BANK LEVERAGE, FINANCIAL FRAGILITY AND PRUDENTIAL REGULATION

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Abstract: We analyse the determinants of bank balance-sheets and leverage-ratio dynamics, and their role in increasing financial fragility. Our results are twofold. First, we show that there is a value of bank leverage that minimises financial fragility. Second, we show that this value depends on the overall business climate, the expected value of the collateral provided by firms, and the risk-free interest rate. These results lead us to advocate for the establishment of an adjustable leverage ratio depending on economic conditions, rather than the fixed ratio provided for under the new Basel III regulation.

Keywords: Bank leverage; Leverage ratio; Financial instability; Prudential regulation.

JEL Classification: E44; G28
1. INTRODUCTION

The devastating consequences of the 2008 financial crisis for economic activity and unemployment have reignited debate on the causes of financial fragility and instability. Thorough empirical overviews of the events preceding and accompanying the current financial crisis is provided in Allen and Carletti (2010), Brunnermeier (2009), Greenlaw et al. (2008) and Taylor (2009). The financial crisis has been attributed to a number of factors associated with the housing and credit markets. Suggested causes include the inability of homeowners to make their mortgage payments, overbuilding during the boom period, high personal and corporate debt levels, financial product innovation, failure of key financial institutions, and errors of judgment by credit rating agencies in the rating of structured products. Macroeconomic factors, such as accommodating monetary policy, global imbalances, and government regulation (or lack thereof), are also considered to have played a direct or indirect role in the crisis (Cabral, 2013).

Another factor that has been highlighted is the significant increase in bank leverage levels in the four or five years preceding the crisis that broke in summer 2007 and the panic in autumn 2008, in particular among the major European banks and US investment banks. The bank leverage increase was around 50% in some cases. The level of asset-to-equity ratios (or the equity multiplier) remained close to a range of 20-25, i.e. capital-asset ratios (or leverage ratio) of 5% to 4%, up to 2003-2004, with significant differences across regions and categories of banks.1 Between 2005 and the onset of the crisis, the top 50 major global banks among US investment banks and European universal banks, had an equity multiplier close to or even exceeding 30 and, therefore, a leverage ratio of only 3% (Financial Stability Forum and Committee on the Global Financial System Joint Working Group, 2009).

This excess leverage prior to the crisis and the devastating impact of the deleveraging in its wake, explain why the G20 and all the prudential supervisors were converted to the idea that a leverage ratio should be added to the traditional prudential measures. It was envisaged that this would be complementary to the prudential risk ratios and, consequently, would not replace the Basel II or Basel III micro-prudential regulation that was under preparation (Ingves, 2014). This leverage ratio is a measure of a bank’s Tier 1 capital as a percentage of its assets plus off-balance sheet exposures and derivatives. The Basel Committee chose a minimum leverage ratio of 3% and, thus, a maximum equity multiplier of 33. The implementation of this ratio on an experimental basis began in January 2013 and, after various adjustment phases between 2015 and 2017, will become imperative in Pillar I of Basel III, in January 2018 (BIS Annual Report, 2011).

1 In this paper, we use the terms ‘equity multiplier’ to refer to the ‘asset-to-equity ratio’ and ‘leverage ratio’ to refer to the ‘capital-asset ratio’.
However, the efficiency of such a regulatory leverage ratio is questionable. If the chosen value of the ratio is too low, it will have a detrimental impact on the banks' ability to make loans. If the chosen value of the ratio is too high, it will not prevent banks' excess risk taking. In both cases, the question of an existing leverage ratio value that minimizes the likelihood of bank bankruptcy (referred to hereafter as banks' financial fragility) and its link with credit availability, needs to be addressed. This is the objective of this paper.

We develop a model of financial intermediation where leverage and the pricing of bank assets (interest rate on loans) are endogenously determined and, in equilibrium, depend on the overall business climate. In this framework, we show that, even if the micro-prudential requirements laid down by the Basel III Internal Rating-based (IRB) capital regulation are met, financial fragility can result from bank profit maximisation. The model also allows us to investigate the existence of an "optimal" leverage ratio to minimise financial fragility. Our analysis provides two main results.

First, we show that there is a non-linear relationship between the level of bank leverage and financial fragility, defined as the critical level of macroeconomic shock at which a bank goes into bankruptcy. More precisely, we show there is an optimal value of leverage that minimises financial fragility, which allows us to identify two states of the economy - the "inefficient equilibrium state" and the "trade-off equilibrium state". In the "inefficient equilibrium state", high levels of financial fragility are associated with low bank leverage and low levels of credit availability. In the "trade-off equilibrium state", high levels of financial fragility are associated with high bank leverage and high levels of credit availability. This result underlines that bank leverage can increase without it being detrimental to financial instability, as long as the level of leverage chosen by the banks is lower than the level that minimises financial fragility. This result is helpful for understanding the potential impact of the new Basel III capital regulation, which introduces a maximum value for bank leverage. If the maximum value fixed by the regulatory authorities is too low, the economy can become trapped in the "inefficient equilibrium state", while excessively high maximum leverage will stimulate credit availability to the detriment of financial stability. This result is in line with Kashyap and Stein (2004) who argue that a policy maker concerned about the objectives of both financial stability and maintaining credit creation, must, in certain cases, be willing to tolerate a higher probability of bank failure.

Second, we show both the bank’s chosen equilibrium level of leverage and the value of leverage that minimises financial fragility, depend on the overall economic situation and on the expected value of the collateral provided by firms to the bank. Thus, we show that there is a critical threshold above which an increase in the expected value of collateral leads to an increase in financial fragility. This result is in line with the growing literature that explicitly links bank behaviour, endogenous debt growth and financial instability (Schularick and Taylor, 2012). Moreover, since the optimal level of leverage minimising financial fragility depends on the overall business climate, we
advocate for the establishment of an adjustable leverage ratio that depends on the economic conditions, rather than the fixed ratio provided for under Basel III. This result accords with Repullo and Saurina’s (2011) argument that a proper assessment of bank risk should be conducted conditional on the state of the economy, not unconditionally.\(^2\)

Our contribution is related to two well-established strands in the literature: Work on bank leverage and financial fragility, and work on leverage ratio restriction.

Among the most important contributions dealing with the question of bank leverage and financial stability are Minsky (1982, 1986), which develop a business cycle theory based on a financial conception of economic fluctuation and propose the “financial instability hypothesis”. In Minsky’s approach, banks' profit-seeking behaviour leads them to deliberately reduce their capital-asset ratio and engage in financial operations involving high leverage when their activities are expanding. Contemporary economists, such as Goodhart (2010) and Roubini and Mihm (2010), have underlined that the recent financial crisis is based largely on similar mechanisms and several economists assign great importance to debt leverage in the dynamics of financial instability. Geanakoplos (2010a,b) postulates a leverage cycle as a recurrent phenomenon in US financial history. In a series of articles on the subprime crisis, Adrian and Shin (2010a,b) examine the role of financial intermediation in the 2007-2009 financial crisis, and also the role of leverage effects. They emphasize the pro-cyclicality of leverage, and the positive relationship between leverage and the size of financial intermediaries’ balance sheets, especially before the crisis. In the same vein, Shin (2009) models a lending boom fuelled by declining measured risk. He shows that in benign financial market conditions when measured risks are low, financial intermediaries expand their balance sheets as they increase leverage. Of course, there is a symmetrical process which accentuates the magnitude of the crisis when the measured risks are high, leading to sharp deleveraging, then a credit crunch.

Compared to this literature, our analysis has two novelties. First, we show that even in an "ideal" economic environment (perfect information, economic expansion, optimistic expectations, rising asset prices, rational agents within the standard meaning of the term), a process of pro-cyclical financial fragility based on the relationship between asset prices and the bank’s lending cycle, can develop. Second, we show that there is a non-linear relationship between leverage and financial instability.

The need for a leverage ratio restriction has been studied by the literature. However, this work focuses essentially on the disciplinary effect induced by a leverage ratio on the bank’s risk loan declaration. In a seminal paper, Blum (2008) shows that in a Basel II framework, banks can report their level of risk untruthfully. In this context, a risk-independent leverage ratio restriction may be necessary to induce truthful risk reporting.

\(^2\) Kashyap and Stein (2004) propose time-varying capital requirement as an optimal scheme for bank regulation.
However, Blum does not propose evaluation of the value of such a ratio. Similarly, Kiema and Jokivuolle (2014) focus on the impact of a risk-independent leverage ratio restriction on model risk which arises if some loans are incorrectly rated by a bank in IRB approach of capital regulation. In contrast to Blum (2008), they show that such a leverage ratio restriction, in some cases, might induce banks with low-risk lending strategies to diversify their portfolios into high-risk loans, which could undermine banking sector stability. They show also that in order to overcome this negative effect, the risk-independent leverage ratio must be higher than the ratio required by Basel III regulation.

Jarrow (2013a), which is closer to our view, tries to provide a rationale for determining the value of a maximal leverage ratio based on Value at Risk rules. In Jarrow’s paper, this value depends on the bank’s microeconomics characteristics and especially the structure of its balance sheet. In our model, the optimal leverage ratio value depends also on the macroeconomics condition, and is not linked only with the specific characteristics of one bank.3

The rest of the paper is organised as follows. Section 2 presents the model, Sections 3 and 4 present and discuss the main results. Section 5 concludes.

