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Value at risk, bank equity and credit risk

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Value at Risk, Bank Equity and Credit Risk

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Value at Risk, Bank Equity and Credit Risk

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Abstract:

We study the implications of the value at risk concept for the bank's optimum amount of equity capital under credit risk. The market value of loans is risky and lognormally distributed. We show that the required equity capital depends upon managerial and market factors. Furthermore, the bank's equity and asset/liability management has to be addressed simultaneously by bank managers.

JEL-Classification: G21

Keywords: equity capital, value at risk, banking, risk management, asset/liability management, credit risk

1. Introduction

In recent years, value at risk (VaR) has become a heavily used risk management tool in the banking sector. Roughly speaking, the value at risk of a portfolio is the loss in market value over a risk horizon that is exceeded with a small probability. Bank management can apply the value at risk concept to set capital requirements because VaR models allow for an estimate of capital loss due to market and credit risk (see, e.g., Duffie/Pan 1997, Jackson/Maude/Perraudin 1997, Jorion 1997, Saunders 1999, Friedmann/Sanddorf-Köhle 2000, Hartmann-Wendels/Pfingsten/Weber 2000, and Simons 2000). The aim of our study is to answer the question what is the *optimum* amount of equity capital of a banking firm under the value at risk concept in the presence of credit risk?

Institutionally, the Basle Committee on Banking Supervision mandates that banks using models of value at risk to set aside capital for market and credit risk of their financial operations use a risk horizon of two weeks and a confidence level of 99 percent (Deutsche Bundesbank 2002).

In our model of a banking firm, a risk averse bank management which has to decide on the bank's business policy regarding assets and liabilities acts in a competitive financial market. For an excellent discussion of bank management see Greenbaum/Thakor 1995, and for modelling a banking firm see, e.g., Wahl/Broll 2000. The return on the bank's portfolio of loans is uncertain. Hence, the banking firm is exposed to credit risk and may not be able to meet its debt obligations. Instead of coping with the exposure of the banking firm to financial risk by using hedging instruments such as futures and options, we incorporate as a risk management tool the value at risk approach in order to address bankruptcy risk.

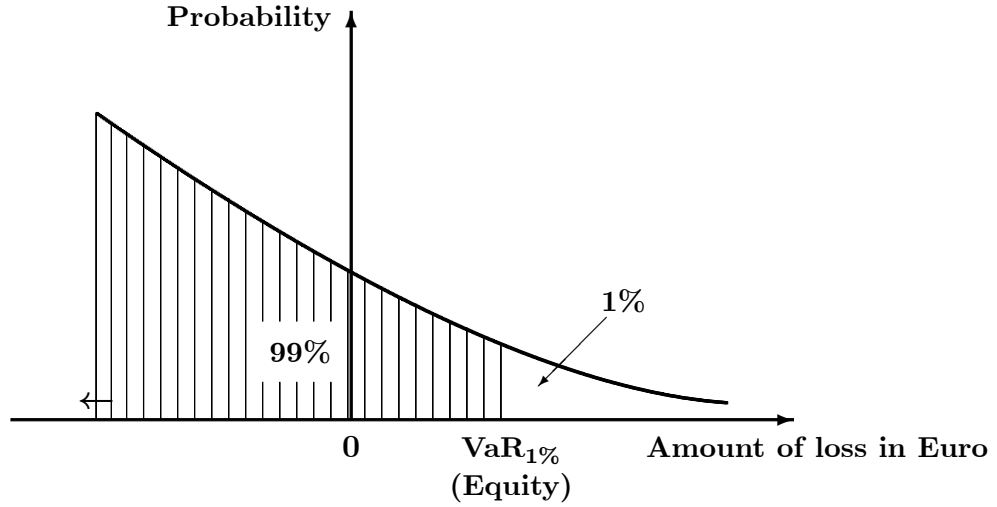


Figure 1: Loss distribution, VaR and bank equity

As depicted in figure 1 the bank faces a loss distribution. Given a confidence level of 99 percent, to the equity holder there is 1 percent chance of losing VaR or more in value. Hence, if VaR determines the optimum amount of bank equity capital, then the confidence level gives the probability that the bank will be able to meet its debt obligations.

