
Research on Credit Risk Assessment of Commercial Banks Based on KMV Model

Yan Bingzheng¹, Bai Puxian²

¹College of Professional Study, Northeastern University, Boston, United States

²School of Business, University of Sydney, Sydney, Australia

Email address:

yanbingzheng20@163.com (Yan Bingzheng), yleBai97@163.com (Bai Puxian)

To cite this article:

Yan Bingzheng, Bai Puxian. Research on Credit Risk Assessment of Commercial Banks Based on KMV Model. *Social Sciences*. Vol. 10, No. 5, 2021, pp. 204-217. doi: 10.11648/j.ss.20211005.11

Received: August 12, 2021; **Accepted:** September 6, 2021; **Published:** September 10, 2021

Abstract: Under the background of the new normal economy, the financing mode of local governments has changed, which has led to the emergence of a new pattern in China's financing market. Under this background, banks are facing the development pressure of subject diversification, financial disintermediation and cross-border competition. Commercial banks also actively promote the compliance development of emerging businesses such as financial market through the "comprehensive direction", so as to form a balanced and complementary development situation with traditional credit business. Therefore, this paper taking credit risk and related theories as the starting point, KMV model is selected to study domestic bank risk monitoring. Then, China Merchants Bank is taken as the research object, Shengjing Bank, Harbin Bank, Qingdao Bank and Chongqing Bank are taken as horizontal comparison. The data sampling time span is January to December 2018, as vertical comparison. Five banks were evaluated for credit risk, and it was found that the default distance of China Merchants Bank was relatively small and the default probability was relatively large. However, according to the calculation and analysis of KMV model, the default probability and return volatility of China Merchants Bank rank first among the five commercial banks, but at the same time, it maintains a high net profit margin of 129.3% in 2018, which shows that China Merchants Bank has a strong ability to control credit risk.

Keywords: Internet Finance, Commercial Banks, Total Factor Productivity, Malmquist Index, Pool Data

1. Introduction

1.1. Research Background

In 2019, the world economy began to slow down, while China's economy is also experiencing some difficulties. The domestic economic growth is slowing down, and the economic structure is facing reform. Under these circumstances, many domestic banking institutions begin to face challenges from various problems such as insufficient effective credit and increased risk resistance. With the continuous adjustment of the domestic interest rate market. Banks show diversified development trend [1]. This change also makes the challenges and environment faced by some banking institutions in the process of operation worse, and the areas involved in the risks become larger and larger, and the probability of taking risks will greatly increase. In the past, China's commercial banks mainly took on the risks of loan business, but with the continuous development of market

economy, banking industry has also been adjusted accordingly, and the loan business undertaken by commercial banks has changed into capital and equity mortgage [2]. In 2018, the total assets of China's commercial banks increased by 181.69 trillion yuan compared with the previous period. Among them, the proportion of banking financial institutions in the total assets was as high as 78.23%, and the amount of non-performing loans of commercial banks was 1.51 trillion yuan, an increase of 18.66% compared with 2017, and the non-performing loan ratio was 1.74%, an increase of 0.07 percentage points compared with the same time of last year, and this index showed an increasing trend year by year. Especially after the economic impact in 2017, the growth rate of non-performing loans has been increasing. In addition, with the gradual decrease of bank deposit and loan interest rates in China, China's commercial banks also need to upgrade their ability to expand their business. Based on this unfavorable situation, it is difficult for some banks to obtain economic benefits on risky assets, and the development trend is

becoming increasingly severe [3]. This also shows that China's commercial banks still have the problems of great downward pressure and high operating credit risk under the condition of low overall asset quality. Therefore, I will focus on the credit risk of China Merchants Bank, and provide some methods to evaluate the credit risk of commercial banks for some governments or local supervisory institutions in order to improve the ability of banks to avoid risks to a certain extent.

1.2. Research Significance

1.2.1. Theoretical Significance

Banking institutions play a very important role in the economic development of the whole society. Therefore, how to avoid some credit risks and risk management has always been the focus of people's research. Through consulting relevant data, we can find that the research directions are mainly in risk measurement, risk early warning and so on. This paper will focus on the development status of bank credit risk and the causes of risk. Through the emphasis of bank credit risk evaluation, the genetic algorithm of artificial intelligence model is combined with the model studied by some scholars, so as to provide a more comprehensive model for predicting bank risk. Achieve the purpose of enriching the existing research results.