2. THE MODEL

We consider three classes of agents – firms, individual investors and a bank – and two periods. In the first period, firms need external funds in order to invest in a risky project subject to a macroeconomic shock. We assume that firms have access only to bank loans. In this period, financial contracts are signed between borrowers and the bank, and investment decisions are made. In the second period, the value of the macroeconomic shock and the effective return on investment are known. Non-defaulting firms have to pay for their external funds and defaulting firms are liquidated. We assume that all parties are risk-neutral and protected by limited liability.

2.1. Firm and bank behaviours

In period 1, firms with zero wealth have access to a risky investment project whose undertaking requires one unit of wealth. We assimilate firm and project and assume that firms (projects) are uniformly distributed over $[0,1]$ according to the level of their

3 In a different spirit, Jarrow (2013b) shows that the mix of capital adequacy rules based on a risk sensitive model, maximum leverage ratio and stress testing (three approaches proposed in Basel III) may increase the probability of catastrophic financial institution failure.
intrinsic or specific characteristics \( x_i \). We assume that this value is common knowledge to all the agents in the economy. There is no financial market, and since firms lack capital, they need to borrow the total amount of their investment from a bank.

In period 2, the total return on investment project \( i \) \((V_i)\) undertaken by firm \( i \) depends on two parameters. The first is the specific characteristics of the project measure by \( x_i \) and related to the firm. The second is a macroeconomic shock \( \theta \) that disrupts the economy at period 2, and which is similar to a systematic project risk. Thus, the total return on project \( i \) at period 2 is given by \( V_i = \theta x_i \).

We model the macroeconomic shock at period 2 using the following formula, \( \theta = \overline{\theta} + \sigma_{\theta} dz \) where \( \overline{\theta} > 1 \) is a measure of the average productivity, \( \sigma_{\theta} \) is a measure of the exogenous volatility of the shock and \( dz = \varepsilon \sqrt{dt} \) is a Wiener Process. \( \varepsilon \sim N(0,1) \) is a normally distributed stochastic variable and the length of the period is equal to 1 \((dt = 1)\). Consequently, the value of the shock at period 2 is equal to \( \theta = \overline{\theta} + \varepsilon \sigma_{\theta} \) and depends only on realisation of the stochastic variable \( \varepsilon \). Since, by assumption, \( E[\varepsilon] = 0 \), the expected value of the macroeconomic shock at period 1 is given by \( E[\theta] = \overline{\theta} > 1 \).

Finally, we assume that firms must provide an asset (e.g. land) as collateral for their loan, and \( Z^* \) is the expected value of this collateral for period 2. \( Z^* \) is assumed to be the same for all firms with \( Z^* \in ]0,1[ \). In the following, we assume that the bank's expectation about the value of the collateral is exogenous and is related to the historical value of the bank’s debt recovery rate, but also to the level of the bank’s "optimism" (or "pessimism") concerning the future.

There is one bank in the economy endowed with its own capital (the bank is owned by shareholders who provide it with equity capital) and individual investors' deposits. These deposits are insured through a government-funded scheme and receive the risk-free return \( \gamma > 1 \) (which is also the opportunity cost of the bank’s funds).

According to our previous assumptions, there is no moral hazard between the bank, individual investors and firms since the value of \( x_i \) is common knowledge at period 1 and realisation of \( V_i \) is freely observable by all parties at period 2.

Let us define \( R \) as the rate of return charged by the bank to the projects it finances. At the beginning of period 1, firms apply for credit and, since there is no moral hazard, the bank finances firms as long as the expected value of their projects exceeds the rate of return they must pay back in period 2, such that

\[
E[V_i] = \overline{\theta} x_i \geq R \quad \text{with} \quad x_i \in [0,1]
\]  

(1)
We assume that $\overline{\theta} > R$, and from equation (1) it is easy to show that the last firm financed by the bank is given by

$$\overline{x}_i (R) = \frac{R}{\overline{\theta}} < 1$$

and the total quantity of financing in the economy is given by

$$D = (1 - \overline{x}_i (R))$$

### 2.2. Bank regulatory capital and firms’ probability of default

Following Repullo and Suarez (2004), we assume that the bank’s level of capital is exactly equal to that required by the banking regulation. According to Basel Committee on Banking Supervision (2006), the level of a bank’s capital requirements is linked to the level of risk related to its loan portfolio. In both the Basel II and Basel III IRB frameworks, these requirements are based on the asymptotic single risk factor model proposed by Vasicek (2002). Thus, the Basel II IRB capital requirement ($k_i$) for a loan $i$ with default probability $p_i$ and maturity $M = 1$ is equal to

$$k_i = \lambda \phi \left[ \frac{\phi^{-1}(\overline{p}_i) + \sqrt{\rho} \phi^{-1}(\alpha)}{\sqrt{1 - \rho}} \right] - \lambda \overline{p}_i$$

where $\phi$ denotes the cumulative distribution function of a standard normal random variable, and $\lambda$ is the Loss Given Default (LGD) of the loan.

The first part of equation (4) measures the default rate of project $i$. This default rate is an increasing function of the class of risk of the project given by its probability of default $\overline{p}_i$, and is adjusted to the target of non-default probability fixed by the regulator ($\alpha$). $\rho$ is a correlation parameter that also is defined by the regulator. The second part of equation (4) ($\lambda \overline{p}_i$) measures the expected loss on loan $i$, which is covered by the bank’s provisions. Consequently, in the Basel regulation, capital requirements only cover the unexpected loss due to the financing of a given loan.

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4 This assumption does not change the main results of the paper and traditionally is justified by the fact that capital is more costly than deposits.

5 Maturity is equal to the length of the period and Exposure at Default is equal to 1 according to our assumption about the size of the loans granted to firms.
There are two possible versions of the IRB approach. In the traditional one, the LGD is given by the regulator, in the advanced IRB approach it is chosen by the bank. However, in both cases, the probability of default must be computed by the bank. In our model, we assume that the bank retains the advanced IRB approach proposed by the Basel II capital requirements in order to compute its level of capital. Consequently, two variables must be estimated: the LGD, and the probability of default for each project (or equivalently each firm) financed by the bank.

Note that the LGD is inversely related to the estimated value of the bank’s debt recovery rate. Also, this estimated debt recovery rate is positively correlated with the expected value of the collateral provided by firms. Consequently, we assume that the LGD chosen by the bank is a decreasing function of the expected value of the collateral provided by firms with

\[ \lambda(Z^*) < 1, \quad \frac{\partial \lambda(Z^*)}{\partial Z^*} < 0 \quad \text{and} \quad \lim_{z^* \to 0} \lambda(Z^*) = 0 \]

This assumption means that the higher the expected value of the collateral for period 2 \((Z^*)\), the higher the estimated debt recovery rate and the lower the LGD retained by the bank.

Finally, the only other parameter required to compute the level of bank capital is the borrowing firm’s probability of default. In our framework, a project \(i\) is in default (liquidated by the bank) if the firm cannot repay the value \(R\) at period 2. Formally, the probability of default of each project is given by the following conditional probability

\[ P[V_i < R \mid x_i \geq \xi_i(R)] \]  (5)

Equation (5) is the probability that the final value of project \(i\) at the end of period 2 is lower than the rate of return charged by the bank, conditional on the fact that the project initially was financed.

As \(V_i = \theta x_i = \overline{\theta} x_i + x_i \varepsilon \sigma_{\theta}\), equation (5) becomes

\[ P[\overline{\theta} x_i + x_i \varepsilon \sigma_{\theta} < R \mid x_i \geq \xi_i(R)] \]

Rearranging this, we obtain

\[ P[\varepsilon < \xi_i(R) = \frac{R - \overline{\theta} x_i}{x_i \sigma_{\theta}} \mid x_i \geq \xi_i(R)] = p_i = \phi(\xi_i(R)) \]  (6)

This is the version retained by most of the large national and international financial institutions.
where $\phi$ denotes the cumulative distribution function of a standard normal random variable. Equation (6) means that project $i$ defaults if the realised value of the shock $\varepsilon$ is larger than the critical value $\xi_i(R) = \frac{R - \bar{\theta}x_i}{x_i\sigma_o}$, with $\xi_i(R) \leq 0$ since $R \leq \bar{\theta}x_i$. This probability of default is an increasing function of the rate of return ($R$) charged by the bank, and the volatility of the shock, $\sigma_o$. Conversely, this probability of default decreases in line with the value of $x_i$, i.e. the intrinsic “quality” of project $i$.

