 9) for different values of the bankruptcy costs parameter $\chi \in [0, 2.5]$.

an infinitely elastic supply with a fixed return R^d. In other words, $R^d D$ represents the bank's deposit liabilities.[6]

The bank manages a financial portfolio consisting of three financial assets: (i) the aforementioned loan to the firm B, for which the bank can set the interest rate R^b; (ii) a risky asset A (such as an index of stocks) with a price p^a; and (iii) a risk-free asset Q with a fixed return R^q, which we will interpret as a sovereign bond. The bank's balance sheet is therefore

$$B + Q + p^a A = D + W^b, \tag{10}$$

where W^b is the bank's equity capital. The bank's profits are then defined as the income

[6]Under the traditional money creation mechanism, the bank is price-taker on the market of commercial savings, i.e. small enough to be able to attract a sufficient number of depositors on the one hand, but unable to influence the deposit rate R^d, on the other hand. Under the modern money creation mechanism, the bank automatically creates an equivalent deposit account for the debtor, hence its liabilities coincide with assets (abstracting from the interbank network). Regardless of the interpretation, our assumption implies that the bank's liabilities are independent of its risk-taking behavior, i.e. the deposit rate does not depend on the bank's own capital ratio or the regulatory minimum capital requirements (c.f. Repullo, 2004).

stream net of funding costs given by

$$\Pi = R^b B + R^a A + R^q Q - R^d D. \tag{11}$$

Analogously to the firm's problem, the bank maximizes its expected profit

$$\max_{A,B,Q} E\left\{\Pi - \Psi(B)F(u)\right\} - \frac{\gamma}{2}Var(R^a A) \tag{12}$$

subject to the budget constraint given by its balance sheet (10) (c.f. Greenwald and Stiglitz, 1988, 1993).

The latter two terms in (12) account for the two sources of risk for the bank. The first penalty comes from the loan component B of the bank's portfolio. Whenever the bank issues a loan B to the firm, the latter can bankrupt with probability $F(u)$, in which case the bank faces a penalty cost $\Psi(B)$.[7] For the sake of simplicity, we will further assume that this penalty cost is a linear function ηB for some $\eta > 0$. Notice that because the default probability $F(u)$ is nonlinear with B, this is not a restrictive assumption. The second penalty term stems from the risky asset component A of the bank's portfolio. We assume that the bank evaluates this asset based on the standard mean-variance utility function, in which the variance $Var(\cdot)$ on the return of A represents the risk penalty associated with that asset, and γ is the constant absolute risk aversion parameter.[8]

Due to the possibility that the representative firm will default on its debt, the expected or risk-weighted rate of return is given by

$$E[R^b] = R^b(1 - F(u)) + \left(\frac{Y}{B} - \eta\right)\int_0^{\bar{u}} uf(\bar{u})du. \tag{13}$$

The expected lending rate involves the contractually determined return R^b to the lender, which is fully repaid with probability $(1 - F(u))$ (if the firm survives). In the case of bankruptcy, however, the bank recovers as much as possible, which is represented by the

[7]The penalty term $\Psi(\cdot)$ can be interpreted (i) as an actual, real cost to the bank, (ii) as the bank's management risk aversion towards lending, (iii) as a risk management measure imposed by the financial oversight, or a blend of these three.

[8]We also considered a specification of the bank's objective (12), in which these two penalty terms were replaced by the variance of the bank's portfolio as whole, i.e. a mean-variance utility function on the whole Π. This specification is analytically difficult to work with, since its first order condition contains a joint and highly nonlinear term $Cov(R^a, R^b)$. We leave a thorough analysis of this alternative specification for future research.

second term of the equation (please refer to Appendix D for a formal derivation).

The maximization of the bank's objective function (12) can be expressed as

$$\begin{aligned} B^S &= \arg\max_B E\left\{R^a A - RD + R(D + W^b - p^a A - B) + R^b B - \eta BF(u) - \frac{\gamma}{2} Var(R^a) A^2\right\} \\ &= h(R^b, R). \end{aligned} \tag{14}$$

Maximizing the bank's objective function (12) w.r.t. the risky stocks A yields

$$A = \frac{E[R^a] - p^a R^q}{\gamma Var(R^a)}, \tag{15}$$

whereas the bank sets the demand for the risk-free asset Q to clear its balance sheet (10). It is important to emphasize here that the bank knows the functional form of the the firm's loan demand, and also understands how the interest rate and the loan volume influence the distribution of the firm's profit. In other words, when the bank optimizes the term $E[R^b]B$, it internalizes the behavior of the firm, and – to use terminology from Game Theory – acts in accordance with the Best Response. This means, however, that the bank's credit supply curve for the firm can only be determined numerically, given strong nonlinearities in equation (14), which arise in particular from the distribution function of the firm's relative price. The credit supply B further depends on the actual loan rate R^b, the funds rate R^q and the firm's net worth W.

The optimal demand for the risky asset A in equation (15) is a standard result of the mean-variance utility function. It characterizes how well the expected return of the risky asset compensates the investor for her perceived risk, and equals the expected excess return of the risky over the risk-free asset, normalized by $\gamma Var(R^a)$, where γ measures the bank's degree of risk aversion.[9]

The bank's first order conditions have an interesting interpretation. Both demand for the risky asset A and supply of the credit B depend on the return of the risk-free asset R^q. On the other hand, the loan supply does not depend on the risky asset's return and *vice versa*. This implies that the bank treats the risk-free asset as a benchmark, and expects a sort of risk premium – in comparison with R^q – on the two other assets, but the volumes of these two assets remain independent from each other. In other words, credit and stock markets are

[9]Notice that if the bank was risk neutral (with $\gamma \to 0$), its demand for the risky asset would diverge to $\pm\infty$ for any non-zero excess return.

not directly “linked” by the banks, who treat them as separate and unrelated entities.

2.3 Equilibrium

For the sake of simplicity we will assume that in fact $R^d = R^q = R$, where R represents the policy rate set by the monetary authority.[10] The bank is price-taker on the market of the risk-free and risky assets, i.e. it treats p^a, R^a and R as given. On the other hand, the bank is price-setter on the credit market: it decides on the contractual amount of credit $\widehat{B}$ and loan rate for the firm $\widehat{R}^b$, where the circumflex indicates the equilibrium value of a variable. Note that an equilibrium, i.e. the loan contract, is found by the market clearing condition $\widehat{B} = B$. Formally, let the market clearing be described as $z(R^b, R, w) = h(R^b, R) - m(R^b, W) = B^S - B^D = 0$. The loan rate is then determined according to

$$\widehat{R}^b = \arg\min_{R^b=\widehat{R}^b} \left\{ \left| z(R^b, R, W) \right| \mid R^b = \widehat{R}^b \right\} = \arg\min_{R^b=\widehat{R}^b} \left\{ \left| h(R^b, R) - m(R^b, W) \right| \mid R^b = \widehat{R}^b \right\}. \tag{16}$$

As both the loan supply and the loan demand curve are highly nonlinear, we could not compute an analytical expression for the equilibrium loan rate, regardless of whether the distribution of the random variable u is normally or uniformly distributed. However, it is fairly straightforward to identify the equilibrium numerically.