1.2.2. Practical Significance

As the hub of the whole social and economic development, banks can play their own role as financial intermediaries, and can influence the trend of money and improve the utilization rate of money funds in the whole market to a certain extent. It is precisely because of these roles played by banks. Therefore, the stability and risks of banks themselves will determine the economic development trend of the whole country. Therefore, this paper puts forward some suggestions and countermeasures on how to effectively avoid risks and reduce the probability of taking risks in commercial banks combined with KMV.

2. Literature Review

2.1. Foreign Research Status

2.1.1. Foreign Research on Credit Risk of Commercial Banks

According to some foreign research data, their research on bank credit exceeds that of our country for many years. The results presented by them are qualitative and quantitative, and then combined with data for comparative analysis.

Beixi Si (1993) made a very specific research on the risk management, its system and capital of the banking industry, and published very important research results and discussions [12]. Jacoby & Fowler (2005) put forward that credit risk can be explored and studied from the perspectives of behaviour and economics, and demonstrated and analysed by mathematical modelling [13]. Meyer and Yeager (2006) analysed the relationship between macroeconomic variables and non-performing loans of commercial banks, and found

that the biggest influencing factors included GDP growth rate, interest rate level and unemployment rate [14]. Pesola (2008), through studying the influence of European countries on commercial banks in the economic cycle, put forward the reasons for the critical situation of non-performing loans of commercial banks, including: With the sharp increase of national debt, GDP level is lower than expected, especially in Denmark, Norway and other places [15]. (Saunders)(2009).

It is suggested that many active and effective measures should be taken to strengthen the assessment of bank credit risk, and special methods can be adopted when necessary to obtain comprehensive and specific data and conclusions to better avoid corresponding risks [16]. Hoggarthetal (2013) analyzed the credit risk of British commercial banks by adopting vector regression. It is concluded that the development of national economy has a vital impact on bank credit risk [17]. David W and David T (2015) effectively analyzed the relationship between bank credit risk and its default rate by using KMV model reasonably and combining with the background of the financial crisis in 2008, and put forward the views and suggestions for prevention and improvement [18].

2.1.2. Foreign Research on Credit Risk Measurement Model

Foreign scholars have been studying and changing the methods of credit risk from the initial expert evaluation method to the later single variable to the present artificial intelligence.

(i). Traditional Model

Expert evaluation method mainly focuses on the research of supervisors. Mainly rely on the relevant research scholars' own ideas to score reasonable scores for the credit institutions they evaluated. Generally, they mainly use 5C, 5P and other methods for implementation. This lacks comprehensiveness to a certain extent, but under special circumstances and circumstances. The implementation of this method is most in line with the risk assessment of commercial banks at that time. Atlman (1968) created a new risk assessment method for commercial banks-Z-scoring method, which uses mathematical modeling in mathematical thinking to reasonably establish corresponding data models and assess the corresponding risk degree of enterprise loans [19]. Grasp the changes of variables carefully to make the model more accurate. Ohlson (1989) determined its accuracy by integrating the diversified differentiation model of Z-score method and using correlation test method, thus a new risk prediction model was born [20]. Martin (1977) established a logit model according to the relevant data indicators of banks. by using this model, he predicted the bankruptcies of various banks before 1975 and 1976. Therefore, this model can predict the bankruptcy risk of banks to a certain extent. Zmijewski (1994) established a probit model which can well predict the credit crisis of enterprises [21].