The study proceeds as follows: Section 2 presents a model of a banking firm in a competitive market environment under default risk of loans. The value at risk concept is formulated for our economic and stochastic setting. In section 3 we investigate how optimum volume of equity capital is affected by value at risk. We demonstrate that managerial and market factors determine optimal asset/liability and equity management of the bank and that the probability of bankruptcy has a complex impact on the decision making of bank management. Section 4 discusses the case of risk neutrality and reports a clear-cut relationship between optimum equity and VaR. Final section 5 concludes the paper.

2. A Banking Firm

In this section we study how a risk averse bank management, acting in a competitive financial market, can use the value at risk approach to deal with credit risk. The question is: What is the *optimum* amount of equity capital of a bank under the value at risk concept?

2.1 The Model

Loans granted by our bank, L , exhibit some default risk. At the beginning of the period the return of the bank's portfolio of loans, \tilde{r}_L , is random. The portfolio is financed by issuing deposits, D , and equity capital, E . The intermediation costs compounded to the end of the period are determined by $C(L + D)$. Hence intermediation costs are modelled to depend upon the sum of the bank's financial market activities. The cost function $C(\cdot)$ has properties $C'(\cdot) > 0$ and $C''(\cdot) > 0$, i.e., marginal cost are positive and increasing.

A simplified balance sheet of a bank is at each point in time:

Bank balance sheet	
Loans L	Deposits D
	Equity E

Equity is held by shareholders and necessarily $E = L - D$. Optimum decision making of bank's management has to satisfy this balance sheet constraint, $L = E + D$, where in our model the debt/equity ratio of the banking firm is endogenous. Given that the bank's loans have risky returns, bankruptcy of the banking firm occurs if the firm cannot meet its debt obligations. Value at risk is a risk management tool which allows to cope with bankruptcy risk.

If the bank's loss in market value does not exceed equity capital at some confidence level $1 - \alpha$, then value at risk, VaR_α , measures the maximum size of that loss in the next period. That is to say, $E \geq \text{VaR}_\alpha$ implies that the firm is able to meet its debt obligations with probability $1 - \alpha$. Therefore, in our context, α measures the maximum probability of bankruptcy of the banking firm.

In the literature, value at risk is discussed as an indicator for minimum capital requirements regarding the solvency of banks (Jackson/Maude/Perraudin 1997). Our paper derives the optimum amount of equity capital and the optimum amount of loans and deposits under the value at risk concept. Note that from the balance sheet identity decision making has to take into account only two of the three magnitudes.

We consider a competitive bank which faces the risky return \tilde{r}_L on its loans and the given nonrandom market rate of deposits, r_D (Freixas/Rochet

1997, Broll/Wahl 2002). The bank's risky profit, $\tilde{\Pi}$, can be stated as follows:

$$\tilde{\Pi} = \tilde{r}_L L - r_D D - C(L + D). \quad (1)$$

Probability distributions of returns are ranked by applying the expected utility hypotheses. Bank management is risk averse and uses a quadratic utility function for the relevant range of profits (i.e., positive marginal utility of profits). Furthermore, bank management assumes that $\ln(1 + \tilde{r}_L)$ is normally distributed with a given expected value and a given variance. Our assumption on preferences implies the well-known mean-variance objective function below.

Bank management has to choose the amount of equity capital which maximizes expected utility of profits:

$$\max_E \{ \mathcal{E}(\tilde{\Pi}) - a [\mathcal{E}^2(\tilde{\Pi}) + \mathcal{V}(\tilde{\Pi})]/2 \}, \quad a > 0, \quad (2)$$

subject to

$$L = D + E, \quad (3)$$

$$\text{VaR}_\alpha \leq E, \quad (4)$$

where \mathcal{E} and \mathcal{V} denote the expected value operator and the variance operator, respectively.

The aim of our competitive bank is to establish the optimum amount of equity capital, E^* , satisfying the balance sheet identity (3) and the value at risk constraint (4). As will be shown, optimum amount of equity E^* is positive if and only if the bank's expected margin is positive.

2.2 Value at Risk

Risk management of the bank has to take into account bankruptcy risk. The risk of bankruptcy means that the bank may not be able to meet its financial obligations vis-à-vis its depositors without further contributions by the owners. If the owners are not able or not willing to contribute the bank goes bankrupt. Value at risk is a risk management tool which allows to control the probability of bankruptcy.