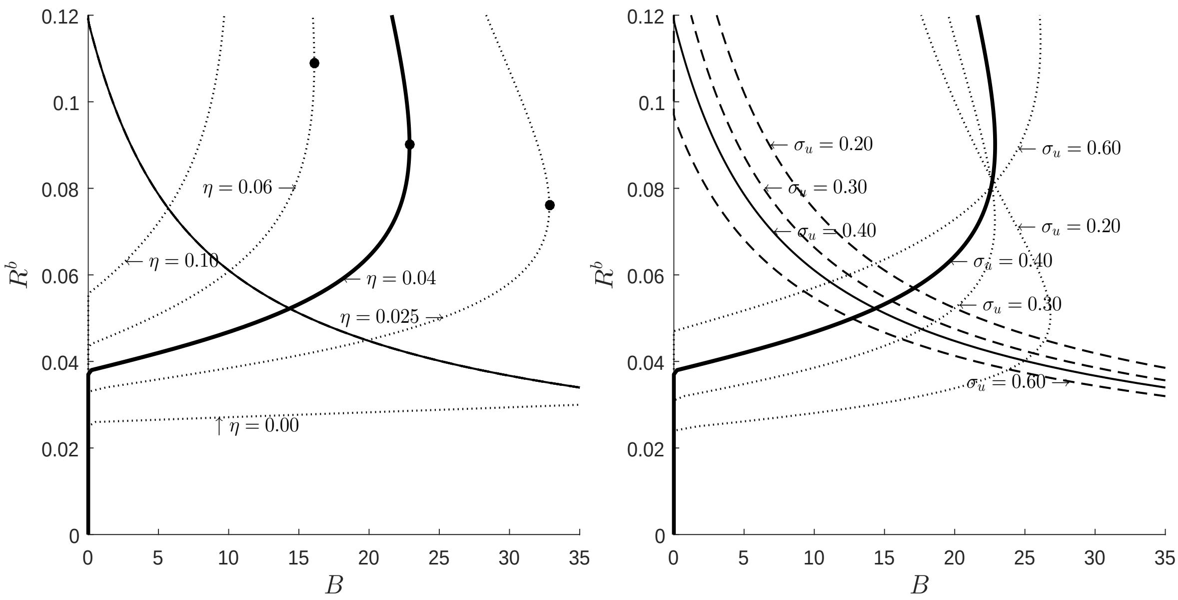
In order to characterize the properties of the model equilibrium we discuss in the next section how the risk aversion of the bank and the firm, as well as the firm’s default probability, affect the loan market outcome.

2.4 Default Risk and Risk Aversion

In our model, the underlying riskiness of the real sector is reflected in the dispersion of the firm’s relative price, measured by its standard deviation σ_u. On the other hand, two parameters represent the attitude towards the real sector’s default risk, namely the weights of the firm’s and bank’s bankruptcy costs functions ($\chi = 1.5$ and $\eta = 0.04$, respectively for

[10] In practice these three rates are not exactly equal. In particular, the deposit rate R^d can vary from the other two. However, it does not affect our model much, since the term $R^d D$ is a constant in the bank’s problem and does not influence its optimal solution. Further research can investigate what happens with R^d when the bank optimizes its deposit portfolio, or when the class of risk-free asset contains bonds with different maturity and yield.

our model's calibration).



(a) The loan offer and variations in η

(b) The loan offer and dispersion σ_u

Figure 2: The shape of the loan offer curve and its dependence on the risk aversion parameter η (left panel) and the standard deviation of the market shock σ_u (right panel). The thin black line refers to the loan demand curve while the bold black curve is the supply curve. The default case (bold lines) refers to $\eta = 0.04$ and $\sigma_u = 0.4$.

Figure 2 illustrates the reaction of the equilibrium to changes in the risk weight η (left panel) and the standard deviation of the firm's individual price σ_u (right panel) using the parametrization reported in Table 1 in Appendix A. As illustrated in Figure 2a, the firm is a price-taker and so the degree of the bank's risk aversion does not affect the credit demand. Unsurprisingly, the higher the risk weight η, the lower the demand, and therefore the higher the interest rate $\hat{R}^b$ and the lower the credit volume $\hat{B}$ in the equilibrium. Interestingly, under the current calibration, the model suggests that even a small change to that parameter has visible effects, which seem to be stronger for the credit volume. For instance, shifting η from $\eta = 0.04$ to $\eta = 0.06$ causes the equilibrium credit volume to fall by about one fifth, whereas the interest rate increases by around one percentage point. As discussed previously, when the interest rate R^b grows, the firm's chance of default increases as well, and at some point the bank reacts with credit rationing. As we see in Figure 2a, the higher the risk weight η, the higher interest rate R^b is required to trigger credit rationing (where the points of inflection are illustrated by black dots), which implies that the credit equilibrium is associated with lower risk in the real sector.

In contrast, Figure 2b displays how the loan demand and supply respond to changes in the dispersion of the relative sales price u. In contrast to the previous case, both supply and demand curves are affected, since both the firm and the bank internalize the possibility of the firm's debt default. As the standard deviation σ_u increases, the bank reacts to the risk by offering less loans, whereas the firm requests less credit and relies more on internal finance. As a result, the credit volume always decreases significantly, while the increase of the equilibrium interest rate is less pronounced. This suggests that the market equilibrium loan interest rate does not react sensitively to an increase in the real sector's riskiness.

3 Monetary Policy and Bank's Risk-Taking

We now turn to analyze how monetary policy (represented by variations in the policy rate R) affects the loan market equilibrium, as well as the bank's financial portfolio composition and its overall financial situation.

3.1 Loan Market Effects

Figure 3 illustrates the firm's loan demand (thin black line) and the bank's loan supply (bold black line) for varying values of the policy rate $R^b \in [0, 0.13]$ using the same numerical calibration as in the previous figures. For the sake of exposition, we plot the loan supply curve for different values of the policy rate contained in the set $R \in \{0.01, \ldots, 0.05\}$ (thin dotted line) where the reference scenario (bold black line) refers to $R = 0.02$. The loan demand curve is a convex, monotonically decreasing curve, as established in section 2.1, Proposition 1. On the other hand, the loan supply curve is convex, but backward-bending instead of monotonic. This result is consistent with the bulk of literature, and was first raised by Hodgman (1960) and later advanced by e.g. Jaffee and Stiglitz (1990).

From a different vantage point, the backward-bending shape of the bank's loan supply (determined in equation (14)) implies that the bank's supply is strictly concave in the loan rate R^b. This can be interpreted as follows: An increase of the loan interest rate has two offsetting effects on the bank's profit. With a higher loan rate, the realized relative price u of the representative firm will more likely fall below the solvency threshold $\bar{u}$ (see equation (4)), making the firm less likely to be able to repay its loan. On the other hand, with a

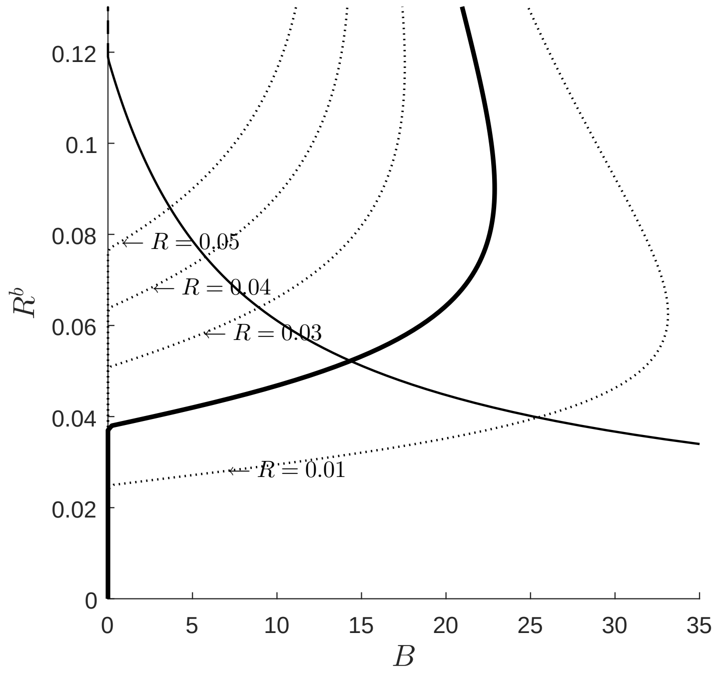


Figure 3: Loan supply and demand functions for $R^d = R^q = R \in \{0.01, \ldots, 0.05\}$

higher interest rate the bank earns a higher marginal return from the loans of the firms that do not go bankrupt. In an intermediate range of the interest rate R^b, the second (positive) effect compensates the first (negative) effect, and the bank's loan supply is an increasing function ($h'_{R^b} > 0$). There exists a threshold value of the interest rate, however, for which the negative effect surpasses the positive effect and the loan supply curve becomes backward-bending ($h'_{R^b} < 0$). This triggers *credit rationing:* because of the firms' decreasing credit worthiness, the bank no longer has an incentive to increase the volume of credit that it offers (c.f. Stiglitz and Weiss, 1981).

3.2 Bank Portfolio's Effects

As we discussed earlier, the firm's optimality condition (9) does not directly depend on the reference policy rate. However, the bank does consider the policy rate when it optimizes its financial portfolio. As a result, there exists a substitution effect between the risk-free asset Q on the one hand, and the risky assets A and B on the other hand, as seen in equations (14) and (15) respectively. This relationship can be analytically established for the risky asset A with $\partial A/\partial R = -p^a \gamma^{-1} Var(R^a)^{-1} < 0$ – the higher the reference rate, the lower the demand for the risky asset. Furthermore, the monetary policy has an additional *pass-through effect* on the equilibrium lending rate $\widehat{R}^b$, which is summarized by the following Proposition.