(ii). Modern Credit Risk Measurement Model

With the continuous changes of economic development in recent years, people pay more and more attention to various

methods of forecasting risk models. Many financial companies look at this risk measurement model from different angles. The most common ones include KMV model and Credit Metrics model. KMV Company (2002) based on the two basic theories of lack-Scholes and Merton. A model called KMV is established. Mcquown (2005) believes that a company's financial situation can only reflect its current operating conditions. The future trend of the company in the market is mainly reflected in the market price [22]. Therefore, if the risk credit evaluation report is accurate, we must consider the influence of these two aspects at the same time. After the KMV model was introduced. Many modern scholars who study credit risk have made relevant researches on this model. Arora et al (2009) studied several commonly used models, and finally found that KMV is the most effective model in evaluating risks [23]. Cao (2012) used KMV model to compare the expected default rate and credit risk premium. Therefore, it is found that this model has a good advantage for this kind of debt in the medium and long term [24]. Korablev & Dwyer (2017) collected data from companies in different regions and countries during the decade from 2006 to 2016, and found that KVM model is much better than traditional Z score model and Logit model in the predictability of credit risk assessment [25]. And has better accuracy.

2.2. Domestic Research Status

2.2.1. Domestic Research on Credit Risk of Commercial Banks

Compared with some foreign research results, it is found that the research on credit risk assessment institutions in China is relatively inadequate.

Zhang Wei and Li Yushuang (2003) reasonably analysed various risks of commercial banks by adopting traditional expert method and Logit model [1]. Tan Yanzhi and Zhang Yundong (2013) compared and analysed the non-performing loan ratio data between banks in China, Japan and the United States from 2006 to 2012. It is found that there is a great relationship between credit risk and unemployment rate of Chinese banks [2]. However, the credit risk of Japanese banks is closely linked with CPI index, and the influence in this respect rarely appears in American banks, which is probably caused by a special environment in which the United States was at that time. Chen Jiali (2013) made accurate use of the credit assessment model and added it to the corresponding risk analysis to ensure no distortion of data and evaluation [3]. Shen Yonghua (2015) put forward the viewpoint of establishing relevant rating system and optimizing the internal management of the bank to improve the credit risk management system through practical analysis of the actual situation of a branch of Agricultural Bank of China [4]. The external factor is mainly to strengthen the information exchange among financial institutions, so as to promote the supervision efficiency of the whole financial institutions. Ling Jianghuai and Liu Yanmei (2016) analysed and evaluated the situation of ten large-scale companies by using KVM model, and compared them with the data of authoritative rating agencies of Poole, and found that there was no significant

difference between them. There is more convergence [5]. Zhang Fan (2017) pointed out that at present, many commercial banks in China lack effective management methods and means, and the internal rules and regulations of banks are also unreasonable. Banking institutions must pay more attention to them, establish and improve corresponding rules and treaties, increase economic investment in risk prevention, and create a team of high-quality and well-served personnel [6]. In some external supervision systems, we should increase the training of credit evaluation institutions or make use of the policies introduced by relevant government functional departments. Panpan Zhang and Zhou Xinmiao (2017) used KMV model to analyse 16 large-scale companies and enterprises, focusing on the growth rate of total assets of each bank in 2014-2016, and found that the credit risk of local commercial banks has the highest utility, and the expected default rate is far higher than that of state-owned commercial banks [7].

2.2.2. Domestic Research on Credit Risk Measurement Model

(i). Traditional Model

Zhang Jingui and Hou Yu (2017) selected more than 160 companies recognized as ST and *ST in 2016 as reference objects, collected samples of their economic data before and after the financial crisis, and then applied logit regression method, which can accurately assess the credit risk of SMEs, to analyse and explain these samples and put forward corresponding improvement measures [8].

(ii). Modern Credit Risk Measurement Model

Yang Xiuyun, Jiang Yuanyuan and Duan Zhenzhen (2018) analysed and demonstrated the relevant economic data of some listed companies in China from 2016 to 2017 by exploring modern risk assessment management models such as Credit Metrics, KMV and Credit Risk+, and combined with KMV model [9]. It is not difficult to find that KMV model has a high matching degree. It also has higher accuracy than other models, but also can carry out differential analysis on the differences of risks among different industries and fields. Ma Ruowei and Zhang Wei (2016) found the applicable value of KMV model in Chinese listed companies by effectively analysing the content of fixed dynamic default points [10]. And use this model to practice some companies in the past five years, and find that: When the long-term debt coefficient is 0.1, the credit ability at this stage is good. And the resolution effect of empirical EDF is much lower than the accuracy of default distance. It is also much lower than the results of European studies. Zhang Dabin, Zhou Zhigang, Liu Wen and Jiao Peng (2017) used differential evolution algorithm (DE) to optimize the default point coefficient [11]. The corresponding DE--KMV model ensures that the default value and risk assessment of the company are more convergent and inclusive, and the model has high accuracy.