We can substitute $\overline{p}_i = \phi(\overline{\xi}_i(R))$ and $\lambda = \lambda(Z^*)$ in equation (4) to obtain the amount of capital required for the bank to finance project $i$, $^7$

$$k_i = \lambda(Z^*) \left[ \xi_i(R) + \frac{\sqrt{\rho} \phi^{-1}(\alpha)}{\sqrt{(1-\rho)}} - \phi(\overline{\xi}_i(R)) \right]$$

For simplicity, hereafter we use $P_i(\alpha, \overline{\xi}_i(R)) = \phi \left[ \frac{\xi_i(R) + \sqrt{\rho} \phi^{-1}(\alpha)}{\sqrt{(1-\rho)}} \right]$ as the rate of default; Basel II advanced IRB bank capital requirements for project $i$ are given by the formula

$$k_i(R) = \lambda(Z^*) \left[ P_i(\alpha, \overline{\xi}_i(R)) - \phi(\overline{\xi}_i(R)) \right]$$

Consequently, since the total amount of loan is given by $D = (1 - \overline{\xi}_i(R))$ (eq. (3)), the total amount of the bank’s capital (which is also the value of its Economic Capital) is equal to the regulatory capital required in order to cover its loan portfolio

$$K(R) = \int_{\overline{\xi}_i(R)}^1 k_i(R) dx_i = \int_{\overline{\xi}_i(R)}^1 \lambda(Z^*) \left[ P_i(\alpha, \overline{\xi}_i(R)) - \phi(\overline{\xi}_i(R)) \right] dx_i$$

$^7$ Note that $\phi^{-1}(\overline{p}_i) = \phi^{-1}(\phi(\overline{\xi}_i(R))) = \overline{\xi}_i(R)$
3. EQUILIBRIUM AND FINANCIAL STABILITY

We assume that the bank is unconstrained in raising capital, and can freely adjust its capital structure and leverage. Consequently, at equilibrium, the bank chooses simultaneously the quantity of projects financed (its loans portfolio) and the amount of capital required by the regulation to cover this portfolio risk. Thus, the amount of deposit is determined by the difference between the value of the bank's loans portfolio and the amount of regulatory capital provided by the bank, which also determines its level of leverage. In such a framework, the problem relies on the optimal quantity of capital the bank must provide in order to finance the various risky loans of its portfolio. Following the papers by Stoughton and Zechner (2007) and Buch et al. (2011), we assume that the bank’s objective is to maximise its Risk Adjusted Return on Capital (RAROC) or the adjusted return per unit of capital that it must provide to finance risky firms. As a consequence, the bank bases its capital allocation process on its shareholder value. This assumption is very close to real bank practice (see e.g. Zaik et al., 2005, for the case of Bank of America).

3.1. Bank's equilibrium and the total value of financing

The bank’s expected RAROC is defined as

$$\text{RAROC} = R_b = \frac{\text{Expected profit}}{\text{Economic Capital}}$$

(9)

Because of our assumption that the bank’s level of capital is exactly equal to that required by the banking regulation, the value of its economic capital is given by equation (8).

The bank’s expected profit depends on the number of projects it finances and the number of defaulting loans. When the bank finances a project, it expects to receive the rate of return $R$ if the project succeeds at period 2 and the expected value of the collateral for period 2, $\langle Z \rangle$ if the project fails.\(^8\) Project $i$’s probability of default is given by $\phi(\pi_i(R))$ and its probability of success is given by $\langle 1 - \phi(\pi_i(R)) \rangle$. We know also that the last project financed by the bank is given by $\pi_i(R)$ and the bank's deposit cost (opportunity cost of the funds) is given by $\gamma > 1$.

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\(^8\) We assume that a project has no residual value in the event of default.
Thus, the expected profit of the bank at period 1, net of the opportunity cost of the funds, is equal to

$$\Pi_b^e(R) = \int_{\pi(R)}^1 \left( \left(1 - \phi(\xi_i(R)) \right) R + \phi(\xi_i(R)) Z^e \right) dx_i - \int_{\pi(R)}^1 \gamma \left(1 - k_i(R) \right) dx_i$$

or

$$\Pi_b^e(R) = \int_{\pi(R)}^1 \left( \left(1 - \phi(\xi_i(R)) \right) R + \phi(\xi_i(R)) Z^e - \gamma \right) dx_i + \gamma \int_{\pi(R)}^1 k_i(R) dx_i$$

As $K(R) = \int_{\pi(R)}^1 k_i(R) dx_i$, we have

$$\Pi_b^e(R) = \int_{\pi(R)}^1 \left( \left(1 - \phi(\xi_i(R)) \right) R + \phi(\xi_i(R)) Z^e - \gamma \right) dx_i + \gamma K(R) \tag{10}$$

Using equation (8) and (10), the expected RAROC of the bank is equal to

$$R_b^e(R) = \frac{\Pi_b^e(R)}{K(R)} = \frac{\int_{\pi(R)}^1 \left( \left(1 - \phi(\xi_i(R)) \right) R + \phi(\xi_i(R)) Z^e - \gamma \right) dx_i}{\int_{\pi(R)}^1 \lambda(Z^e) \left( P_i(\alpha, \xi_i) - \phi(\xi_i) \right) dx_i} + \gamma \tag{11}$$

Finally, the value of the RAROC net of the opportunity cost of capital (which is also a measure of the risk premium for each unit of capital provided by the shareholders) is equal to

$$\Gamma(R) = (R_b^e(R) - \gamma) = \frac{\int_{\pi(R)}^1 \left( \left(1 - \phi(\xi_i(R)) \right) R + \phi(\xi_i(R)) Z^e - \gamma \right) dx_i}{\int_{\pi(R)}^1 \lambda(Z^e) \left( P_i(\alpha, \xi_i) - \phi(\xi_i) \right) dx_i} \tag{12}$$

From equation (12), we can see immediately that the rate of return charged by the bank $(R)$ has an ambiguous effect on its net RAROC. On the one side, a rise in $R$ will increase the profitability of the bank since it leads to a higher return from each successful project. On the other side, since firms' default probability $(\phi(\xi_i(R)))$ is an
increasing function of the rate of return, a rise in \( R \) will decrease the profitability of the bank because it will lead to a higher probability of default for each project financed. Note also that the higher the firms' probability of default, the higher the quantity of regulatory capital the bank must provide. The balance between these two opposite forces – rise in profitability, and rise in default and capital – determines the equilibrium value of the rate of return that maximises the bank RAROC.

Thus, the bank’s objective is to choose the rate of return value that maximises equation (12). Proposition 1 gives the formal condition for the existence of this value. It also indicates the equilibrium level of leverage compatible with RAROC maximisation.

**Proposition 1.**

a. For \( 2\gamma - Z^* < \bar{\theta} < \frac{5\gamma \sigma_g}{(\gamma - Z^*)} \), there is a unique value \( R^* \in [R_e, \bar{\theta}] \) with \( R_e > \gamma \) that maximises the net RAROC of the bank and \( \Gamma(R^*) > 0 \).

b. The total level of financing in the economy is given by \( D^*(R^*) = \left(1 - \pi(R^*)\right) > 0 \) with \( \frac{\partial D(R)}{\partial R} < 0, \forall R \) and the equilibrium level of the bank’s leverage (or equity multiplier) is equal to \( \ell^*(R^*) = \frac{D^*(R^*)}{K^*(R^*)} \) with \( \frac{\partial \ell(R)}{\partial R} < 0, \forall R \).

Proof of Proposition 1: see Appendix A.

According to part a. of proposition 1, the bank’s net expected RAROC is maximised for a unique value of the rate of return it charges to firms. This value depends on the expected value of the collateral for period 2 \( (Z^*) \), the risk-free rate of return \( (\gamma) \) and the value of \( \bar{\theta} \) and \( \sigma_g \) which can be understood as proxying for the overall business climate.

In addition, as stated in part b. of proposition 1, the total quantity of financing in the economy is a decreasing function of the rate of return charged by the bank, since when the bank’s rate of return on loans falls, new firms will be financed. Finally, the level of bank leverage is a decreasing function of the rate of return it charges to firms. This result is straightforward since firms are financed partly by bank capital and partly by deposits. Thus, when the bank cuts the rate of return it charges to firms, its level of assets increases (since the amount of loans financed increases) at a faster pace than its level of regulatory capital, leading to a rise in its equilibrium level of leverage.
3.2. Bank leverage and financial fragility

In this section, we identify the relationship between the level of bank leverage and bank financial fragility. As already said, we refer to the bank’s financial fragility to mean the bank’s likelihood of bankruptcy. Following Heid (2007), we assume that the bank is bankrupt if its value at period 2 is lower than the level of capital required by the regulation since in that case, the bank can be shut down by the regulatory authorities.9

The value of the bank at period 2 is comprised of two parts. The first part is the capital endowment that allows the bank to absorb part of the firms default linked to realisation of the macroeconomic shock; the second part is determined by the value of the bank’s assets.

Bank capital consists only of regulatory capital, whose value is fixed at period 1 for period 2 according to the level of risk of the bank loans portfolio. In contrast, the value of the bank's assets is linked to the realised value of the macroeconomic shock and the effective value of the collateral at period 2, which we label \( \bar{Z} \) as opposed to \( Z^e \) which is the expected value of the collateral at period 1 for period 2.

We make two assumptions at this stage. First, we assume there is no reason for the effective value and the expected value of the collateral to be equal. In fact, if the bank is pessimistic or optimistic concerning the future, the expected value of the collateral will be respectively lower or higher than the effective value. Second, for the sake of simplicity we assume that the effective value of the collateral is independent of realisation of the macroeconomic shock.

Under these assumptions, the bank’s value at period 2 essentially depends on realisation of the macroeconomic shock.

Let us define \( \varepsilon < 0 \) as the value of the macroeconomic shock at which firms \( i \) with \( \bar{x}_i < x_i \leq x_c = \frac{R}{\theta + \sigma \varepsilon} \) will default. This means that financed firms with \( x_i \in [x_c, 1] \) are successful, while financed firms with \( x_i \in [\bar{x}_i, x_c] \) are in default (see figure 1 for a graphical illustration).

