A Survey of Financial Risk Measurement

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Abstract. Financial risk management is the core content of financial institutions' management activities, and the basic work of risk management is to measure risk. Choosing appropriate risk measurement indicators and scientific calculation methods is the basis of measuring risk correctly, and also the premise of establishing an effective risk management system. By using literature research methods, this paper collates, analyses and summarizes the theory and practice of risk measurement, points out that there are some limitations in existing risk measurement indicators, and the new risk measurement indicators should be improved in terms of good performance, easy calculation and reasonable testing.

Introduction

Financial risk management is the core content of all kinds of financial institutions' business and management activities. It is called the three pillars of modern financial theory together with time value and asset pricing. According to the definition of BIS, the risk management process can be divided into four parts: risk identification, risk measurement, risk rating and reporting, risk control and management. Risk identification is to classify the risk into market risk, credit risk, operational risk, liquidity risk and other risks according to the source of risk. Risk measurement is the application of various models and data to measure and analysis risks. Risk rating and reporting is to evaluate, report and monitor risks in a timely manner. Risk control and management is the choice and balance of risk limits, the determination of risk positions that can be assumed, and the use of derivatives to manage and control various risks.

Among them, the measurement of financial risk is the core link of financial risk management and the premise of establishing an effective financial risk management system. The quality of risk measurement largely determines the effectiveness of financial risk management. The selection of reasonable risk measurement index is an effective guarantee to improve the quality of risk measurement. The earliest financial risk management was hedging through derivatives. Modern research on risk began with Markowitz's portfolio theory, which put risk and return in the same important position. Since the 1980s, major western countries have gradually relaxed their control over the financial system, shifting the risks controlled by the government to various financial and non-financial institutions. The demand for risk management greatly promotes the research of risk management related technology and issues. The development of derivative financial market and financial engineering technology has greatly improved the content of risk management. The application of financial products is becoming more and more complex, especially the emergence of new financial derivatives, which makes it more difficult for financial institutions to measure risks, and financial crises erupt frequently. Risk measurement plays an increasingly important role in risk management, and various risk measurement theories emerge in endlessly. This paper attempts to summarize various risk measurement theories, and to explore the trend of development of risk measurement.

Market Risk

Market risk refers to the losses that financial institutions may incur in their trading positions in the financial market due to changes in market price factors. Since the collapse of the Bretton Woods

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system in the 1970s, market risk has become an important risk faced by financial institutions due to the intensified fluctuations of interest rate and exchange rate in the international financial market, and has been paid more attention to because it can intensify the outbreak risks of other types. With the development of portfolio theory, option pricing model, computer technology and financial industry technology, the following methods of measurement of market risk have been developed.

Volatility Model

The earliest measurement of market risk was put forward in the study of Markowitz's portfolio selection, which was measured by the standard deviation of expected return in portfolio selection theory. According to Poon and Granger (2002) [1], the volatility models used to measure variance can be divided into four categories: historical volatility model, GARCH series model, stochastic volatility model and intrinsic volatility model, and improved models include high frequency data model and multivariate volatility model.

Value at Risk

Value at risk (VaR) of a portfolio represents the maximum loss at a certain confidence level over a period of time. VaR consists of three basic elements: the current position of the relevant risk factors, the sensitivity of the position to the change of risk factors and the prediction of the adverse direction of risk factors. There are three methods most commonly used for VaR calculation: analytical method, historical method and Monte Carlo simulation method. Dowd (1998) [2] provides more in-depth application of VaR methods. For the risk loss events with low frequency, the general VaR method cannot fully use the information in the data, so it is necessary to use the method for extreme events to give a high confidence VaR estimation.

Expected Shortfall and C-VAR

Expected shortfall (ES) and C-VAR are also called expected tail loss. They are closely related and can be seen as an improvement of the VaR method. ES and C-VAR are equivalent if the cumulative density function of the portfolio's gain and loss is continuous. Artzner , Delbaen, Eber, and Heath (1999) [3] found that VaR method can not meet the consistency requirements of risk measurement, lacking additivity and convexity. It violates the consensus that the risk of portfolio investment is more diversified than single investment. This may result in several local minimization problems in the combinatorial optimization problem of minimizing VaR.

Worst-case Expectations

Worst-case expectation, also known as worst-case VaR, was first introduced by Artzner, Delbaen, Eber, and Heath as an example of consistent risk measurement. The author believes that all possible bad situations should be notified to all traders and all enterprises. Even though each manager can have a good risk management method based on quantile, they can not measure the joint risk caused by their respective actions. Zhu and Fukushima (2005) [4] assume that the worst-case scenario is to take the maximum of C-VaR from all probability distributions of set under the condition of C-VaR. Compared with the original C-VaR, the portfolio selection model using worst-case C-VaR as a measure of risk is more robust and reliable, and has greater flexibility in portfolio selection.