2.3. Comments at Home and Abroad

To sum up, foreign research on credit risk has spent a lot of

time and experience, and combined with various aspects of research, the test model is relatively comprehensive, which makes the risk assessment process more accurate, which is worth learning and learning. According to the domestic research in this field, China's internal information dissemination has been recorded in the measurement model of credit risk assessment. However, credit risk research still lags behind some foreign countries to a great extent, so we need to further increase research in this area.

3. Commercial Bank Credit Risk and Related Theoretical Analysis

3.1. Definition of Credit Risk of Commercial Banks

We can distinguish the risks borne by commercial banks from two aspects: narrow sense and broad sense. In narrow sense, the credit risks borne by commercial banks mainly come from some default risks, that is, it is common for our bank borrowers to fail to repay the loan amount according to the prescribed time before, thus causing losses to the banks. This kind of risk is mainly manifested in the credit business of banks. For some reasons, people who borrow money from banks can't repay the relevant funds according to the relevant contracts, which leads to the bank's losses, which may occur in the process of bank loans and borrowing. However, with the emergence of credit derivatives, many lending behaviors take credit as a certain standard. (Chen Ying and Zhang Shouchuan, 2010). Therefore, to a certain extent, the risks involved in credit are gradually widening. Besides the narrow risks, the risks in a broad sense also include the risks that banks have to bear losses in various fields, as well as the situation that the credit rating of the other party is lowered due to some unexpected circumstances. For example, in the process of business operation, the poor management of enterprises or the decline of solvency will increase the risks borne by banks. Therefore, the generalized risk can be characterized as: the credit of some loans is affected due to some uncertain factors, so that the actual income of commercial banks is less than the expected income and causing the bank to suffer losses in this respect.

3.2. China's Commercial Banks Credit Risk Status

Since Basel II, Chinese commercial banks have learned their advanced ideas from some foreign banks, thus establishing a risk management decision-making and evaluation mechanism with RAROC as the main structure. The basic idea is to get the benefits and economic capital after the risks in a controllable range. Then, through certain means, an agreement is reached between the loan pricing and the bank to compensate for the loss of the bank in order to achieve a balanced state between them. RAROC has brought a brand-new concept to China's commercial banks, and has become an important means of business decision-making and performance appraisal within banks.

According to Basel III, the credit evaluation of borrowing customers and borrowing projects should be done by banks themselves in order to make rational use of capital. With the continuous development of domestic economy, all financial institutions should strengthen their cooperation with some foreign financial institutions so that our financial institutions have greater competitiveness. Therefore, in order to face these risks, some financial institutions in China have specially formulated relevant government systems to ensure that financial institutions in China can do a good job in avoiding risks. Moreover, it is established to conduct preliminary evaluation on various banking institutions at the end of 2010, so as to prepare for the future advanced evaluation. After R&D and integration, China has made clear standards for various indicators such as the probability of default proposed in Basel III, and initially formed various forms of customer evaluation and loan project rating systems. A large number of banking institutions can cover all businesses in the bank in their risk assessment models, and make its own internal management system more scientific and reasonable.

Below, I will analyze and explain the commercial banks as a whole, as well as some non-performing loans of different banks and non-performing loans of commercial banks in various industries. The credit risk situation of commercial banks in recent five years is mainly displayed by listing and drawing trend charts, and makes a brief analysis of the data trends and large change time points in the table.

Table 1. List of Non-performing Loans and Loan Rates of Commercial Banks from 2014 to 2018.