9 Heid (2007, pp. 3888-3889) states that "regulatory requirements shift the bank’s default point from 0 [the solvency constraint] to the regulatory constraint".
The value of the bank at period 2 is thus given by

\[ V_b(R) = \int_{\pi_i(R)}^{x_i(R)} R \, dx_i + \int_{\pi_i(R)}^{x_i(R)} Z \, dx_i - \int_{\pi_i(R)}^{x_i(R)} \gamma \, dx_i + K(R) \]  

Equation (13) means that the bank earns \( R \) for each non-defaulting loan, \( Z \) for each defaulting loan, and pays the opportunity cost \( \gamma \) for the whole value of its loans portfolio. According to our assumption, the bank goes into bankruptcy when

\[ V_b(R) < K(R) \text{ or } V_b(R) - K(R) < 0 \]

We have

\[ V_b(R) - K(R) = \int_{\pi_i(R)}^{x_i(R)} R \, dx_i + \int_{\pi_i(R)}^{x_i(R)} Z \, dx_i - \int_{\pi_i(R)}^{x_i(R)} \gamma \, dx_i \]

Consequently, the bank goes into bankruptcy when

\[ R[1 - x_i(R)] + Z[x_i(R) - \bar{x}_i(R)] - \gamma[1 - \bar{x}_i(R)] < 0 \]

Or equivalently with \( x_i(R) = \frac{R}{\bar{\theta} + \varepsilon_i \sigma_\theta} \) and \( \bar{x}_i(R) = \frac{R}{\bar{\theta}} \)

\[ R \left[ 1 - \frac{R}{\bar{\theta} + \varepsilon_i \sigma_\theta} \right] + Z \left[ \frac{R}{\bar{\theta} + \varepsilon_i \sigma_\theta} - \frac{R}{\bar{\theta}} \right] - \gamma \left[ 1 - \frac{R}{\bar{\theta}} \right] < 0 \]  

Equation (14) depends on the risk-free rate of return, the effective value of the collateral, the rate of return chosen by the bank, and the state of the business climate \((\bar{\theta}, \sigma_\theta)\). For a given value of these variables, it is possible to determine the value of the
macroeconomic shock at which the bank goes into bankruptcy. This main result is given in proposition 2.

**PROPOSITION 2.**

\[ \varepsilon < \varepsilon_c < 0 \] with

\[ \varepsilon_c = \frac{\bar{\theta} \left( R - \gamma \right) \left( R - \bar{\theta} \right)}{\sigma \left( R \left( \gamma - Z \right) + \bar{\theta} \left( R - \gamma \right) \right)} \]

the bank goes into bankruptcy.

b. There is a value \( R_{\text{min}} \) of the rate of return associated with a value of bank leverage \( \ell \left( R_{\text{min}} \right) \) that minimises the bank’s probability of default.

Proof of Proposition 2: see Appendix B.

The intuition for proposition 2 is straightforward. The value \( \varepsilon_c \) can be considered as a measure of the financial fragility of the economy because it defines the critical level of the macroeconomic shock for which the bank is bankrupted. A rise in \( \varepsilon_c \) means that the bank is more sensitive to a shock in the sense that the value of the shock that is required to make it fail is lower: financial fragility increases. In our model, the degree of financial fragility depends on the overall business climate \( \left( \bar{\theta}, \sigma \right) \), the risk-free rate of return \( \gamma \), the effective value of the collateral \( Z \) and the rate of return charged by the bank \( R \).

In fact, the balance between two coexisting forces determines a nonlinear relationship between the rate of return charged by the bank and financial fragility.

In order to understand this result, let us assume first that the rate of return charged by the bank is high. According to proposition 1, this means that the value of leverage and the total quantity of financing are low. Let us then assume that the bank decides to cut the value of the rate of return it charges to firms. Two mechanisms that work in opposite directions come into play. First, firms’ ex-ante probability of default falls with the rate of return charged by the bank. This mechanism positively affects bank financial stability. Second, as the rate of return charged by the bank decreases, more firms are financed and the bank’s regulatory capital increases with the quantity of financing. However, since firms are financed partly by bank capital and partly by deposits, the value of leverage increases (see part b. of proposition 1). As leverage increases, the ex-post value of the bank becomes more dependent on the value of its assets. This second mechanism negatively affects the bank’s financial stability since the ex-post value of the bank’s assets is related to the level of the macroeconomic shock. Consequently, there is a critical value of the rate of return \( \ell \left( R_{\text{min}} \right) \) charged by the bank beyond which the second effect outweighs the first effect, and the bank becomes more sensitive to the
The critical value of the macroeconomic shock. This critical value of the rate of return charged by the bank is associated with a critical value of leverage $\ell (R_{\text{min}})$ at which financial fragility increases in line with leverage.

$\ell (R_{\text{min}})$ is thus defined as the “maximum stability value of leverage” which means the value of the equity multiplier at which the bank’s probability of default is at its minimum, and financial stability is at its maximum. However, there is no reason for the bank to choose this specific value. On the contrary, we have shown that the equilibrium level of leverage chosen by the bank is the level that maximises its net RAROC, $\ell (R^*)$.

Consequently, two situations are possible. In the first case, $\ell (R^*) < \ell (R_{\text{min}})$ and the equilibrium value of leverage chosen by the bank is lower than the "maximum stability value". This situation is inefficient from the point of view of the economy as a whole, since it is possible to increase the quantity of financing and financial stability simultaneously. In fact, a lower rate of return charged by the bank will increase the amount of funds available to firms. Simultaneously, this increase in the quantity of financing will lead to an increase in the level of bank leverage and a decrease in the bank’s probability of default. In the second case, $\ell (R^*) > \ell (R_{\text{min}})$ and the equilibrium value of leverage is higher than the "maximum stability value". In this case, there is a trade-off between financial stability and credit availability since a higher degree of financial fragility must be accepted in order to increase the quantity of credit available to firms above $\ell (R_{\text{min}})$.

Figure 2 provides a graphical representation of this mechanism. The right quadrant describes the relationship between the rate of return charged by the bank and the value of bank leverage $\ell (R)$. This relationship is decreasing since a decline in the rate of return charged by the bank leads to a rise in leverage (proposition 1). The left quadrant links the value of bank leverage to its probability of default $\phi (\varepsilon_c)$, which is related to the critical value of the macroeconomic shock $\varepsilon_c$ (proposition 2).

As the rate of return charged by the bank decreases, the amount of funds available to firms increases and more projects can be undertaken. Simultaneously, this increase in the quantity of financing leads to a rise in the level of bank leverage and a decrease in the probability of default as long as $\ell (R) < \ell (R_{\text{min}})$. When the level of bank leverage becomes higher than $\ell (R_{\text{min}})$, the bank’s probability of default increases in line with

\[ 10 \] This result is in line with Inderst and Mueller (2008) who show that leverage is beneficial, at least up to a certain point, to provide an incentive for banks to make new risky loans.
the level of financing. Consequently, from that point, higher credit availability is possible if one accepts a higher level of financial instability.

4. RISE IN COLLATERAL, FINANCIAL STABILITY AND MACROPRUDENTIAL REGULATION

So far, we have shown that the equilibrium rate of return charged by the bank depends on the expected value of the collateral for period 2, the risk-free rate of return and the overall business climate of the economy. Below, we study the impact of a change in the expected value of the collateral on bank behaviour and financial stability.

First, we show that the bank’s equilibrium level of leverage increases with the expected value of the collateral. Second, we show there is a critical threshold for the expected value of the collateral after which the equilibrium value of bank leverage becomes higher than "the maximum stability value". This means that, above this threshold, bank financial fragility increases with the expected value of the collateral. Therefore, we estimate "the maximum stability value of leverage" for given parameter values. This heuristic experiment shows that this "maximum stability value" might be far from the value fixed by the regulator and can vary with the overall business climate.
4.1. Rise in collateral and financial stability

It is possible to show that a rise in the expected value of the collateral has a positive impact on the total level of financing and the equilibrium value of leverage chosen by the bank. We show also that, after a given threshold, an increase in the expected value of the collateral and bank leverage is detrimental to financial stability.

**Proposition 3**

a. $\ell(R^e)$ is an increasing function of the expected value of the collateral $Z^e$.

b. There is a critical value $Z_c^e$ for which $\ell(R^e) > \ell(R_{\min})$ and financial fragility increases along with the rise in the expected value of the collateral.

**Proof of proposition 3:** see Appendix C.

The two parts of proposition 3 are straightforward.

First, a rise in the expected value of the collateral has a direct positive impact on the bank’s net expected profit since, ceteris paribus, it increases the expected return in the event of firm default. Note also that a change in the expected value of the collateral directly alters the required level of regulatory capital (it decreases), since it depends on the LGD value estimated by the bank in the advanced IRB model. Consequently, there is a kind of "freeing" of the amount of regulatory capital compared to the previous situation, and the bank has to change its behaviour in order to reach a new equilibrium. The "freeing" in the level of capital and the increase in the net expected profit for each loan that is financed, means the bank is inclined to increase its level of financing. This can be done by cutting the rate of return charged on each loan. In this case, the amount of funds provided to firms increases and the ex-ante probability of default of each project falls as the rate of return charged to each firm decreases. At the same time, as the quantity of financing increases, the required level of regulatory capital increases. This process stops as soon as the bank has restored the equilibrium value of its RAROC. Lastly, the equilibrium level of leverage increases in line with the quantity of financing (see proposition 1).