In our model of a banking firm bankruptcy risk can be defined as the probability of bankruptcy $\text{Prob}(-\tilde{r}L > E) > 0$, where $\tilde{r} = (1 + \tilde{r}_L)/(1 + r_D) - 1$

(see Appendix A1). This means that with positive probability the decline in market value of the bank's loans can be greater than equity capital of the bank. In order to control bankruptcy risk bank management has to limit the probability of bankruptcy by choosing α . This leads to the solvency condition

$$\text{Prob}(-\tilde{r}L \leq E) = 1 - \alpha. \quad (5)$$

Statistically speaking, the value loss that leads the firm to bankruptcy has an α percent probability of occurring at the end of the period.

Given that the log-return on the bank's loans, $\ln(1 + \tilde{r}_L)$, is normally distributed, the random variable $\ln(1 + \tilde{r})$ has also a normal distribution with expected value μ and variance σ^2 , where $\mu = \mathcal{E}(\ln(1 + \tilde{r})) = \mathcal{E}(\ln[(1 + \tilde{r}_L)/(1 + r_D)])$ and $\sigma^2 = \mathcal{V}(\ln(1 + \tilde{r})) = \mathcal{V}(\ln[(1 + \tilde{r}_L)/(1 + r_D)]) = \mathcal{V}(\ln(1 + \tilde{r}_L))$. It follows that the solvency condition (5) can be stated as (see Appendix A2):

$$r_\alpha L = E, \quad (6)$$

where $r_\alpha = 1 - \exp(-y_\alpha)$ and $y_\alpha = -(\mu + u_\alpha \sigma) > 0$. u_α denotes the α -fractile of the unit normal distribution.

r_α represents value at risk of a risky investment of Euro 1 and is denoted as percentage-VaR, pVaR. Note that pVaR is a decreasing function of the probability of bankruptcy α and, hence, an increasing function of the confidence level $1 - \alpha$. Value at risk is then determined by multiplying the amount of risky loans by pVaR: $\text{VaR}_\alpha = r_\alpha L$.

Bank management restricts the size of loss in the value of the bank by choosing the bankruptcy probability and, with that, defines the maximum loss of value on the portfolio of the bank's loans over the planning period at a given confidence level.

2.3 The Bank's Profit

Assuming that the value at risk constraint (4) is binding, taking into account the solvency condition (6) and the balance sheet identity (3) the profit equation (1) results in the following definition of bank's random profit:

$$\tilde{\Pi} = \left(\frac{1}{r_\alpha} \tilde{r}_L - \frac{1 - r_\alpha}{r_\alpha} r_D \right) E - C \left(\frac{2 - r_\alpha}{r_\alpha} E \right). \quad (7)$$

Hence the bank's random profit is a function of the bank's equity capital which has to be chosen by bank management in order to maximize expected utility of profits.

3. Optimal Capital Requirement

In the following we derive the implications of the value at risk concept to optimum equity and asset/liability management of our banking firm.

The amount of equity capital which maximizes expected utility of profits depends upon the probability of bankruptcy set by bank management. Let us consider quadratic intermediation costs: $C(L + D) = \theta(L + D)^2/2$ ($\theta > 0$).

We claim the following propositions:

Proposition 1 (Equity Management) *Risk management by value at risk implies that optimum amount of equity capital depends upon*

(i) *managerial factors such as the confidence level, the degree of risk aversion and expectations about the return on risky loans and*

(ii) *market factors such as the rate of deposits and the intermediation costs.*

Proof. Maximizing the mean-variance function (2) under the profit equation (7) with respect to equity E leads to:

$$E^* = r_\alpha \frac{\mu_L - r_D(1 - r_\alpha)}{R(\mu_{\Pi^*}) \sigma_L^2 + \theta(2 - r_\alpha)^2}, \quad (8)$$

where absolute risk aversion $R(\mu_{\Pi^*}) = (1/a - \mu_{\Pi^*})^{-1}$ and $\mu_{\Pi^*} = \mathcal{E}(\tilde{\Pi}^*)$, $\mu_L = \mathcal{E}(\tilde{r}_L)$ and $\sigma_L^2 = \mathcal{V}(\tilde{r}_L)$. This proves the claim. \square

Proposition 1 demonstrates that even our simplifying assumptions do not allow to generate the traditional textbook result of a clear-cut relationship between the probability of bankruptcy and the required equity capital under credit risk. Note that equation (8) reveals that optimum equity is determined implicitly only.