Credit Risk

Credit risk refers to the uncertainty of the safety factor of credit funds, which is reflected in the possibility that enterprises are unwilling or unable to repay the principal and interest of bank loans for various reasons, making bank loans unable to be recovered and forming bad debts. The main purpose of credit risk measurement is to evaluate the expected loss under a given default condition. Generally, the expected credit loss of a portfolio depends on three factors: the probability of default, the position held in default, and the recovery rate.

$$LCR = P_d E(X) * (1 - R) \tag{1}$$

Where, LCR for the loss of credit risk, P_d for the probability of default, X for the position held in default, R for the recovery rate.

The most important factor in calculating credit risk loss is default probability. There are five main methods: credit transfer matrix, structured model, simplified model, actuarial model and model with a large number of assets in a portfolio.

Credit Transfer Matrix

Credit transfer matrix models the credit risk of securities on the basis of the probability of credit rating changes of credit issuers. The emphasis of this method is the setting of credit transfer matrix, which provides the probability of credit rating improvement or decline in a given period of time. The credit transfer matrix is constructed by obtaining data from rating agencies. This method is especially popular in the fixed income market. The most commonly used method is the credit matrix method. However, there are also problems in credit transfer method. Firstly, rating agencies use historical data for rating, but some data of sovereign credit issuers are difficult to obtain. Secondly, different rating agencies may give different credit ratings to the same credit issuer, and resulting in separate ratings. Finally, the credit transfer matrix is static and can not reflect the dynamic changes of business cycle and rating.

Structured Model

Structural model is a series of models based on option pricing theory and developed by Merton (1974) [5]. This kind of model assumes that a company's equity can be regarded as the underlying assets of the company, the execution price is the value of the company's debt and the European option whose maturity date is the maturity date of the debt. In Marton's view, the probability of default is related to the probability of the option being executed. However, this method is feasible in theory, but there are many obstacles in practice. The KMV model proposed by Kealhofer (2003) [6] based on contingent benefit solves some problems of the above methods. Other structured models include Black and Cox (1976) [7] proposed the "first method", which is closely related to the contingent income method. The default time is the time when the asset value is lower than a threshold for the first time, so that the default probability can be found in a given period of time. The credit extension obtained by this model is closer to that observed in the corporate bond market than the previous model.

Simple Model

Simplified model overcomes these shortcomings from another point of view , and directly models the default event itself. This kind of model abandons the assumptions of asset value and capital structure, directly assumes the dynamic process of default probability and recovery rate, and regards the default event and the loss when default occurs as independent random events. Duffie and Singleton (2003) [8]summarized the pricing, measurement and management of credit risk, and gave the common models of simplified models, such as jump mean regression simplified model, CIR simplified model, HJM forward default rate model and modified simplified model.

Actuarial Models

Actuarial model uses actuarial theory to model the probability of default of large portfolio. The most famous actuarial method is CreditRisk+ (Gundlach and Lehrbass 2004) [9]. CreditRisk + method assumes that the probability distribution of default times in portfolio obeys Poisson distribution, and then models the default frequency, and then obtains the probability distribution of portfolio credit loss. Then calculate the default loss of each default event. The data needed in the analysis are all historical statistics, and the estimated quantity and data input are less. Only the data of default and risk exposure of debt instruments are needed. The default probability and loss distribution of credit portfolios such as debt and loan can be derived completely.

Portfolio Model with Large Assets

The above credit model is more effective in solving the problem of small assets, but when the number of assets in the portfolio is large, the calculation becomes very difficult. Vasicek (2002) [10] extends structured Marton model to portfolios with large amounts of assets. By calculating the default correlation of different loans, Vasicek analyzed the asymmetric behavior of Merton valuation model when the loan volume increased to infinity. It also assumes that the portfolio is homogeneous, that is, all loans have the same parameters and default correlation. His model gives a good estimate of the portfolio that includes a lot of loans.

Operational Risk

The formal definition of operational risk by the Basel Committee on Banking Supervision is that operational risk refers to the risk of direct or indirect loss caused by imperfect or problematic internal operating processes, personnel, systems or external events. This definition includes legal risk, but does not include strategic risk and reputation risk.

Operational risk is more difficult to measure than credit risk and market risk. The main problem is the probability distribution of operational risk loss. However, with more and more attention paid to operational risk, many scholars have carried out in-depth research and analysis on operational loss. The model of operational risk is also explained in the regulation of Basel Ⅱ and Ⅲ. Embrechts, Frey, and McNeil (2005) [11] discussed Operational risks in their book. The book explains the definition, classification and position of operational risk in financial risk management, and introduced the modeling of operational risk, including the top-down model, such as multi-factor equity pricing model, capital asset pricing model and operational leverage model. There are also bottom-up models, such as process-based models and actuarial models.