Second, as the equilibrium value of leverage chosen by the bank increases with the rise in the expected value of the collateral, there is a critical expected value of the collateral at which the bank’s effective leverage becomes higher than the “maximum stability value of leverage” (part b. of proposition 3). This result is straightforward since the "maximum stability value of leverage" depends on the effective value of the collateral, which is constant. This means that financial fragility increases with the rise in the expected value of the collateral because the bank becomes increasingly sensitive to macroeconomic shocks.
However, because of the structure of the model, which is strongly non-linear, it is impossible to compute this critical expected value of collateral. Thus, in the last part of the paper, we provide a numerical illustration of proposition 3. This illustration is purely heuristic in the sense that we do not consider it a prescriptive tool, but rather a way of stressing that both the “maximum stability value of leverage” and the critical expected value of the collateral above which financial fragility increases, depend on the overall business climate and may differ from the value proposed by the regulator.

4.2. A numerical illustration

We have underlined that the Basel Committee has chosen a minimum leverage ratio of 3%, and thus a maximum equity multiplier of 33. These values seem to be consistent with the historical averages in non-crisis periods, but they are not based on specific economic reasoning (Jarrow, 2013a). In this part of the paper, we provide a numerical illustration of proposition 3 in order to show that, for some plausible values of the various parameters of the model, the “maximum stability value of leverage” is far from 33.

Table 1 presents the parameter values adopted for the simulation; Figure 3 is a graphical representation of the "maximum stability value" and effective levels of leverage retained by the bank.

<table>
<thead>
<tr>
<th>$\tilde{\theta}$</th>
<th>$\sigma$</th>
<th>$\gamma$</th>
<th>$Z$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.45</td>
<td>0.055</td>
<td>1.015</td>
<td>0.65</td>
</tr>
</tbody>
</table>

Table 1. Values of the parameters

We retain a debt recovery rate ($Z$) of 65% which is compatible with the average mean recovery rate observed in Moody's or S&P's reports during financial crises.\(^{11}\) We choose a risk-free interest rate of 1.5% which is near to the average rate of refinancing fixed by central banks between 2002 and 2005. Finally, the volatility of the macroeconomic shock ($\sigma$) and the maximum rate of return on financed projects ($\tilde{\theta}$) are chosen to be compatible with a "good business climate" (5.5% and 45% respectively).

Figure 3 provides a numerical illustration of proposition 3 for the values in Table 1. The “maximum stability value of leverage” ($\ell (R_{\text{min}})$) is equal to 23.76 and corresponds to the horizontal line in Figure 3. It is well below the maximum equity multiplier of 33 fixed by Basel III prudential regulation (dotted line in Figure 3).

\(^{11}\) Moodys Annual Default Study, 2012.
The increasing function represents the various equilibrium values of leverage chosen by the bank \( \ell \left( R^* \right) \) according to the expected value of the collateral, for the range \( Z^e \in [0.55;0.75] \).\(^{12}\)

As expected, the equilibrium level of leverage chosen by the bank increases with the rise in the value of the collateral. Figure 3 provides a graphical illustration of the area of financial fragility of the economy. This area of financial fragility is defined as the equilibrium situations where the level of leverage chosen by the bank (the level that maximises its profits) is higher than the “maximum stability value of leverage”. This means that, in this area, the incentive for banks to increase their equilibrium level of leverage leads to a rise in financial fragility. This area is bounded by the threshold expected value of the collateral which, in this case, is equal to 0.7.

![Figure 3. Level of leverage and area of financial fragility](image)

This result highlights that the choice of a fixed regulatory level for the leverage ratio could be misleading if the objective is to reinforce financial stability. Under specific macroeconomic conditions or a specific business climate, a bank may choose a level of leverage lower than that fixed by the new regulation, but higher than the “maximum

\(^{12}\) Simulations are performed using Mathematica. This program is available from the authors on request.
stability value of leverage”. In that case, financial stability will not be guaranteed by achievement of the new leverage ratio.

5. CONCLUSION

We have shown in this paper that financial fragility can emerge even if it is assumed that banks make rational decisions under perfect information. Our analysis provides two main results. First, we show that risk-sensitive microprudential regulation, such as Basel II, cannot prevent an increase in financial fragility due to bank behaviour. In periods of expansion, characterised by a rise in assets prices, optimal bank behaviour leads to an increase in leverage that heightens financial fragility. Consequently, a maximum leverage ratio constraint seems justified in order to prevent financial fragility. This is the path followed by the new Basel III macroprudential regulations which aim to impose a maximum bank leverage (equity ratio) of 33. However, our second result highlights that the value of leverage that maximises financial stability is not constant along the cycle. This means that the regulator should adjust the leverage ratio in order to be efficient. This result is in line with the set of Basel III regulatory innovations which includes countercyclical capital ratios leading to stricter capital requirements during boom periods in order to restrict the supply of loans (Arnold et al., 2012). In Basel III, these countercyclical provisions must be calibrated not according to the specific exposure of each financial institution, but in response to the total exposure relating to the stage in the economic cycle. Rather than resorting to totally discretionary devices as might apply to an enriched Pillar 2 within Basel II or, conversely, adopting automatic rules, the option chosen by the Basel Committee is to define guidelines or targets (for instance the value of total loans on GDP), which if exceeded might justify a gradual increase in the capital requirements of Pillar 1. Since our model shows that the value of leverage that maximises financial stability is not constant within the cycle, we would advocate for a similar approach based on targets to define an adjustable leverage ratio. Our results support targets based on the level of the risk-free interest rate, asset prices and macroeconomic volatility.

The analysis in this paper could be extended in several directions.

First, our analysis deals with only one aspect of systemic risk created by banks' behaviour, namely aggregate systemic risk, whereas there are two main sources of financial instability linked to two kinds of systemic risk (Bank of England, 2009). The first is the tendency for the bank to take excessive risks in a boom phase. This mechanism leads to the emergence of aggregate systemic risk due to the collective tendency of banks to take excessive risk and adopt high leverage levels during expansionary periods in the cycle. The second is the underestimation of spillovers in the banking system, which leads to network systemic risk. This systemic risk is the outcome of common exposure and interconnections among financial institutions, and is due to
the sharp increase in funding markets and interbank flows, especially since 2002. In this paper, we addressed only the first source of bank distress, which led to our proposal to establish the leverage ratio. However, we do not underestimate the danger of network systemic risk and consequent contagion mechanisms for triggering a systemic crisis. We believe that this contagion process could amplify the main risk-taking mechanisms proposed in this paper. However, because of our specific, one bank framework, these networks effects cannot be properly modeled.

Second, we ignore the literature on systemic risk and financial fragility based on securitization and untruthful declarations by banks (Blum, 2008). As we stress in the introduction, our focus is on the possible increase in financial fragility in a perfect framework with no "perturbation" due to informational problems between banks and the regulator. However, untruthful declarations or securitization could amplify financial instability by adding to the main cause of the financial instability (higher leverage) proposed in this paper.

Finally, our paper is linked to the literature on risk-taking channels, which underlines that monetary policy affects risk-taking by banks because of the relationship between the level of short-term interest rates, the level of leverage and the level of banking risks (Dell'Ariccia et al., 2014 for instance). This risk-taking channel seems to have played a major role in the run-up to the present financial crisis. Empirically, although the relationship is far from homogeneous, depending on the bank and the level of its capital, credit quality changes during the cycle and according to short-term rates. Thus, there is a clearly negative relationship between the interest rates set by monetary authorities and banks’ risk-taking, measured in different ways (spread, internal bank ratings). Low interest rates not only encourage quantitative expansion of credit but also reduce its inherent quality in terms of risk.

These results for risk-taking can be obtained using our framework since the equilibrium level of leverage chosen by the banks depends on the risk-free rate of return. A decrease in the risk-free rate of return reduces the opportunity cost of funds for banks and might encourage them to reduce their equilibrium rate of return. This reduction could lead to a rise in leverage and might increase financial fragility if the new equilibrium level of leverage chosen by the banks is higher than the "maximum stability value of leverage". Our results go beyond this simple risk-taking channel mechanism by stressing that it seems impossible to determine the "maximum stability value of leverage" and, thus, the "optimal" value of the leverage ratio, independent of the risk-free rate of return. This would require, at least, extensive coordination between the central banks and the supervisory authorities if they remain separate, wherever they are located. Much remains to be done to redefine a new central banking system that would ensure both monetary and financial stability.
REFERENCES


APPENDICES

Appendix A. Proof of proposition 1.