Proposition 2 (Asset/Liability Management) *Optimum equity of the banking firm under the value at risk concept determines optimum amount of risky loans and optimum amount of deposits.*

Proof. The proof is a direct implication of (8), the value at risk constraint (4) and the balance sheet constraint (3). \square

Proposition 2 shows that the required amount of equity capital cannot be derived solely from value at risk considerations but, instead, has to be determined simultaneously with the bank's asset/liability policy.

A further implication of our model reads:

Corollary 1 *If bank management sets a higher probability of bankruptcy, then optimum debt/equity ratio increases.*

Proof. The claim follows from the fact that $D^*/E^* = (1 - r_\alpha)/r_\alpha$ and $\partial r_\alpha / \partial \alpha < 0$. \square

Hence, the value at risk concept implies that the optimum debt/equity ratio is determined by pVaR. Therefore, reducing the confidence level means that optimum liability management has to adjust in a way that the proportion of debt augments. Though meeting debt obligations is allowed to be less probable note that the volume of deposits need not necessarily increase.

Summing up, the implicit form of equation (8) shows that the optimum amount of bank equity capital under VaR depends upon several key factors, where the comparative static impacts of the different input parameters are, in general, *indetermined*. This points out the complex interaction between equity, expected value, variance of return on risky loans, market rate of deposits, probability of bankruptcy, level of risk aversion and the unit variable intermediation costs.

4. Risk Neutrality and Bank Equity

Let us investigate a risk neutral bank management (set $a \equiv 0$ in equation (2)). Hence, bank management has to choose the amount of equity capital which maximizes expected profits:

$$\max_E \mathcal{E}(\tilde{\Pi}), \tag{9}$$

subject to

$$L = D + E, \tag{3}$$

$$\text{VaR}_\alpha \leq E, \tag{4}$$

where, as before, \mathcal{E} denotes the expectation operator and the bank's risky profit, $\tilde{\Pi}$, is determined by equation (1).

Since the bank's random profit is still represented by equation (7), optimum amount of equity capital for the banking firm reads:

$$E^* = r_\alpha \frac{\mu_L - r_D(1 - r_\alpha)}{\theta(2 - r_\alpha)^2}. \quad (10)$$

Therefore the following claim holds:

Proposition 3 (Equity Management) *The value at risk concept under risk neutrality implies that optimum amount of equity capital depends upon*

(i) *managerial factors such as the confidence level and expectations about the return on risky loans and*

(ii) *market factors such as the rate of deposits and the intermediation costs.*

Although return risk does not affect equity management under risk neutrality the probability of bankruptcy does. However, optimum equity is indirectly affected by the volatility of the loans' return. The reason is that the value at risk on the equity at some confidence level depends upon the variance σ_L^2 of the risky returns.

Proposition 4 (Effect of Confidence Level) *Under risk neutrality the bank's optimum amount of equity capital decreases when a higher probability of bankruptcy is set.*

Proof. >From the balance sheet constraint (3), the solvency condition (6) and a positive expected margin $\mu_L - r_D(1 - r_\alpha) > 0$, we get $\partial E^*/\partial \alpha < 0$, since $D^* > 0$ implies $r_\alpha < 1$. \square

Proposition 4 holds under risk neutrality and required equity capital increases if the confidence level increases. Furthermore, the variance of the return on risky loans still affects optimum equity. Therefore, optimum amount of loans and deposits of the bank are also affected by the volatility of the loans' return.

We state the following observation:

Corollary 2 *A mean preserving spread in return on risky loans increases the optimum amount of equity capital.*

Proof. The claim follows from equation (10) and the fact that pVaR r_α increases when variance σ_L^2 increases. \square

Hence, under risk neutrality the impact of the volatility of the loans' risky return upon optimum equity becomes unambiguous.

5. Conclusion

Models of value at risk (VaR) have become a widespread risk management approach in many different types of organizations. Our paper uses the value at risk concept to analyze optimum equity capital requirements for a competitive banking firm under lognormal credit risk.

Our study shows that the optimum endowment of a bank in equity depends upon managerial and market factors. Especially the confidence level set by bank management for the assumed risk horizon has a nontrivial impact on the optimum amount of equity capital even under fairly restrictive assumptions for the bank model. Additionally, under VaR asset/liability and equity management have to be optimized simultaneously.