Proposition 2 *Consider the set of optimal loan contracts $(\widehat{B}, \widehat{R}^b)$, chosen conditional on the bank's opportunity costs R^a and R, for which credit rationing is not triggered, i.e. $(\widehat{B}, \widehat{R}^b) \in \{(\tilde{B}, \tilde{R}^b) | \widehat{B} \in \mathbf{B},\ \widehat{R}^b \in \mathbf{R},\ h'_{R^b} > 0\ \forall\ \tilde{R}^b\}$, where $\mathbf{B}$ and $\mathbf{R}$ are admissible sets for the credit and the interest rate. When the contractual lending rate $\widehat{R}^b$ belongs to that set, then it is weakly increasing in R, $d\widehat{R}^b/dR \geqslant 0$, and strictly increasing whenever the contractual loan rate R^b is not equal to its boundary solution.*

The proof is provided in Appendix E.

This *interest rate pass-through effect* is also observable in Figure 3, where it is shown that changes in the policy rate R may shift the supply for credit and thus the associated market equilibrium. In line with Proposition 2, an increase in the policy rate R is reflected in an upward shift of the loan-offer curve and hence of the loan market equilibrium point, which in turn determines the repayment rate $\widehat{R}^b$ of the loan contract. From the bank's profit equation (11), we can infer that $\partial\widehat{\Pi}/\partial\widehat{R}^b = \widehat{B} \geqslant 0$, i.e. that the bank's gross profits in equilibrium increase with the policy rate R. The bank managers reallocate the bank's financial portfolio based on their risk aversion which is reflected in the bankruptcy costs penalty in equation (12). Since the expected lending rate bears the actual average risk margin, while the contractual loan rate is determined through negotiations between the firm and the bank, one can conjecture the following result:

Proposition 3 *The equilibrium loan risk premium, defined by $\widehat{RP} = \widehat{E[R^b]} - R$, declines in R, $d\widehat{RP}/dR < 0$.*

The proof of Proposition 3, for the case when the random price u is drawn from a uniform distribution, is reported in Appendix F. When u is normally distributed, on the other hand, the loan risk premium is analytically no longer tractable, but Figure 4b illustrates that this premium (defined as $\widehat{E[R^b]} - R$) is higher for low policy rates R, slightly decreases as the policy rate increases and drops strongly for high policy rates. We will get back to this point and the arising discontinuities later in this section.

Proposition 3 corroborates findings of Gilchrist and Zakrajšek (2012) and Muir (2017), who report that risk premia widen during recessions (where the policy rate is usually lowered), especially during the last financial crisis of 2007. Consistently with the analytical results of Martinez-Miera and Repullo (2017), Proposition 3 also shows that the bank managers exhibit more risk averse behavior in low interest rate regions, despite having a constant degree of risk aversion η.

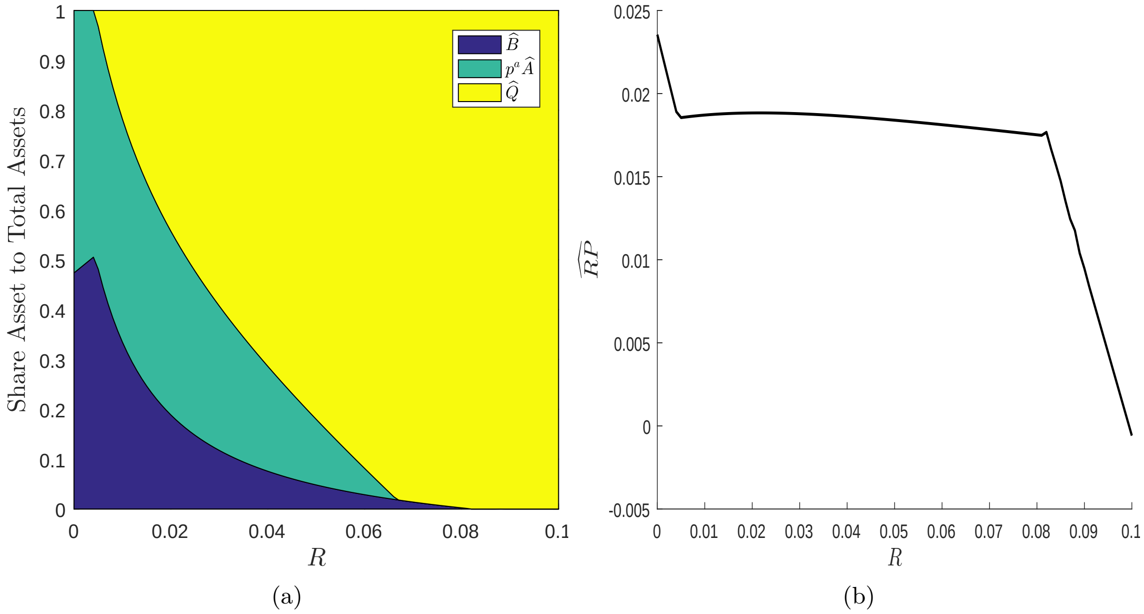


Figure 4: The bank's financial portfolio composition (left panel) and loan risk premium $\hat{RP}$ (right panel) as functions of the policy rate R.

The reference interest rate R has also a direct effect on the demand for the risky asset A. A decline in the policy rate raises the expected net return on the risky asset (as seen in the numerator of equation (15)), which induces the bank to recompose its financial portfolio towards a more risky profile. This leads us to the following proposition.

Proposition 4 *If the policy rate decreases, the bank increases – ceteris paribus – its demand for the risky asset by* $p^a/(\gamma Var(R^a))$ *in the interior solution. The elasticity among the returns on the tradable assets is equal to* $-(R^a+\mu_a)/[p^a(R^a-\mu_a)]$.

The proof is provided in Appendix G.

Figure 4a illustrates this effect by displaying the bank's asset structure as a function of the policy rate. The shares of the loan, the risky asset and the risk-free asset in the bank's financial portfolio are depicted through the blue, green and yellow areas, respectively. An intuitive pattern emerges: with higher reference interest rates, the bank substitutes out the loan and risky asset with the risk-free one due to the bank managers' risk aversion. This asset reallocation explains the discontinuities we observe in the risk premium reported in Figure 4b. There the loan risk premium drops vastly in the reference interest rate R until a threshold rate $R \approx 0.005$ is met. We will refer to this boundary with $\underline{\varepsilon}$. Based on Figure 4a, we can infer that the bank managers start to invest into the risk-free asset Q at $\underline{\varepsilon}$, inducing a reallocation effect from the loan and risky asset to the risk-free one. Beyond that boundary, where the bank manages the proper three-asset portfolio, the equilibrium loan risk premium decreases slowly with R. As indicated in the proof of Proposition 3 in Appendix F, the loan risk premium is declining in this area as long as the interest rate pass-through effect is less than one-to-one to the change in the interest rate R. It follows that a rise in the interest rate R increases the expected loan repayment rate as well as the contractual loan rate, but in a less than a one-to-one correspondence. This in turn reduces the loan risk premium, i.e. $dRP/dR = d(\widehat{E[R^b]} - R)/dR \leqslant 0$. The next discontinuity appears at a relatively high rate of interest, at which the bank manager starts to invest the entire amount of bank assets in the risk-free bond Q. This reallocation effect is illustrated in Figure 4a. We will refer to this threshold interest rate with $\bar{\varepsilon}$. Beyond that threshold, the equilibrium risk premium drops vastly because the bank's financial portfolio consists exclusively of the risk-free asset, which induce the managers to reduce the risk premium on the loan, which is associated with a decline in the asset managers' risk taking behavior, as described before.