Preliminary

Recall that the level of bank capital is given by
\[ K(R) = \int_{\tau_i(R)} k_i(R) \, dx_i = \int_{\tau_i(R)} \lambda(Z^i) \left( P_i\left(\alpha, \varepsilon_i(R)\right) - \phi\left(\varepsilon_i(R)\right)\right) \, dx_i \quad \text{(equation (8))} \]

We define \( B(R) \) as the gross expected profit of the bank (the numerator of equation (12)).
\[ B(R) = \int_{\tau_i(R)} \left(1 - \phi(\varepsilon_i(R))\right) R + \phi(\varepsilon_i(R)) Z^i - \gamma \right) \, dx_i \]

With \( \tau_i(R) = \frac{R}{\theta} \), \( \varepsilon_i(R) = \frac{R - \theta x_i}{x_i \sigma_\theta} \) and \( P_i\left(\alpha, \varepsilon_i(R)\right) = \phi \left[ \frac{\phi(\varepsilon_i(R)) + \sqrt{\rho} \phi^{-1}(\alpha)}{\sqrt{1 - \rho}} \right] \)
defined previously.

Note that \( K(R) \) and \( B(R) \) are continuous and differentiable on \( R \in [\gamma, \bar{R}] \).

We know that for \( R \to F(R) = \int_{w(R)}^{u(R)} f(R, x) \, dx \) we have
\[ \frac{\partial F(R)}{\partial R} = F'_R(R) = \int_{w(R)}^{u(R)} \frac{\partial f}{\partial R}(R, x) \, dx + w'_R(R) \cdot f[R, u(R)] - w'_R(R) \cdot f[R, w(R)] \]

Consequently, the partial derivatives of \( K(R) \) and \( B(R) \) relative to \( R \) are given by the following two equations.
\[ \frac{\partial K(R)}{\partial R} = K'_R(R) = \int_R^1 \lambda(Z') \left( \frac{\partial P_1(\alpha, \overline{R}_i(R))}{\partial \overline{R}_i(R)} - \frac{\partial \phi(\overline{R}_i(R))}{\partial \overline{R}_i(R)} \frac{\partial \overline{R}_i(R)}{\partial R} \right) dx_i - \lambda(Z') \frac{1}{\theta} \left[ P_1(\alpha, 0) - \phi(0) \right] \]

\[ K'_R(R) = \lambda(Z') \int_R^1 \left[ P_1(\alpha, \overline{R}_i(R)) - \phi_1'(\overline{R}_i(R)) \right] \frac{1}{x_i \sigma_\theta} dx_i - \frac{1}{\theta} \left[ P_1(\alpha, 0) - \phi(0) \right] \]

\[ \frac{\partial B(R)}{\partial R} = B'_R(R) = \int_R^1 \left[ (1 - \phi(\overline{R}_i(R))) - R \frac{\partial \phi(\overline{R}_i(R))}{\partial \overline{R}_i(R)} \frac{\partial \overline{R}_i(R)}{\partial R} + Z' \frac{\partial \phi(\overline{R}_i(R))}{\partial \overline{R}_i(R)} \right] dx_i - \frac{1}{\theta} \left[ (1 - \phi(0)) R + \phi(0) Z' - \gamma \right] \]

\[ B'_R(R) = \int_R^1 \left[ (1 - \phi(\overline{R}_i(R))) - (R - Z') \frac{\phi_1'(\overline{R}_i(R))}{x_i \sigma_\theta} \right] dx_i - \frac{1}{\theta} \left[ \frac{1}{2} (R + Z') - \gamma \right] \]

With \( \phi(0) = \frac{1}{2}, \overline{R}_i(R) = \frac{\partial \overline{R}_i(R)}{\partial R} = \frac{1}{\theta} > 0 \) since \( \overline{R}_i(R) = \frac{R}{\theta} \),

\[ \frac{\partial \phi(\overline{R}_i(R))}{\partial \overline{R}_i(R)} = \phi_1'(\overline{R}_i(R)) > 0, \quad \frac{\partial \overline{R}_i(R)}{\partial R} = \frac{1}{x_i \sigma_\theta} \quad \text{as} \quad \overline{R}_i(R) = \frac{R - \theta x_i}{x_i \sigma_\theta} \quad \text{and} \]

\[ \frac{\partial P_1(\alpha, \overline{R}_i(R))}{\partial \overline{R}_i(R)} = P_1(\alpha, \overline{R}_i(R))_\varepsilon' > 0. \]

**Lemma 1.**

For \( 2\gamma - Z' < \overline{\theta} < \frac{5\gamma \sigma_\theta}{(\gamma - Z')} \), there is \( \overline{R} \) such that

a. For \( R \in [\gamma, \overline{R}] \) we have \( B'_R(R) > 0 \)

b. For \( R \in [\overline{R}, \overline{\theta}] \) we have \( B'_R(R) < 0 \)
and \( \overline{R} \) is the unique value of the rate of return charged by the bank for which \( B(R) \) is the maximum.

**Proof of Lemma 1.**

We know that

\[
B'_R(R) = \int_0^1 \left[ \left( 1 - \phi_i(\overline{R}) \right) - \frac{\phi_i'(\overline{R})}{x_i \sigma_\theta} \right] dx_i - \frac{1}{\theta} \left[ \frac{1}{2} \left( R + Z^* \right) - \gamma \right]
\]

- Assume that \( R = \overline{\theta} \).

In that case we have

\[
B'_R(\overline{\theta}) = \int_0^1 \left[ \left( 1 - \phi_i(\overline{\theta}) \right) - \frac{\phi_i'(\overline{\theta})}{x_i \sigma_\theta} \right] dx_i - \frac{1}{\theta} \left[ \frac{1}{2} \left( \overline{\theta} + Z^* \right) - \gamma \right]
\]

We know that \( \int_0^1 \left[ \left( 1 - \phi_i(\overline{\theta}) \right) - \frac{\phi_i'(\overline{\theta})}{x_i \sigma_\theta} \right] dx_i = 0 \). Moreover, for \( \overline{\theta} > 2\gamma - Z^* \) we have \( \frac{1}{2} \left( \overline{\theta} + Z^* \right) - \gamma > 0 \). Consequently, we can conclude that

\[
B'_R(\overline{\theta}) = -\frac{1}{\theta} \left[ \frac{1}{2} \left( \overline{\theta} + Z^* \right) - \gamma \right] < 0 \text{ for } \overline{\theta} > 2\gamma - Z^*.
\]

- Assume that \( R = \gamma \).

In that case we have

\[
B'_R(\gamma) = \int_0^1 \left[ \left( 1 - \phi_i(\gamma) \right) - \left( \gamma - Z^* \right) \frac{\phi_i'(\gamma)}{x_i \sigma_\theta} \right] dx_i - \frac{1}{\theta} \left[ \frac{1}{2} \left( \gamma - Z^* \right) \right]
\]

Note that \( -\frac{1}{\theta} \left[ \frac{1}{2} \left( \gamma - Z^* \right) \right] > 0 \) since by assumption \( Z^* < \gamma \).

Thus, it is sufficient to prove that \( \int_0^1 \left[ \left( 1 - \phi_i(\gamma) \right) - \left( \gamma - Z^* \right) \frac{\phi_i'(\gamma)}{x_i \sigma_\theta} \right] dx_i > 0 \) in order for \( B'_R(\gamma) > 0 \).

Let us prove that \( \left( 1 - \phi_i(\gamma) \right) - \left( \gamma - Z^* \right) \frac{\phi_i'(\gamma)}{x_i \sigma_\theta} > 0 \), \( \forall x_i \in \left[ \frac{\gamma}{\theta}, 1 \right] \).
We know that \( (1 - \phi(\bar{g}_i(\gamma))) \) reaches its minimum, equal to \( (1 - \phi(0)) = \frac{1}{2} \), for 
\[ x_i = \frac{\gamma}{\bar{\theta}} \] as 
\[ \bar{g}_i(\gamma) = \frac{\gamma - \bar{\theta} \frac{\gamma}{x_i \sigma_\theta}}{\bar{\theta}} = 0 \]. Moreover, \( (1 - \phi(\bar{g}_i(\gamma))) \) is increasing with \( x_i \) since the probability of success of a project is an increasing function of its "intrinsic quality" defined by \( x_i \).

Recall that \( \phi_i'(\bar{g}_i(R)) = \frac{\partial \phi(\bar{g}_i(R))}{\partial \bar{g}_i(R)} \) with \( \phi(\bar{g}_i(R)) = \int_{-\infty}^{\bar{\tau}(R)} \varphi(t) dt \) and \( \varphi(t) \) the density function of a normally distributed stochastic variable. Thus, we have 
\[ \phi_i'(\bar{g}_i(R)) = \varphi(\bar{g}_i(R)) \] and 
\[ (\gamma - Z^c) \frac{\phi_i'(\bar{g}_i(\gamma))}{x_i \sigma_\theta} = (\gamma - Z^c) \varphi(\bar{g}_i(\gamma)) \] reaches its maximum for 
\[ x_i = \frac{\gamma}{\bar{\theta}} \] as \( \phi_i'(0) = \varphi(0) = 0, 4 \). Moreover, \( (\gamma - Z^c) \frac{\varphi(\bar{g}_i(\gamma))}{x_i \sigma_\theta} \) is decreasing when \( x_i \) increases.

Consequently, if 
\[ \left[ (1 - \phi(\bar{g}_i(\gamma))) - (\gamma - Z^c) \frac{\phi_i'(\bar{g}_i(\gamma))}{x_i \sigma_\theta} \right] > 0 \] for \( x_i = \frac{\gamma}{\bar{\theta}} \), we are sure that 
\[ \left[ (1 - \phi(\bar{g}_i(\gamma))) - (\gamma - Z^c) \frac{\phi_i'(\bar{g}_i(\gamma))}{x_i \sigma_\theta} \right] > 0, \forall x_i \in \left[ \frac{\gamma}{\bar{\theta}}, 1 \right] \] since the first part of the equation is an increasing function of \( x_i \) while the second part of the equation is a decreasing function of \( x_i \).