Appendixes

A1 (Bankruptcy Risk):

The bank is exposed to insolvency risk if and only if

$$\text{Prob}\left((1 + \tilde{r}_L)L - (1 + r_D)D < 0\right) > 0.$$

Using the balance sheet identity this condition is equivalent to

$$\text{Prob}\left((1 + \tilde{r}_L)L - (L - E)(1 + r_D) < 0\right) > 0,$$

which implies

$$\text{Prob}\left((1 + r_D)((1 + \tilde{r})L - L + E) < 0\right) > 0,$$

where $1 + \tilde{r} = (1 + \tilde{r}_L)/(1 + r_D)$. Hence,

$$\text{Prob}(-\tilde{r}L > E) > 0.$$

A2 (Solvency Condition):

If \tilde{x} is normally distributed with expected value $\mu_x = \mathcal{E}(\tilde{x})$ and variance $\sigma_x^2 = \mathcal{V}(\tilde{x})$, then the $N(\mu_x, \sigma_x^2)$ -fractile of order α is defined by (see, e.g., Fisz 1977)

$$\text{Prob}(\tilde{x} \geq x_\alpha) = 1 - \alpha,$$

where $x_\alpha = \mu_x + u_\alpha \sigma_x$ and u_α is the $N(0, 1)$ -fractile of order α . Since $1 + \tilde{r}_L$ is lognormally distributed, the solvency condition (5) for the normally distributed $\ln(1 + \tilde{r}_L) - \ln(1 + r_D) = \ln(1 + \tilde{r})$ reads

$$\text{Prob}\left(\ln(1 + \tilde{r}) \geq [\ln(1 - E/L)]_\alpha\right) = 1 - \alpha.$$

It follows that

$$[\ln(1 - E/L)]_\alpha = \mu + u_\alpha \sigma,$$

where $\mu = \mathcal{E}(\ln(1 + \tilde{r}))$ and $\sigma^2 = \mathcal{V}(\ln(1 + \tilde{r}))$. Defining $y_\alpha = -(\mu + u_\alpha \sigma)$ and $r_\alpha = 1 - \exp(-y_\alpha)$ we get equation (6).

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Zusammenfassung

Kreditausfallrisiko, Eigenkapitalunterlegung und Value at Risk

In internen Risikomodellen von Banken findet das Value at Risk-Konzept verstärkt Anwendung. Dieses Konzept dient der Erfassung, Steuerung und Kontrolle von Markt- und Kreditrisiken. Bei gegebener Eigenkapitalausstattung definiert der Value at Risk einen maximalen Verlustbetrag der Bank in Bezug auf Marktwertminderungen der Bankaktiva. Die Gefährdung der Bankeinlagen ist mit einer hohen Wahrscheinlichkeit ausgeschlossen, wenn im Aktivgeschäft der Bank dieser Verlustbetrag nicht erreicht wird. Solange das Eigenkapital den Value at Risk der Bank deckt, sind die Gläubigeransprüche mit hoher Wahrscheinlichkeit gesichert.

Unser Beitrag untersucht lognormalverteiltes Kreditausfallrisiko auf der Grundlage der stochastischen Effektivverzinsung von Krediten. Er leitet den Zusammenhang zwischen optimaler Eigenkapitalunterlegung und Insolvenzwahrscheinlichkeit der Bank unter Verwendung des Value at Risk-Konzepts ab. Es zeigt sich, dass die optimale Eigenkapitalausstattung einmal von *Management* bestimmten Einflussgrößen (Insolvenzwahrscheinlichkeit, Risikoverhalten, Renditeerwartungen) und zum anderen von *Markt* bestimmten Einflussgrößen (Einlagenzins, Kosten der Finanzintermediation) abhängt. Des Weiteren können die optimalen Volumina von Aktiv- und Passivgeschäft der Bank nicht isoliert bestimmt werden, sondern sind zusammen mit dem optimalen Eigenkapitalvolumen festzulegen. Insgesamt ist festzuhalten, dass der Zusammenhang zwischen Insolvenzwahrscheinlichkeit und notwendiger Eigenkapitalunterlegung auch unter dem VaR-Konzept sich nicht so einfach darstellt, wie häufig suggeriert wird.

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