Bank	Balance of non-performing loans					Non-performing loan ratio				
	2014	2015	2016	2017	2018	2014	2015	2016	2017	2018
commercial bank										
Large commercial banks	4929	5921	8426	12744	15122	0.95%	1.00%	1.25%	1.67%	1.74%
Joint-stock commercial bank	3095	3500	4765	7002	7761	0.99%	1.00%	1.23%	1.66%	1.68%
municipal commercial bank	797	1091	1619	2536	3407	0.72%	0.86%	1.12%	1.53%	1.74%
Rural commercial bank	419	548	855	1213	1498	0.81%	0.88%	1.16%	1.40%	1.48%
Foreign bank	564	726	1091	1862	2349	1.76%	1.67%	1.87%	2.48%	2.49%

The data in Table 1 shows the details of non-performing loan balances and non-performing loan ratios of commercial banks and banking institutions in China from 2014 to 2018. In 2016, the non-performing loan ratio of commercial banks in China reached 1.74%, up by 0.07 percentage points compared with 2015 and 0.79 percentage points compared with 2014. At the same time, we can see that the non-performing loan ratio

increased sharply in 2017, up from 2016. It can be concluded that the credit risk level faced by commercial banks increased significantly in 2017 and 2018. According to the types of commercial banks in China, in 2018, the highest non-performing loan ratio of rural commercial banks was 2.49%, while that of foreign banks was 0.96%, which was 2.59 times that of foreign banks .48% is still 1.54 times that of

foreign banks. This shows that compared with foreign banks, there are many defects in risk management of commercial banks in China, such as lack of scientific risk identification, measurement and monitoring, lack of professional talents, low overall credit level, and need to improve risk management. Therefore, China's financial supervision should learn from foreign ideas and technologies. A suitable credit risk measurement model is introduced into the bank risk management system, and the calculation results are combined with other indicators to comprehensively evaluate the bank credit risk, so as to improve the risk resistance of China's commercial banks and reduce the possibility of credit risk.

3.3. The Causes of Credit Risk of Commercial Banks

The risks undertaken by commercial banks mainly include operational risks, system risks, etc. Credit risk is one of the risks with the highest probability of occurrence, the most complicated situation and the largest scope of influence. To a great extent, the probability and frequency of its occurrence, as well as the impact and loss caused by it will have an impact on the daily activities of commercial banks. Therefore, it is very necessary for us to explore the causes of this kind of risk, so as to provide some basis for the following credit risk management.

3.3.1. External Factors

(i). Macro Environment

To a great extent, the credit risk of commercial banks will have a certain impact on the operation of enterprises and the future development direction of enterprises. However, the profit of the enterprise at present and the future development of the company will be affected by some external factors to a great extent. Under different economic conditions, the profitability, debt repayment and self-credit of enterprises will be affected by some external uncertainties, which will affect the overall ability to fulfill credit. When the domestic economic conditions are in an underdeveloped period, the benefits obtained by enterprises themselves will be relatively reduced at this time. Therefore, the demand for capital of enterprises will be reduced, and some investment will be reduced relatively. During this period, due to the influence of these factors, the borrower may not be able to recover the funds from the enterprises according to the agreed time, which makes the credit risk of commercial banks increase a lot, and vice versa. At the same time, according to the current economic situation, development trend and future goals, every country can prevent the economy from fluctuating greatly through a series of policies or regulation implemented by the government, so that the national economy is in a relatively stable phenomenon. However, the country's use of policies to influence the economy will also have certain influence from the perspective of future economy. For example, when the fiscal expenditure increases, it will lead to an increase in investment. On the other hand, the increase in investment will increase the relevant interest rates, which will have a certain chain effect and have a certain impact on the credit structure of commercial banks. Finally, it will directly reflect the risks of commercial banks.

(ii). Operating Conditions of the Borrower

The borrower's own situation will have a great impact on the bank, which can be explained in two aspects.

On the one hand, there are many uncertain factors in the operation of enterprises, which may lead to poor management due to market factors or other factors, thus affecting the credit of enterprises. For example, in 2017, the government tightened the mortgage business. Because of this impact, Wanda Group was greatly affected in terms of capital. In order to ensure the normal operation of the enterprise, the property of the company has to be sold. On September 27, 2017, Moody's and other credit rating companies rated Wanda as junk. Thus, to a great extent, the bank's line recovery rate declined. On the other hand, the information held by some enterprises and banks is inconsistent. This may be because some enterprises deliberately cheat their own company's credit limit in order to get high low-interest loans from banks. However, even if banks make relevant preparations in advance, they still can't grasp a situation of their own operation. In addition, after the loan is completed, banks are still on the passive side in the mastery of information, so that borrowers can use the amount of loans from banks in other places, such as some high-risk investment projects, which lead to a great increase in the risks borne by banks.