For \( x_i = \frac{\gamma}{\bar{\theta}} \) we have 
\[ \left[ (1 - \phi(\bar{g}_i(\gamma))) - (\gamma - Z^c) \frac{\phi_i'(\bar{g}_i(\gamma))}{x_i \sigma_\theta} \right] = (1 - \phi(0)) - (\gamma - Z^c) \frac{\varphi(0)}{x_i \sigma_\theta} > 0 \] if 
\[ (\gamma - Z^c) \frac{0, 4}{\gamma \sigma_\theta} < \frac{1}{2} \] which is true for 
\[ \bar{\theta} < \frac{5 \gamma \sigma_\theta}{(\gamma - Z^c)} \].

Consequently, for 
\[ \bar{\theta} < \frac{5 \gamma \sigma_\theta}{(\gamma - Z^c)} \] we have 
\[ \left[ (1 - \phi(\bar{g}_i(\gamma))) - (\gamma - Z^c) \frac{\phi_i'(\bar{g}_i(\gamma))}{x_i \sigma_\theta} \right] > 0, \forall x_i \in \left[ \frac{\gamma}{\bar{\theta}}, 1 \right] \] and
Finally, we have to prove that $B'(R) < 0$, $\forall R$.

\[
B'(R) = -\int_{\frac{\pi}{2}}^1 \frac{\phi_i'(\tilde{\varepsilon}_i(R))}{x_i\sigma_\theta} \, dx_i - \frac{1}{2\theta} \int_{\frac{\pi}{2}}^1 \left[ \frac{\phi_i'(\varepsilon_i(R))}{x_i\sigma_\theta} + (R - Z) \frac{\phi_i''(\varepsilon_i(R))}{(x_i\sigma_\theta)^2} \right] \, dx_i - \frac{1}{2\theta}
\]

which leads, after simplification, to

\[
B'(R) = -2\int_{\frac{\pi}{2}}^1 \frac{\phi_i'(\varepsilon_i(R))}{x_i\sigma_\theta} \, dx_i - \frac{1}{2\theta} \int_{\frac{\pi}{2}}^1 (R - Z') \frac{\phi_i''(\varepsilon_i(R))}{(x_i\sigma_\theta)^2} \, dx_i < 0
\]

since

\[
\frac{\phi_i'(\varepsilon_i(R))}{x_i\sigma_\theta} > 0; \frac{\phi_i''(\varepsilon_i(R))}{(x_i\sigma_\theta)^2} > 0; \frac{1}{2\theta} > 0; (R - Z') > 0, \text{ for } \varepsilon_i(R) \leq 0 \text{ which is always the case.}
\]

Thus, as $B'(R) < 0$ $\forall R$, $B(R)$ is concave on $R \in \left[\gamma, \bar{\theta}\right]$ and $\bar{R}$ is the unique maximum of $B(R)$.

Moreover, we have $B(\gamma) < 0$ and $B'(\gamma) > 0$, $B(\bar{\theta}) = 0$ and $B'(\bar{\theta}) < 0$, we can conclude that $B(\bar{R}) > 0$ and there is $R_e \in \left[\gamma, \bar{R}\right]$ such that $B(\bar{R}) = 0$ and $B(R) \geq 0 \forall R \in \left[R_e, \bar{R}\right]$.

The proof of Lemma 1 is completed.\[\blacksquare\]

**Lemma 2.**

For $R \in \left[\gamma, \bar{\theta}\right]$ we have $K_R'(R) < 0$.

**Proof of Lemma 2.**

We have

\[
K_R'(R) = \lambda \left( Z' \right) \left[ \int_{\frac{\pi}{2}}^1 \left[ P_i(\alpha, \varepsilon_i(R)) \right] \, dx_i - \frac{1}{2\theta} \frac{1}{x_i\sigma_\theta} \right] - \frac{1}{2\theta} \frac{1}{x_i\sigma_\theta} \left[ P_i(\alpha, 0) - \phi(0) \right]
\]
We know that $\phi'_x(\xi(R)) > 0$ and $P_i(\alpha, \xi(R)) > 0$. Moreover, we have

$$P_i(\alpha, \xi(R)) < \phi'_x(\xi(R)), \forall \xi(R) \quad \text{as} \quad P_i(\alpha, \xi(R)) = \phi \left[ \frac{\phi(\xi(R)) + \sqrt{\rho} \phi^{-1}(\alpha)}{\sqrt{1 - \rho}} \right]$$

and

$$\frac{\partial \rho}{\partial \xi(R)} < 0$$

since by construction of the Basel II IRB approaches, the sensitivity to systematic risk decreases when the specific risk of the project increases (Basel Committee on Banking Supervision, 2006). Consequently, as $\frac{1}{x_i \sigma_\theta} > 1$, we have

$$\left[ P_i(\alpha, \xi(R)) \right]_x - \phi'_x(\xi(R)) \left[ \frac{1}{x_i \sigma_\theta} \right] < 0, \forall x_i.$$ 

Finally, as $\frac{1}{\theta}[P_i(\alpha,0) - \phi(0)] > 0$ we have

$$K'_R(R) = \lambda(Z) \left[ \int_0^1 \left[ \left( P_i(\alpha, \xi(R))_x - \phi'_x(\xi(R)) \right) \frac{1}{x_i \sigma_\theta} \right] dx_i - \frac{1}{\theta}[P_i(\alpha,0) - \phi(0)] \right] < 0$$

The proof of Lemma 2 is complete.

**Proof of part a. of Proposition 1.**

In order to prove the existence of a unique maximum for $\Gamma(R) = \frac{B(R)}{K(R)}$, we use Darboux's Theorem$^{13}$

$\Gamma(R)$ is continuous and differentiable on $R \in [R_e, \bar{R}]$.

According to Lemma 1 and 2 we have:

$$\Gamma'(R_e) = \frac{\partial \Gamma(R)}{\partial R}(R_e) = \frac{B'(R_e)K(R_e) - B(R_e)K'(R_e)}{K^2(R_e)} = \frac{B'(R_e)}{K(R_e)} > 0 \quad \text{as} \quad B(R_e) = 0$$

and $B'(R_e) > 0$, $K'(R_e) > 0$

\[
\Gamma'(\bar{\theta}) = \frac{\partial \Gamma(R)}{\partial R}(\bar{\theta}) = \frac{B'(\bar{\theta})K(\bar{\theta}) - B(\bar{\theta})K'(\bar{\theta})}{K^2(\bar{\theta})} = \frac{B'(\bar{\theta})}{K(\bar{\theta})} \to -\infty \quad \text{as} \quad B(\bar{\theta}) = 0, \quad K(\bar{\theta}) = 0, \text{and} \quad B'(\bar{\theta}) < 0.
\]

The Darboux's Theorem conditions are fulfilled and we can conclude that there is a unique \( R^* \in [R_c, \bar{\theta}] \) such that \( \Gamma'(R^*) = 0 \) and \( R^* \) is a maximum for \( \Gamma(R) \).

Moreover, since \( R^* > R_c \) we have \( B(R^*) > 0, \ K(R^*) > 0 \text{ and } \Gamma(R^*) > 0 \)

Part b. of proposition 1

Recall that \( \pi_i(R) = \frac{R}{\bar{\theta}} \) and it is obvious that \( \frac{\partial \pi_i(R)}{\partial R}(R^*) = \frac{1}{\bar{\theta}} > 0 \). Moreover, since the total level of financing is given by \( D = (1 - \pi_i(R)) \) we have

\[
\frac{\partial D(R)}{\partial R}(R^*) = D'(R^*) = -\frac{1}{\bar{\theta}} < 0.
\]

Consequently, the total level of financing increases as the equilibrium rate of return charged by the bank decreases.

Part c. of proposition 1

The level of the equity multiplier is given by \( \ell^*(R^*) = \frac{D'(R^*)}{K'(R^*)} \). Consequently, we have

\[
\frac{\partial \ell^*(R^*)}{\partial R^*} = \frac{D'(R^*)K(R^*) - D(R^*)K'(R^*)}{K^2(R^*)} < 0 \quad \text{since} \quad \frac{D'(R^*)}{D(R^*)} > \frac{K'(R^*)}{K(R^*)}
\]

as the bank capital finances only a part of the new projects.

Proof of proposition 1 is complete. \( \blacksquare \)

Appendix B. Proof of proposition 2.