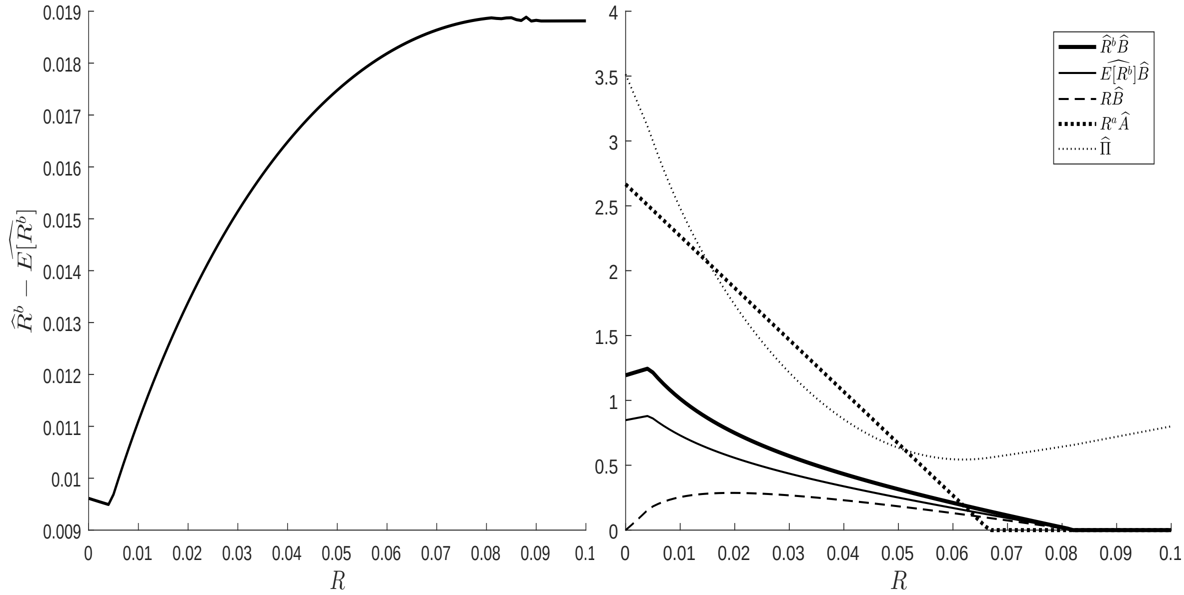
Even though we showed that the reference interest rate R does not exert a direct pressure on the firm's choice variables, such as its loan demand given by equation (9), it does exhibit an indirect effect on the bank's expected and actual loan rates of return via the default probability $F(\cdot)$ and through the market clearing mechanism reflected in changes in the loan market equilibrium as illustrated in Figure 3.

The following Proposition establishes that when an internal solution for the equilibrium exists, the spread between the contractual and expected loan rate $\widehat{R}^b - \widehat{E[R^b]}$ is increasing in the reference interest rate R.

Proposition 5 *Consider the spread* $\widehat{R}^b - \widehat{E[R^b]}$. *This spread is increasing in* R, $d(\widehat{R}^b - \widehat{E[R^b]})/dR < 0$, *in the intermediate domain* $\widehat{R}^b - \widehat{E[R^b]} : \mathbb{R}^n \to \bar{\mathbb{R}}$ *where*

$$\bar{\mathbb{R}} = \mathbb{R} \cup \{\underline{\varepsilon}, \overline{\varepsilon}\}.$$

A proof for the Proposition, for the case of uniformly distributed u, is provided in Appendix H.



(a) Spread between contractual and expected loan rate.

(b) Expected profit decomposition

Figure 5: Spread between contractual and expected rate (left panel) and elements of the total profit of the bank (right panel) as functions of the reference interest rate R.

Figure 5a shows graphically that Proposition 5 is also true for the case of the normally distributed price u. It follows that a high policy rate R has two effects on the real sector. On the one hand, it decreases the total volume of the credit (see Section 3.1). On the other hand, a high risk-free rate means that the bank demands a higher rate from the firms as well, which makes it more difficult for the firms to repay their loans. As a result, more firms face bankruptcy and the real sector diminishes, in line with standard macroeconomic models. This is also reflected in the profit of the bank, seen in Figure 5b, which relies less on the risky assets and more on the revenue from bonds.

3.3 The Bank's Financial Position

In this section we investigate how the bank's financial position is affected by changes in the policy rate. For this purpose we use the bank's capital ratio

$$\text{CAR} = \frac{W^b + \Pi}{B + p^a A} \times 100\% \geqslant 10.5\% \tag{17}$$

as a measure for the bank's financial position. This ratio is defined along the guidelines of the Basel III accord. It relates the bank's minimum common equity (Tier 1 capital), consisting of the bank shareholder's equity and disclosed reserves, to the bank's risk weighted assets (RWA). Since in our model no dividends are distributed to the bank's shareholders, retained earnings coincide with total profits.

The RWAs are computed using the *Standardized Credit Risk Assesment Approach* (SA).[11] Under the SA, supervisors set the risk weights that banks use to determine the RWAs. For the sake of simplicity, and consistently with the assumptions related to the risk weights in e.g. Benes and Kumhof (2015), we choose weights for all risky assets of 100%.[12] Hence, each type of credit risk that appears in our model is weighted equally. The goal of the Basel guidelines was to strengthen the microprudential regulation by e.g. constraining bank leverage, imposing robust capital buffers, etc. One important instrument imposed by the guidelines are minimum capital requirements, which in the Basel III accord are defined as the minimum capital adequacy ratio. This includes a 2.5% capital conservation buffer and amounts to 10.5%.[13] However, the more risk is incurred in the bank's asset portfolio, the greater the bank's RWAs, and the more its capital ratio is reduced. The bank's financial position is impaired when its capital ratio approaches the regulatory minimum capital requirements.[14]

[11]Beside the SA, the Basel Committee of Banking Supervision (BCBS) proposed the *Internal Ratings-Based Approach* (IRB) to calculate the RWAs for the assessment of credit risk. The goal of IRB is to provide a more accurate measure for credit risk in contrast to the SA, but it also requires banks to rely on more complicated estimation procedures. SA allows us to determine risk-weights in our model in a straightforward manner, and it is moreover the most common approach in the global banking sector (see e.g. Basel Committe on Banking Supervision (BCBS), 2017*b*,*a*).

[12]According to the Basel III guidelines, a 100% risk-weight refers to general exposures to corporates with an external rating of $BB+$ to $BB-$ or even for unrated exposures. An overview for RWAs and the standardized approach to assess credit risk is provided by Basel Committe on Banking Supervision (BCBS) (2017*b*, Table 1)

[13]Notice that common and total equity capital coincide with each other in our model due to the absence of the bank's Tier 2 capital. Thus, we can also refer to the capital ratio in equation (17) as the capital adequacy ratio. The minimum requirements and the construction of the microprudential measures are recorded in Basel Committe on Banking Supervision (BCBS) (2017*a*, p. 137). We do not account for the countercyclical capital buffer due to the static nature of our stylized model and leave this issue for future research.

[14]In our model the bank does not face pecuniary costs from converging towards the minimum requirements. We leave this issue for future research.

A supplementary measure to the risk-based capital requirement is the non-risk-based (Tier 1) leverage ratio which was introduced by the BCBS in order to (1) discourage destabilizing deleveraging processes, and (2) supplement and reinforce the risk-based capital adequacy requirement, serving as a non-risk-based "backstop" measure.[15] The leverage ratio comprises, however, bank's on- and off-balance sheet activity. It is formally defined as the percentage of the Tier 1 capital to the total (non-risk-based) exposures, namely

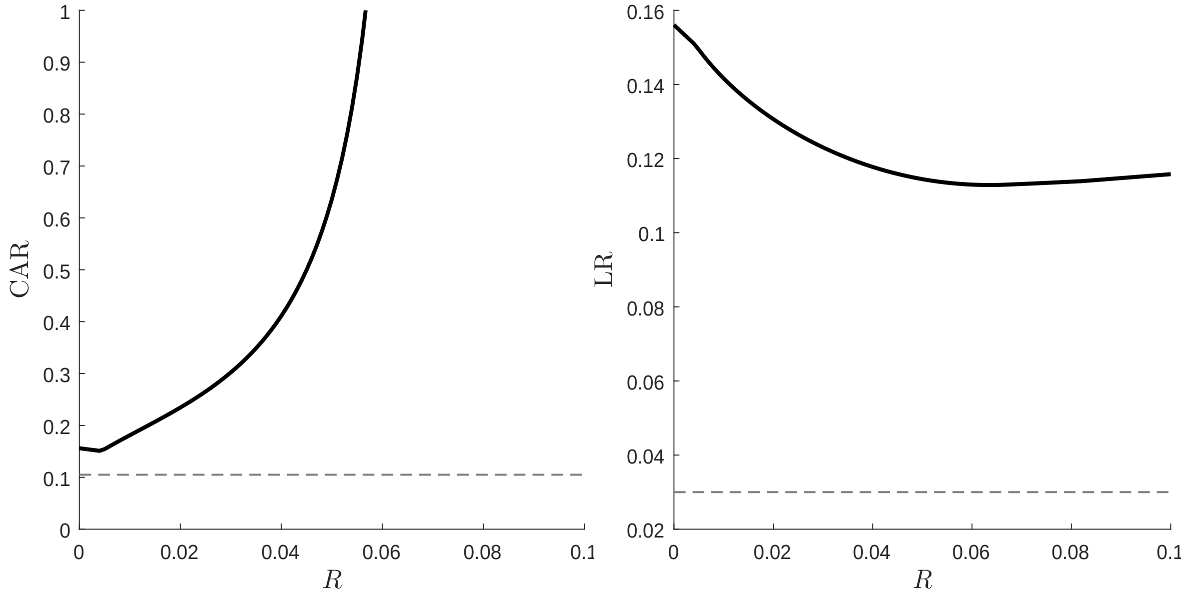
$$\mathrm{LR} = \frac{W^b + \Pi}{B + p^a A + Q} \times 100\% \geqslant 3\%. \tag{18}$$