3.3.2. Internal Factors

- (i) The reason of influencing internal factors is that the bank's management level and control system are not systematic enough. From the beginning, the hierarchical institutions established within commercial banks were too cumbersome to implement relevant policies and measures well. Moreover, there are too many branches opened by commercial banks in China, and a completely unified management mode has not been established. There are different situations in the management level. There is also imbalance among the departments in charge when exercising their respective rights. At the same time, because of the influence of regional and local economic level, the bank staffs also have great differences in their professional qualities, which restrict the development of the bank to a certain extent. In addition, individual banks have made wrong decisions in the future development planning of banks because they have failed to combine the actual situation in the process of internal assessment, only aiming at some immediate interests, while ignoring the stability of banks in the overall development. Therefore, many banks have not made correct judgments. Accepting customers who have higher risks or are not real enough in credit system evaluation greatly increases the risks borne by banks. Finally, our commercial banks have not put forward a unified method for customer evaluation, which is far from the requirements of Basel III in terms of customer credit evaluation.
- (ii) The greater the competition between banks, the greater the risks the banks themselves will bear. When the interest rates of bank deposits and loans were implemented through the People's Bank of China, the

income of commercial banks was mainly determined by the difference between deposits and loans. Even many banks have low returns. So later, credit business has become the main means for banks to compete in the market. In order to expand the market, many banks, especially some smaller banks, often choose some enterprises with government support, such as real estate, steel industry and so on. As a result, there is a phenomenon of overcapacity in the supply of credit assets. At the same time, there is relatively little tracking and management by banks after lending to enterprises, which easily leads some enterprises to change their uses after obtaining funds, such as carrying out high-risk projects, which leads to banks taking huge risks in assets. With the gradual opening of bank interest rates, each bank began to have the right to make its own decisions. This makes the competition among banks more intense. When faced with some customers with good credit, the quality of banks themselves is low, and the ability in traditional business can not meet the needs well. It is precisely because of the bank's insufficient handling capacity in related business that the risk borne by the bank is increasing.

3.4. Comparative Analysis of the Adaptability of Credit Risk Measurement Methods

From the very beginning, the credit risk measurement model is mainly quantitatively analyzed by subjective scoring and judgment. Up to now, some risk measurement methods have become more and more perfect by constantly maturing and exploring the structure. However, theoretical research does not mean that we can get what we deserve in practice. This needs to fully consider the influence of various factors in various environments, so it needs to be further updated.

3.4.1. Traditional Credit Risk Measurement Model

(i). Expert Analysis

There are too many aspects of credit risk, and it is difficult to make a relatively fixed evaluation from the aspects of business operation. At the beginning, the risk evaluation of commercial banks mainly depends on experienced personnel in the bank, who have accumulated a lot of experience in the long-term risk evaluation process. Thereby providing some support for their evaluation. Although this is subjective to a certain extent, it can still be used as a means. And has the characteristics of small workload and high evaluation efficiency. Moreover, many domestic small-scale loan companies still use this method, and the subjective evaluation of credit risk is mostly "5C" factor analysis method, which is mainly through the comprehensive evaluation of the character and capital of the borrower. Character refers to the credit of the enterprise itself, as well as some previous loan and repayment records and the evaluation among banks. Capital mainly refers to the proportion of money borrowed by an enterprise in its assets. It is a manifestation of the repayment ability of enterprises. The lower the proportion, the higher the

enterprise's ability to repay debts. Repayment ability is mainly manifested in the profit and profit of the enterprise. The higher the profit generated, the lower the fluctuation, and the higher the repayment rate of the enterprise. Guarantee is some assets provided by the borrower when borrowing money. When the borrower fails to change money according to regulations, guarantee can be used as a means of compensation. The economic cycle rate is reflected in the correlation between the bad debt rate of banks and the economic cycle, which plays a supporting role. Expert analysis must rely on professional experience if it wants to play its role, and this method does not have good stability.