Jarrow (2008) [12]supposed that the operational risk of banks can be divided into two parts from the point of view of corporate finance: (1) loss caused by company operating technology; (2) risk loss caused by agency cost. Moreover, he believed that the data of operational risk is internal to the company. If the net present value of the company is not taken into account in the calculation of operational risk, there will be a large deviation of capital requirements. Combining internal data with the standard risk rate estimation process can provide a more accurate method than estimating market risk. Ergashev (2011) [13] introduced a framework that incorporates scenario analysis into operational risk model. The basic idea of this framework is that only the worst case contains tail behavior information of operational risk, because the worst case compares the normal loss with the corresponding severity loss distribution quantile determined by historical loss. Huang, Smith and Durr (2013) [14] proposed a simple weighted average model to measure internal operational risk. Previous complex models are affected by insufficient historical data or models based on probability theory, which can not be widely used. This model is based on subjective judgment of uncertain stage of operational risk identification, and is a feasible alternative to traditional probability model.

Liquidity Risk

Liquidity risk refers to the possibility of a company's assets encountering economic losses due to liquidity uncertainties. Liquidity risk mainly arises from banks'inability to cope with liquidity difficulties caused by falling liabilities or increasing assets. When a company lacks liquidity, it can not rely on debt growth or quick liquidation of assets at a reasonable cost to obtain sufficient funds, which will affect its profitability. In extreme cases, insufficient liquidity can lead to company failure.

Compared with credit risk, market risk and operational risk, liquidity risk has more complex and extensive causes, and is usually regarded as a comprehensive risk. In addition to the imperfect liquidity plan of the company, the defects of risk management in credit, market, operation and other fields will also lead to the lack of liquidity of the company, and even lead to the spread of risk, resulting in liquidity difficulties in the entire financial system.

There are two main methods to measure liquidity risk: one is to assume that the exogenous variables of the holding period remain unchanged without considering the market risk of the holding period, and only consider the liquidity risk caused by liquidity cost. This kind of model focuses on the endogenous liquidity risk; the other is a liquidity risk measurement model based on bid-ask spreads, which takes exogenous liquidity risk into account. However, it ignores the endogenous liquidity risk, that is, the impact of the trader's own trading strategy on asset prices. The most recognized model is the BDSS model.

Bangia et al. (2008) [15] proposed the BDSS model, which uses price spreads as a measure of liquidity risk. By adding liquidity risk to market risk, we can measure the total risk of both. The assumption in the BDSS model that market risk is completely related to liquidity risk is too simple. In addition, the correlation coefficient only measures the linear correlation, which obviously can not accurately describe the correlation structure between the two.

Duffie and Ziegler (2003) [16] studied liquidity risk using three-factor models: cash, relative liquidity and non-liquidity. They found that it is usually better to sell non-current assets first and hold cash and relative current assets, but this method is not ideal when there is a thick-tailed distribution of return on assets and bid-ask spreads. Acerbi and Scandolo (2008) [17] made an analysis of the status of liquidity risk under the uniform risk measure, and defined a series of combined uniform risk measure methods.

Integration Risk

Integration risk means the integration of all financial risks. The deep influence of various financial risks makes the financial risk management of modern financial institutions not only measure individual financial risks, but also integrate all financial risks to measure integrated financial risks. Enterprises need to make a financial risk budget and allocate the financial risk to different departments in order to control the financial risks they undertake. This requires enterprises to effectively integrate all types of financial risk into a consistent framework. In a top-down financial risk management system, the fundamental of measure of the over all financial risk is reflected in the variance of asset return, which can be divided into systematic risk and non-systematic risk.

In recent years, Copula has been widely used in the analysis and modelling of overall financial risk in academic research. This function links the joint cumulative distribution of variables with the marginal cumulative distribution function of variables. Copula method can be used not only for the correlation analysis between assets, but also for the synthesis of different financial risk categories, taking market risk, credit risk and operational risk into account. Embrechts et al. first applied Copulas to the financial field. Dimakos and Aas used Monte Carlo simulation method to estimate the loss distribution of marginal risk and total risk. It was found that accurately VaR value could not be obtained simply by accumulating market risk, credit risk and operational risk.

Conclusions

In a word, after decades of development, financial risk measurement has become an important research field of finance, and new financial risk measurement methods and tools have been emerging. The application of financial risk measurement has a strong guiding significance in risk management in portfolio optimization. However, the theory of risk measurement is still an area to be further developed and improved, and there are many topics worthy of in-depth study. Because of the limitations of various existing risk measures, the new risk measurement theory base on indicators such as good performance, easy calculation and reasonable testing etc., are the focus and direction for further research in the future.

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