This leverage ratio is closely related to the risk-based capital ratio CAR in equation (17), because we weighted all risky exposures by 100% factor. The main difference between the two required ratios is that the total exposure measure in the leverage ratio (18) contains in addition the risk-free asset Q (which appears in the denominator). According to the Basel III guidelines, the bank must meet a 3% leverage ratio (18) minimum requirement at all time.

The effects of changes in the policy rate R on the bank's capital and the leverage ratio (computed under the same model parameterization as in previous sections) are illustrated in Figure 6. As seen in 6a, the capital ratio (17) is a strictly increasing function of the policy rate. In particular, in a regime with a moderate interest rate between hundred and four hundred basis points, the bank has a well-capitalized financial position, since its financial portfolio includes a significant amount of the risk-free asset. Even though the bank has "skin in the game", i.e. it holds a certain amount of the risky asset, it does limit its risk exposure due to its risk aversion. If the interest rate falls below hundred basis points, the bank moves from a well-capitalized to a critically under-capitalized position where it barely meets the Basel III minimum capital requirement of 10.5% (gray dashed line). This in turn makes the bank more vulnerable to financial distress, since it begins to *search-for-yield* and adjust its asset structure towards the risky assets despite of its risk aversion. This substitution effect can also be observed in Figure 4a, where we showed that for very low policy rates the bank stops buying risk-free bonds.

Figure 6b displays the relationship between the policy rate and the bank's non-risk-based

[15] Before the global financial crisis, many banks built up their leverage excessively, while at the same time reporting strong capital ratios. This led to a deleveraging process in the banking sector when banks were suddenly confronted with a rampart decline of asset prices, which in response amplified the downward pressure on asset prices and sealed a vicious cycle that led to the global financial meltdown. The additional regulation aims at preventing this type of developments from happening again.



(a) The capital ratio

(b) The leverage ratio

Figure 6: The bank's financial position in different interest rate regimes

leverage ratio. It remains fairly stable, with the exception of the vicinity of the zero bound. Here, the leverage starts to increase, because the bank's demand for the risk-free asset Q approaches zero (see Figure 4a), whereas small increases in the policy rate exert an upward pressure on the lending rate R^b through the pass-through effect. Once the policy rate exceeds the level of 0.6%, the bank starts to substitute out the risky exposures with the risk-free asset. The bank's average leverage ratio is equal to $\mu_{LR} = 12.19$ with the standard deviation of $\sigma_{LR} = 0.012$. These properties are broadly comparable with empirical observations, see Appendix I for details.

It is not uncanny that the two regulatory measures do not react in the same fashion to the policy rate. Indeed one cause of the 2007 global financial crisis was the build-up of excessive bank leverages, while many banks recorded at the same time strong risk-based capital ratios due to mispriced financial assets.

4 Concluding Remarks

As previously discussed, the search-for-yield behavior of the financial sector has been often linked with the ultra-low policy interest rates observable in recent years. Against this background we set up in this paper a stylized partial equilibrium model where both the borrower and the lender are risk averse: the firms' managers fear the possibility of default, and the bank managers, featuring a mean variance utility, are averse to reallocate the bank's asset financial portfolio towards a higher exposure to asset price risk. Within this theoretical framework we showed that lower policy interest rates may affect the bank's portfolio risk management while leaving the firm's demand function unchanged. As the policy (risk-free) rate decreases, the bank faces high opportunity costs, inducing the bank to rebalance its portfolio towards more risky assets in order to stabilize its profits. This search-for-yield behavior is reinforced through the positive interest rate pass-through effect which lowers the loan rate contractually determined with the firm. In compliance with empirical evidence, the model also replicates the stylized fact that the risk premium increases in low interest rate regimes. Further, when the interest rate approaches zero, the bank's capital structure moves from a well- to a poor-capitalized position, converging towards the minimum capital requirement.

There are several potential extensions of this study. First, due to the various strong non-linearities on both the firm's and on the bank's side, our model could be studied analytically only when the relative price u followed a uniform distribution. Embedding the present framework into an agent-based model would overcome this shortcoming, probably delivering also further interesting insights into the consequences of a search-for-yield behavior by banks for macro-financial stability.

And second, as it is done in the recent paper of Martinez-Miera and Repullo (2017), we did not incorporate the time dimension which plays a crucial role for many stylized facts which were found in the data. However, it would be interesting to extend the framework by a dynamic model to check whether it may match with some dynamic empirical regularities such as the procyclical nature of risk premia, countercyclical risk premia and the fact that the policy rates were "too low for too short" as the empirical results of e.g. Maddaloni and Peydró (2011) suggest. We expect our theoretical foundation to be flexible enough to adopt the main mechanism in other classes of financial-macroeconomic models, e.g. dynamic general equilibrium and agent-based models.

The model clearly exhibits testable implications for policy makers, such as the Basel Committee of Banking Supervision or even the central bank. First, we may consider that the bank has to face penalties whenever its capital ratios approach, or even fall short of the regulatory minimum capital ratios. This induces the bank to take its capital ratios into account when composing its optimal asset composition. Second, in a dynamic version of this model, one could test the interplay between the countercyclical capital buffer, which was introduced with Basel III, and monetary policy and moreover, its effect on financial intermediation.

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Appendix

A Numerical Values and Distribution Functions

The numerical values that are used to compute all figures in the main text are reported in the following table.

Table 1: Baseline numerical values

Parameter	Description	Value
γ	risk aversion parameter	0.06
σ_a	standard deviation of stock return	0.1
μ_a	mean expected stock return	0.03
$\sigma_{\bar{u}}$	standard deviation of firm's relative price	0.4
μ_u	mean of firm's relative price	0.267
η	parameter in bank's bankruptcy cost function	0.04
χ	parameter in firm's bankruptcy cost function	1.5
ϕ	production parameter/output-capital ratio	1.4
ψ	production cost function parameter	0.51
p^a	stock price	0.6
$\bar{B}$	reference amount of loans	60
$\bar{Q}$	reference amount of risk-free assets	10
$\bar{A}$	reference amount of risky assets	10
D	amount of deposits	10
R^a	expected return on stocks	0.04
R	reference policy rate	0.02
$\bar{R}^b$	reference loan rate	0.06
W^b	initial equity capital of the bank	8
W	initial equity capital of the firm	15

Moreover, in order to compute the figures numerically, we assume that the random variable u follows a normal distribution which can explicitly be written as

$$f(\bar{u}) = \frac{1}{\sigma_u\sqrt{2\pi}} \exp\left[-\frac{1}{2}\left(\frac{\bar{u}-\mu_u}{\sigma_u}\right)^2\right]. \tag{A.1}$$

$$F(u) = \frac{1}{2}\left[1 + \text{erf}\left(\frac{\bar{u}-\mu_u}{\sigma_u\sqrt{2}}\right)\right]. \tag{A.2}$$

where erf is the error function given by $\text{erf}(z) = \frac{2}{\sqrt{\pi}} \int_0^z e^{-t^2} dt$ with $z = (\bar{u}-\mu_u)/(\sigma_u\sqrt{2})$.