**Proof of part a.**

The ex-post value of the bank is given by equation (13)

\[
V_b(R) = \int_{\pi_i(R)}^{x_i(R)} Rdx_i + \int_{\pi_i(R)}^{x_i(R)} Zdx_i - \int_{\pi_i(R)}^{x_i(R)} \gamma dx_i + K(R)
\]

The bank goes into bankruptcy when
\[
V_b(R) - K(R) = \int_{x_i(R)}^{1} R dx_i + \int_{\pi_i(R)}^{1} Z dx_i - \int_{\pi_i(R)}^{1} \gamma dx_i < 0 \quad \text{or equivalently with}
\]
\[
x_e(R) = \frac{R}{\theta + \varepsilon \sigma_\theta} \quad \text{and} \quad \bar{x}_i(R) = \frac{R}{\bar{\theta}}
\]
\[
R \left[ 1 - \frac{R}{\theta + \varepsilon \sigma_\theta} \right] + \bar{Z} \left[ \frac{R}{\theta + \varepsilon \sigma_\theta} - \frac{R}{\bar{\theta}} \right] - \gamma \left[ 1 - \frac{R}{\bar{\theta}} \right] < 0 \quad (14)
\]

Consequently, there is \( \varepsilon_e = \frac{\bar{\theta} \left[ (R - \gamma)(R - \bar{\theta}) \right]}{\sigma \left[ R (\gamma - \bar{Z}) + \bar{\theta} (R - \gamma) \right]} \) such that
\[
R \left[ 1 - \frac{R}{\theta + \varepsilon_e \sigma_\theta} \right] + \bar{Z} \left[ \frac{R}{\theta + \varepsilon \sigma_\theta} - \frac{R}{\bar{\theta}} \right] - \gamma \left[ 1 - \frac{R}{\bar{\theta}} \right] = 0
\]

and \( \varepsilon_e \) is the critical level of the macroeconomic shock at which the bank goes into bankruptcy. We know that \( \bar{\theta} > 0, \quad (R - \gamma) > 0, \quad \left( R - \bar{\theta} \right) < 0, \) and \( \bar{\theta} \left[ (R - \gamma)(R - \bar{\theta}) \right] < 0 \). Moreover, as \( \gamma > \bar{Z} \) and \( R > \gamma \) we have
\[
\sigma \left[ R (\gamma - \bar{Z}) + \bar{\theta} (R - \gamma) \right] > 0 \quad \text{and} \quad \varepsilon_e < 0 \]

**Proof of part b.**

We search for the value of \( R \) that minimises the bank’s probability of default. We know that this probability of default decreases with the value of \( \varepsilon_e \).
\[
\frac{\partial \varepsilon_e}{\partial R} = \frac{\bar{\theta} \left[ \gamma (\bar{Z} - 2R\bar{\theta}) + R^2 (\bar{\theta} + \gamma - \bar{Z}) \right]}{\sigma \left[ R (\gamma - \bar{Z}) + \bar{\theta} (R - \gamma) \right]^2} = 0 \quad \text{for}
\]
\[
R_1 = \frac{\bar{\theta} \gamma - \sqrt{\bar{\theta} \gamma (\gamma - \bar{Z})(\theta - \bar{Z})}}{\gamma + \bar{\theta} - \bar{Z}}
\]
\[
R_2 = \frac{\bar{\theta} \gamma + \sqrt{\bar{\theta} \gamma (\gamma - \bar{Z})(\theta - \bar{Z})}}{\gamma + \bar{\theta} - \bar{Z}}
\]
with $\gamma \bar{\theta} (\gamma - \bar{Z})(\theta - \bar{Z}) > 0$. Moreover, it is obvious that $R_2 > 1$, $R_1 < 1$ and

$$\frac{\partial^2 \varepsilon_c}{\partial R^2} = \frac{-2\bar{\theta}^2 \gamma [(\bar{Z} - \bar{\theta})(\gamma - \bar{Z})]}{\sigma [R(\gamma - \bar{Z}) + \bar{\theta}(R - \gamma)]^3} > 0.$$  

Consequently, there is a unique value, $R_{\text{min}} = \frac{\bar{\theta} + \sqrt{\gamma \bar{\theta} (\gamma - \bar{Z})(\theta - \bar{Z})}}{\gamma + \bar{\theta} - \bar{Z}} > 1$ that minimises the value of $\varepsilon_c$. In addition, $\varepsilon_c$ is decreasing between the two roots $R_1, R_2$ (which means that the bank’s probability of default is also decreasing) whereas $\varepsilon_c$ is increasing outside the two roots $R_1, R_2$ (which means that the bank’s probability of default is also decreasing).

Finally, there is a unique value of bank leverage $\ell(R_{\text{min}}) = \frac{D(R_{\text{min}})}{K(R_{\text{min}})}$ that minimises the bank’s probability of default and the relation between the bank’s leverage and the bank’s probability of default is nonlinear. In fact, the bank’s probability of default is decreasing between $\left[\gamma, R_{\text{min}}\right]$ (between the two roots of the equation) and is increasing between $\left[R_{\text{min}}, \bar{\theta}\right]$ (outside the two roots of the equation).

Appendix C. Proof of proposition 3.

Proof of part a.

We have to show that $\ell(R^*) = \frac{D(R^*, Z^*)}{K(R^*, Z^*)}$ is an increasing function of the expected value of the collateral $Z^*$.

Taking the partial derivative of $\ell(R^*)$, we have

$$\frac{\partial \ell(R^*)}{\partial Z^*} = \frac{\partial D(\bullet)/\partial Z^* K(\bullet) - D(\bullet)\partial K(\bullet)/\partial Z^*}{K(\bullet)^2}.$$  

As $K(R^*, Z^*) > 0$, $D(R^*, Z^*) > 0$ and $\frac{\partial K(R^*, Z^*)}{\partial Z^*} < 0$ we are sure that $\frac{\partial \ell(R^*)}{\partial Z^*} > 0$ if $\frac{\partial D(R^*, Z^*)}{\partial Z^*} > 0$. 

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As \( D(R^*, Z^*) = \left(1 - \frac{R^*}{\theta} \right) \), we have \( \frac{\partial D(R^*, Z^*)}{\partial Z^*} > 0 \) if \( \frac{\partial R^*}{\partial Z^*} < 0 \).

We have \( \Gamma(R^*, Z^*) = \frac{B(R^*, Z^*)}{K(R^*, Z^*)} \) the maximum value of the RAROC for a given expected value of the collateral. Takes the total derivative of \( \Gamma(R^*, Z^*) \) and equates it with zero

\[
d\Gamma(R^*, Z^*) = \frac{\partial \Gamma(R^*, Z^*)}{\partial Z^*} dZ^* + \frac{\partial \Gamma(R^*, Z^*)}{\partial R^*} dR^* = 0 \quad \text{and}
\]

\[
\frac{dR^*}{dZ^*} = -\frac{\frac{\partial \Gamma(R^*, Z^*)}{\partial Z^*}}{\frac{\partial \Gamma(R^*, Z^*)}{\partial R^*}}
\]

We have:

\[
\frac{\partial \Gamma(R^*, Z^*)}{\partial R^*} = 0
\]

\[
\frac{\partial \Gamma(R^*, Z^*)}{\partial Z^*} = \frac{\partial B(\bullet)}{\partial Z^*} K(\bullet) - B(\bullet) \frac{\partial K(\bullet)}{\partial Z^*} > 0 \quad \text{as}
\]

\[
K(R^*, Z^*) > 0, \quad B(R^*, Z^*) > 0, \quad \frac{\partial K(R^*, Z^*)}{\partial Z^*} < 0 \quad \text{and}
\]

\[
\frac{\partial B(\bullet)}{\partial Z^*} = \int_{\xi(R^*)}^{1} \phi(\xi) dx > 0.
\]

Consequently we have \( \frac{dR^*}{dZ^*} < 0 \).

This means that when the expected value of the collateral increases, the equilibrium rate of return charged by the bank decreases and the value of leverage increases.

**Proof of part b.**

We search for the critical value \( Z^*_c \) for which \( \ell(R^*) > \ell(R_{\text{min}}) \)

According to proposition 1, there is an equilibrium rate of return for the bank if \( \bar{\theta} > 2\gamma - Z^* \) or, put differently, for \( Z^* > 2\gamma - \bar{\theta} < 1 \) with \( \bar{\theta} > 2\gamma - 1 \).

Thus, for \( Z^* < 2\gamma - \theta < 1 \) there is no equilibrium and \( \ell(R^*) = 0 \).
Also, since \( K(R) = \int_{\pi(R)}^1 \lambda(Z^\varepsilon)(P_i(\alpha, \xi) - \phi(\xi))dx \) and \( \lim_{\varepsilon \to 0} \lambda(Z^\varepsilon) = 0 \), we have

\[
\lim_{\varepsilon \to 0} \ell(R^\varepsilon) \to +\infty.
\]

Thus, \( \ell(R^\varepsilon) \) is an increasing function of \( Z^\varepsilon \), \( \forall Z^\varepsilon \in [0,1] \).

And since \( \ell(R_{\min}) = \frac{D(R_{\min}, \tilde{Z})}{K(R_{\min}, \tilde{Z})} \) with \( R_{\min} = \frac{\tilde{\theta} + \sqrt{\gamma \tilde{\theta} (\gamma - \tilde{Z})(\theta - \tilde{Z})}}{\gamma + \tilde{\theta} - \tilde{Z}} \) we have

\[
0 < \ell(R_{\min}) < \infty.
\]

Consequently, we are sure there is \( Z_c^\varepsilon \in [2\gamma - \tilde{\theta}, 1] \) such that \( \ell(R^\varepsilon(Z_c^\varepsilon)) = \ell(R_{\min}) \) and \( \ell(R^\varepsilon(Z^\varepsilon)) > \ell(R_{\min}) \) for \( Z^\varepsilon > Z_c^\varepsilon \).

The proof of proposition 3 is complete. ■
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