B Proof of Proposition 1

For the sake of simplicity, we assume that the distribution of the random sales price u is the uniform distribution with support $[0, \overline{x}]$ to exclude negative market prices. Thus, the distribution function for the intermediate range $0 < u < \overline{x}$ is given by

$$f(u) = \frac{1}{\overline{x}} \tag{B.3}$$

$$F(u) = \int f du = \frac{R^b}{\overline{x}} \left(\frac{g(Y) - W}{Y} \right). \tag{B.4}$$

Using the firm's budget equation (2), the weighted bankruptcy function is $(\chi R^b/\overline{x})(\psi Y^2 - W)$. It follows that the marginal bankruptcy costs from equation (8) refer to $\rho = (2\chi\psi R^b Y)/\overline{x}$. Hence, the optimal level of production is

$$Y = \frac{1}{2\psi R^b \left(1 + \frac{\chi}{\overline{x}}\right)}.$$

The firm's loan demand function is then obtained by using the financing identity (2) again and by solving for B which gives

$$\psi Y^2 - W = B$$

$$Y = \sqrt{\frac{1}{\psi}(B + W)}$$

Replacing Y in the optimality condition yields

$$\sqrt{\frac{1}{\psi}(B + W)} = \frac{1}{2\psi R^b \left(1 + \frac{\chi}{\overline{x}}\right)}$$

$$\frac{1}{\psi}(B + W) = \frac{1}{4\psi^2 R^{b^2} \left(1 + \frac{\chi}{\overline{x}}\right)^2}.$$

Finally, the optimal loan demand is given by

$$B^D = \frac{1}{4\psi R^{b^2} \left(1 + \frac{\chi}{\overline{x}}\right)^2} - W = m(R^b, W) \tag{B.5}$$

with the following properties:

$$\frac{\partial m(R^b,W)}{\partial R^b} = -\frac{1}{2\psi R^{b^3}\left(1+\frac{\chi}{\overline{x}}\right)^2} < 0$$

and

$$\frac{\partial^2 m(R^b,W)}{\partial R^{b^2}} = \frac{3}{2\psi R^{b^4}\left(1+\frac{\chi}{\overline{x}}\right)^2} > 0.$$

Hence, we can infer that the loan demand function is convex in the lending rate R^b. The demand function is thus downward sloping in the lending rate, i.e. the more credit the bank is willing to provide to finance the firm's production project, the lower the interest rate the firm is willing to pay for the loan. These properties hold for any support $\overline{x} \lesseqgtr 0$ due to the quadratic character the distributional boundaries enter the equation.

C Proof for Lemma 1

As already mentioned in the main text it is quite unwieldy to derive an analytical expression for the firm's optimal loan demand due to the strong nonlinearities in the marginal bankruptcy cost function for the case of a normally distributed variable u. Solving for the optimal level of production Y and under the validity of Lemma 1, we obtain the interior solution

$$Y = (2\psi R^b)^{-1}. \tag{C.6}$$

Since $\mathrm{d}Y/\mathrm{d}R^b = -(2\psi R^{b^2})^{-1} < 0$ and $\mathrm{d}^2Y/\mathrm{d}R^b\mathrm{d}R^b = (\psi R^{b^3})^{-1} > 0$ we can infer that optimal output is convex in the loan rate R^b.

Taking into account the concave production function and the finance identity (2), and setting the parameter χ in equation (B.5) to zero, we obtain the credit demand function

$$B^D = (4\psi R^{b^2})^{-1} - W \tag{C.7}$$

with $\mathrm{d}B^D/\mathrm{d}R^b = -(2\psi R^{b^3})^{-1} < 0$ and $\mathrm{d}^2B^D/\mathrm{d}R^b\mathrm{d}R^b = 3/(2\psi R^{b^4}) > 0$ that indicates that the loan demand function is also convex in the funding rate R^b at least in the case of zero marginal bankruptcy costs.

To show that the bankruptcy costs do actually contribute to but do not essentially define the curvature of the credit demand function, i.e. its convex shape, Figure 1 in the main text illustrates how sensitively the credit demand reacts to changes in the bankruptcy cost parameter χ in the domain $\chi = [0, 3]$. Subsequently, we may infer – at least for the considered domain $\chi = [0, 3]$ – that equation (9) satisfies $\partial B^d / \partial \chi < 0$ and $\partial^2 B^D / \partial \chi \partial \chi > 0$.

D Composition of the expected lending rate

When the bank computes it's expected return rate on granting credit to the firm, it takes into account two cases, namely *i)* the case when the firm remains solvent and *ii)* when it defaults on its debt. The expected payoffs are

$$E[R^b] = \begin{cases} R^b & \text{if} \quad u \geq \bar{u} \\ \dfrac{uY - \Psi(B)}{g(Y) - W} & \text{if} \quad u < \bar{u}. \end{cases} \tag{D.8}$$

Related to the critical sales price (4), the payoff in the default case is considered to be the revenues net of bankruptcy costs relative to the firm's production costs. The expected (real) rate of return is then obtained by weighting the respective returns with the probability of survival and the average probability that ensures that the firm's ability to pay back the loan is impaired. The expected lending rate is

$$\begin{aligned} E[R^b] &= R^b(1 - F(u)) + \frac{Y - \Psi_j(B)}{B} \int_0^{\bar{u}} u dF(u) \\ &= R^b(1 - F(u)) + \frac{f(u)}{2} \left(\frac{\phi(B + W)^{\frac{1}{2}}}{B} - \eta \right) \left(\frac{R^b B}{\phi(B + W)^{\frac{1}{2}}} \right)^2. \end{aligned}$$

E Proof of Proposition 2

Let $\widehat{R}^b$ be a solution to the problem specified in (16) and exclude any solutions that lead to credit rationing, i.e. assume that $h'_{R^b} > 0$. From Proposition 1, we know that the demand for loans is shrinking in the lending rate $m'_{R^b} < 0$. Further, from Figure 3 in Section 2.3, we inferred that the bank's offered credit volume reacts negatively on the risk-free reference rate R, hence $h'_R < 0$. To carry out the comparative statics, we can use the *Implicit Function Theorem.* Correspondingly, let $z(\widehat{R}^b, R, W)$ be the market clearing function that is equilibrated for $\widehat{R}^b$. The theorem then states

$$\frac{d\widehat{R}^b}{dR} = -\frac{\frac{z(\widehat{R}^b,R,W)}{\partial R}}{\frac{z(\widehat{R}^b,R,W)}{\partial \widehat{R}^b}} = -\frac{z'_R}{z'_{R^b}} = -\frac{h'_R}{h'_{R^b} - m'_{R^b}} > 0. \tag{E.9}$$

In words, the model predicts a positive interest rate pass-trough effect for the interior solution, the domain where no financial market frictions in terms of credit rationing prevail.

F Proof of Proposition 3

Similar to Appendix B, we consider the random sales price u being uniformly distributed with support $[0, \overline{x}]$. The loan risk premium then refers to the expected risky return on lending less than the risk-free return, which reflects the opportunity to invest the amount into the risk-free asset Q, formally

$$\begin{aligned} RP &= E[R^b] - R \\ &= R^b(1 - F(u)) + \left(\frac{Y}{B} - \eta\right) \int_0^{\bar{u}} u f(u)\, du - R \\ &= R^b - R + \frac{R^{b2}}{2\overline{x}} \left(\frac{B}{Y}\right) - \frac{\eta}{2\overline{x}} \left(\frac{R^b B}{Y}\right)^2 \end{aligned}$$

which can also be expressed by

$$\begin{aligned} RP &= R^b - R - \frac{R^b}{2} F(u) + \frac{\eta \overline{x}}{2} F(u)^2 \\ &\text{or} \\ RP &= R^b - R - \frac{R^b}{2\overline{x}} \bar{u} + \frac{\eta}{2\overline{x}} \bar{u}^2 \end{aligned} \tag{F.10}$$

The equilibrium credit spread is obtained by evaluating the previous equation at the equilibrium point, it yields

$$\widehat{RP} = \widehat{R}^b - R - \frac{\widehat{R}^b}{2\overline{x}} \widehat{\bar{u}} - \frac{\eta}{2\overline{x}} \widehat{\bar{u}}^2. \tag{F.11}$$

The first derivative gives

$$\frac{d\widehat{RP}}{dR} = \frac{d\widehat{R}^b}{dR} - 1 - \frac{\widehat{\overline{u}}}{2\overline{x}}\frac{d\widehat{R}^b}{dR} - \frac{\widehat{R}^b}{2\overline{x}}\left[\frac{d\widehat{\overline{u}}}{dR} + \frac{\partial\widehat{\overline{u}}}{\partial\widehat{R}^b}\frac{d\widehat{R}^b}{dR}\right] - \frac{2\eta}{2\overline{x}}\widehat{\overline{u}}\left[\frac{d\widehat{\overline{u}}}{dR} + \frac{\partial\widehat{\overline{u}}}{\partial\widehat{R}^b}\frac{d\widehat{R}^b}{dR}\right] \tag{F.12}$$

where the part $\frac{\partial\widehat{\overline{u}}}{\partial\widehat{R}^b}\frac{d\widehat{R}^b}{dR}$ is zero by the *envelope theorem.* The derivative of the random sales price w.r.t. the reference interest rate is

$$\frac{d\widehat{\overline{u}}}{dR} = \frac{\left[\frac{d\widehat{R}^b}{dR}\widehat{B} + \widehat{R}^b\frac{\partial\widehat{B}}{\partial\widehat{R}^b}\frac{d\widehat{R}^b}{dR}\right]\widehat{Y} + \widehat{R}^b\widehat{B}\frac{\partial\widehat{Y}}{\partial\widehat{R}^b}\frac{d\widehat{R}^b}{dR}}{\widehat{Y}^2}.$$

Applying the *envelope theorem* again, the indirect derivatives $\frac{\partial\widehat{B}}{\partial\widehat{R}^b}\frac{d\widehat{R}^b}{dR}$ and $\frac{\partial\widehat{Y}}{\partial\widehat{R}^b}\frac{d\widehat{R}^b}{dR}$ are zero as well. Consequently, the derivative is

$$\frac{d\widehat{\overline{u}}}{dR} = \frac{d\widehat{R}^b}{dR}\frac{\widehat{B}}{\widehat{Y}}. \tag{F.13}$$

It follows, conditional on a positive interest rate pass-trough effect, i.e. if Proposition 2 holds, that $d\widehat{\overline{u}}/dR > 0$ as long as u is in the domain $0 < \widehat{\overline{u}} = \widehat{R}^b\widehat{B}/\widehat{Y} < \overline{x}$. Collecting all intermediate results, i.e. a positive interest rate pass-though effect $d\widehat{R}^b/dR > 0$, the positive effect on the critical sales price $d\widehat{\overline{u}}/dR > 0$ and assuming that the equilibrium threshold price $\widehat{\overline{u}} > 0$, then equation (H.21) is greater than zero, indicating that the risk premium that is charged in equilibrium rises with the reference interest rate R. Formally,

$$\frac{d\widehat{RP}}{dR} = \left(1 - \frac{\widehat{\overline{u}}}{2\overline{x}}\right)\frac{d\widehat{R}^b}{dR} - 1 - \left(\frac{\widehat{R}^b + 2\eta\widehat{\overline{u}}}{2\overline{x}}\right)\frac{d\widehat{\overline{u}}}{dR} \lesseqgtr 0.$$

Using equation (F.13) and the definition $\widehat{\overline{u}} = (\widehat{R}^b\widehat{B})/\widehat{Y}$, one can simplify the latter result by writing

$$\frac{d\widehat{RP}}{dR} = -\frac{d\widehat{R}^b}{dR}\widehat{\overline{u}} - \left(1 - \frac{d\widehat{R}^b}{dR}\right)\overline{x} - \frac{\eta}{\widehat{R}^b}\frac{d\widehat{R}^b}{dR}\widehat{\overline{u}}^2 \leq 0 \tag{F.14}$$

which gives a unique negative solution for the case where Proposition 2 holds and the interest rate pass-through is less than or equal to one-to-one, i.e. $0 \leq d\widehat{R}^b/dR \leq 1$. Otherwise, the sign of the derivative depends on the risk aversion parameter η, the support of the random sales price $\overline{x}$ and the size of the equilibrium critical price $\widehat{\overline{u}}$.

G Proof of Proposition 4

To study monetary policy in terms of comparative statics we briefly recall the optimality condition referring to the demand for the risky asset when the credit contract is optimally signed. It is given by

$$\widehat{A} = \frac{E[R^a] - p^a R}{\gamma Var(R^a)}. \tag{G.15}$$

The reallocation of the bank's asset portfolio towards A in response to R may be inferred by simply calculating the slope of the optimality condition, it is given by

$$\frac{\partial \widehat{A}}{\partial R} = -\frac{p^a}{\gamma Var(R^a)} \tag{G.16}$$

If the expected return is assumed to be constant, the optimality condition (15) is linear with the slope expressed in (G.16).

We may also analyze how much the expected return on the risky asset must increase in order to maintain a stable demand on this asset in the case when the policy rate increases by 1%. Analytically we derive the MRS, it is given by

$$MRS_{\{R^a,R\}} = \frac{\partial \widehat{A}/\partial R^a}{\partial \widehat{A}/\partial R}. \tag{G.17}$$

The partial derivative w.r.t. R^a is given by

$$\frac{\partial \widehat{A}}{\partial R^a} = \frac{Var(R^a) - 2R^a(R^a - \mu_a)}{\gamma (R^a - \mu_a)^4}. \tag{G.18}$$

Substitute out both partial derivatives in equation (G.17) and notice that $Var(R^a) = (R^a - \mu_a)^2$, we get[16]

$$MRS_{\{R^a,R\}} = -\frac{R^a + \mu_a}{p^a(R^a - \mu_a)}. \tag{G.19}$$

Using the numerical values depicted in Table 1, we infer that the slope of the stock demand function is $\partial \widehat{A}/\partial R = -1000$, indicating that a decrease in the policy rate by 1% lowers the

[16] The variance of the expected return on the risky asset is defined by $Var(R^a) = E(R^a - \mu_a)^2$. Since R^a already represents the expected value of the stock return, we leave the expectation operator E out by virtue of the law of iterated expectations.

demand for the risky asset by 10 units which gives a change in the bank's balance sheet for this asset by $d(p^a\widehat{A}) = -6$. The substitution elasticity among the tradable assets refers to $MRS_{\{R^a,R\}} = -11.6667\%$.

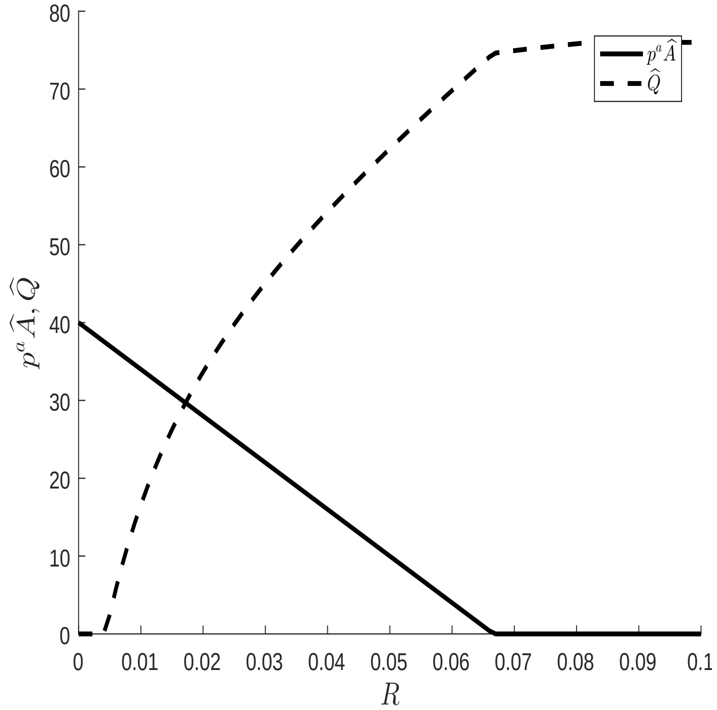

Figure 7: The demand for the financial assets p^aA and Q

H Proof of Proposition 5

Similar to the proof on Proposition 3, we consider the random sales price u being uniformly distributed with support $[0, \overline{x}]$. The spread between the contractual and the expected lending rate then refers to

$$R^b - ER^b = R^b - R^b(1 - F(u)) - \left(\frac{Y}{B} - \eta\right) \int_0^{\bar{u}} uf(u)\, du$$
$$= \frac{R^{b^2}}{2\overline{x}} \left(\frac{B}{Y}\right) + \frac{\eta}{2\overline{x}} \left(\frac{R^b B}{Y}\right)^2$$

which can also be expressed by

$$R^b - ER^b = \frac{R^b}{2}F(u) + \frac{\eta\overline{x}}{2}F(u)^2$$

or

$$R^b - ER^b = \frac{R^b}{2\overline{x}}u + \frac{\eta}{2\overline{x}}u^2.$$

This spread evaluated at the equilibrium point gives

$$\widehat{R}^b - \widehat{ER^b} = \frac{\widehat{R}^b}{2\overline{x}}\widehat{\overline{u}} + \frac{\eta}{2\overline{x}}\widehat{\overline{u}}^2. \tag{H.20}$$

The first derivative gives

$$\frac{d(\widehat{R}^b - \widehat{ER^b})}{dR} = \frac{\widehat{\overline{u}}}{2\overline{x}}\frac{d\widehat{R}^b}{dR} + \frac{\widehat{R}^b}{2\overline{x}}\left[\frac{d\widehat{\overline{u}}}{dR} + \frac{\partial\widehat{\overline{u}}}{\partial\widehat{R}^b}\frac{d\widehat{R}^b}{dR}\right] + \frac{2\eta}{2\overline{x}}\widehat{\overline{u}}\left[\frac{d\widehat{\overline{u}}}{dR} + \frac{\partial\widehat{\overline{u}}}{\partial\widehat{R}^b}\frac{d\widehat{R}^b}{dR}\right]. \tag{H.21}$$

We apply the same reasoning as in the previous proof on Proposition 3 in Appendix F. In particular, the part $\frac{\partial\widehat{\overline{u}}}{\partial\widehat{R}^b}\frac{d\widehat{R}^b}{dR}$ is zero by the *envelope theorem*. The derivative of the random sales price w.r.t. the reference interest rate is

$$\frac{d\widehat{\overline{u}}}{dR} = \frac{\left[\frac{d\widehat{R}^b}{dR}\widehat{B} + \widehat{R}^b\frac{\partial\widehat{B}}{\partial\widehat{R}^b}\frac{d\widehat{R}^b}{dR}\right]\widehat{Y} + \widehat{R}^b\widehat{B}\frac{\partial\widehat{Y}}{\partial\widehat{R}^b}\frac{d\widehat{R}^b}{dR}}{\widehat{Y}^2}.$$

From Appendix F we know that

$$\frac{d\widehat{\overline{u}}}{dR} = \frac{d\widehat{R}^b}{dR}\frac{\widehat{B}}{\widehat{Y}}.$$

It follows, conditional on a positive interest rate pass-trough effect, i.e. if Proposition 2 holds, that $d\widehat{\overline{u}}/dR > 0$ as long as u is in the domain $0 < \widehat{\overline{u}} = \widehat{R}^b\widehat{B}/\widehat{Y} < \overline{x}$.

Collecting all intermediate results, i.e. a positive interest rate pass-though effect $d\widehat{R}^b/dR > 0$, the positive effect on the critical sales price $d\widehat{\overline{u}}/dR > 0$ and assuming that the equilibrium threshold price $\widehat{\overline{u}} > 0$, then equation (H.21) is greater than zero, indicating that the equilibrium credit spread $\widehat{R}^b - \widehat{ER^b}$ rises with the reference interest rate R. Formally,

$$\frac{\widehat{\widehat{u}}}{2\overline{x}}\frac{d\widehat{R}^b}{dR} + \frac{\widehat{R}^b + 2\eta\widehat{\widehat{u}}}{2\overline{x}}\frac{d\widehat{\widehat{u}}}{dR} > 0.$$

Using equation (F.13) and the definition $\widehat{\widehat{u}} = (\widehat{R}^b\widehat{B})/\widehat{Y}$, one can simplify the latter result by writing

$$\begin{aligned}
\frac{\widehat{\widehat{u}}}{2\overline{x}}\frac{d\widehat{R}^b}{dR} + \frac{\widehat{R}^b + 2\eta\widehat{\widehat{u}}}{2\overline{x}}\frac{d\widehat{\widehat{u}}}{dR} &\lesseqgtr 0 \\
\frac{\widehat{\widehat{u}}}{2\overline{x}}\frac{d\widehat{R}^b}{dR} + \frac{\widehat{R}^b + 2\eta\widehat{\widehat{u}}}{2\overline{x}}\frac{d\widehat{R}^b}{dR}\frac{\widehat{B}}{\widehat{Y}} &\lesseqgtr 0 \\
\widehat{\widehat{u}} + \widehat{\widehat{u}} + 2\eta\widehat{\widehat{u}}\frac{\widehat{B}}{\widehat{Y}} &\lesseqgtr 0
\end{aligned}$$

which leads to the following result

$$\frac{d(\widehat{R}^b - \widehat{ER^b})}{dR} = 1 + \eta(\widehat{B}/\widehat{Y}) > 0 \qquad \text{(H.22)}$$

which is satisfied for all $\eta > 0$.

I Empirical data on the bank's leverage ratio

Figure 6b displays the bank's capital ratio which is the bank's equity capital (including retained earnings) relative to its RWAs. As the figure suggests, it possesses a relatively stable magnitude around 12% over the entire range of the reference interest rate R. In order to show that the leverage ratio exhibits a convenient order of magnitude, we compare it with the empirical time series of US banks' average capital-asset ratio in the time domain 2000-2016. The data has an annual frequency. The capital term comprises Tier 1 capital and total regulatory capital including distinct subordinated types of debt instruments that need to be repaid if the funds are required to maintain minimum capital levels. The term total assets includes financial as well as nonfinancial assets. A direct comparison is difficult since the data comprises several bank specific terms that are not covered in our stylized model, e.g. general and special reserves, provisions, Tier 2 and Tier 3 capital, etc. However, we refer to it as a directive to check the meaningfulness of the calibration and the results. The empirical bank reference leverage ratio is illustrated in the following figure.

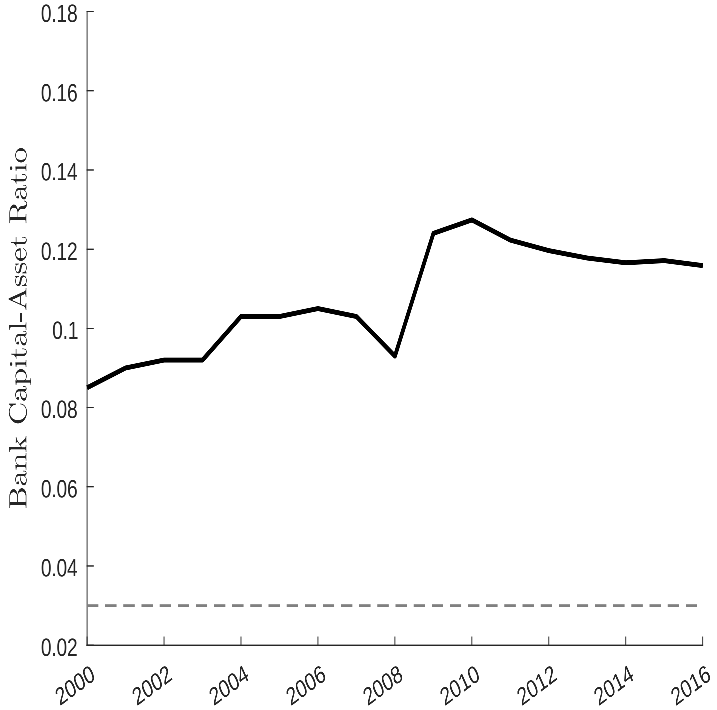

Figure 8: Bank's capital-asset ratio in the US. Source: World Bank, Bank Capital to Total Assets for United States [DDSI03USA156NWDB], retrieved from FRED, Federal Reserve Bank of St. Louis;
`https://fred.stlouisfed.org/series/DDSI03USA156NWDB`, February 13, 2019.

Note that the bold black line refers to the data and the dashed gray line to the Basel III minimum requirement. It possesses a mean of $\widehat{\mu}_{LR} = 10.75$ with standard deviation $\widehat{\sigma}_{LR} = 1.35$. From the figure we can infer that the banks' average capital-asset ratio fluctuates relatively stable around its mean with the standard deviation of 1.36. It also shows that the banks' leverage ratio increased persistently in the post-crisis era, from 2008 onwards, when the FED lowered the federal funds rate close to zero.

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