(ii). Credit Scoring Method

The credit scoring method mainly uses the relevant financial data of the borrowing enterprise and the relevant credit rating to make evaluation means, and the proportion given according to different data is different. Methods of evaluating default risk of borrowing enterprises. The main principle is that an enterprise's finance is the best reflection of its operating conditions, and the better the financial situation. The higher the enterprise's credit rating, the lower the possibility that the loan will not be repaid. At present, there are several common credit models, such as Z-score model and logistic model. This risk assessment model for enterprise finance has been used more and more widely, but with the continuous development and change of economy, the shortcomings of these models are constantly revealed. First of all, in the analysis process, the model only pays attention to the financial data of the company, while ignoring some external factors. Secondly, the data used is historical data and has no timeliness. Finally, the model does not consider all aspects.

3.4.2. Modern Credit Risk Measurement Model

(i). KMV Model

In 1997, KMV in the United States established this model, which was applied to the default rate of borrowing companies. This model is mainly based on the financial data of enterprises and listed stocks, and predicts the changes of the company's future assets through the calculation of relevant aspects of the model. According to the current situation of the company, the default point of the enterprise is obtained, and then the default distance of the borrower is calculated, so as to obtain the default rate of the company.

(ii). Credit Metrics Model

Credit Metrics model was established by J. PMorgan in 1997. This model was established to evaluate the credit risk of enterprises. The Credit Metrics model does not consider the current market situation, and the company's credit rating is the only criterion for judging, and the value of credit rating is different. The enterprise's own credit rating will be changed according to other credit ratings. Thus, a transition probability matrix is formed, and the default rate of this enterprise can be judged by this transition matrix.

(iii). Credit Risk+ Model

Credit Risk+ model was established by Boston Bank in 1996 for insurance calculation. The model presupposes that

there is no relationship between loans, the default bank of each loan is very small, and the probability is also changing. The model studies the segment of loan portfolio loss. In this theory, the unexpected loss rate of this loan portfolio can be obtained at a given confidence level.

(iv). *Credit Portfolio View Model*

In 1997, McKinsey & Company developed a multi-factor credit risk quantitative model-Credit Portfolio View model.

This model is based on the predecessors, and some uncontrollable factors are added. This model holds that the credit rating evaluation is influenced by two factors: systematic macro-economy and non-systematic shock variables. Systematic macroeconomic variables depend on historical data and random shock variables. This model mainly measures the credit risk of customers as a whole by evaluating the default probability and default risk.

Table 2. Comparison of Modern Credit Risk Measurement Models.

Credit risk measurement model	Credit Metrics model	Credit-Portfolio -View model	Credit Risk+ model	KMV model
asset value	Discrete type	Continuous or discrete type	Discrete type	successive type
Data dependency	High, long-term accumulated industry data (strictly based on the credit rating evaluated by rating companies), national and industry indexes and stock trading information	High, not only needs a lot of historical default data, but also needs a lot of national macroeconomic data	Medium, need risk exposure level and a large number of company default probability data	Medium, you need to know the stock price information and some financial index information of listed companies
Risk driver	The value of company assets	National macro economy	Default rate of the company	The value of company assets
Applicability of method	Widely, the model relies on a large amount of credit rating data	Widely, the model depends on the historical price and transaction volume of a large number of loans	Widely, the model relies on a large amount of credit rating data	Medium, applicable to listed companies
Evaluate the accuracy	The evaluation results are more accurate, ignoring the situation of industries and companies	The evaluation result is accurate, but it has a certain time delay	The evaluation results are accurate and continuous	The evaluation results are accurate and real-time

From the above several commonly used risk measurement models in Table 2, each model has different advantages and disadvantages. Although these models have been widely used abroad, our economic policies and economic situation are different from those of foreign countries, so the risk assessment for our own commercial banks is quite different from those of foreign countries. So, several models in the table are not necessarily applicable to the risk assessment of China's commercial banks. This needs to be combined with China's current economic situation so as to establish a model suitable for China. First of all, China's credit rating agencies are not perfect at present, although they are working hard to build them. Our current external rating agencies have not yet existed in scale, and lack of relative international authority. Secondly, due to the special period of China's national conditions, rating agencies are vulnerable to some political reasons, thus lacking relative objectivity and impartiality. Finally, we need to improve the law of bank management.

Credit Portfolio View model and Credit Metrics model depend on credit rating system to a great extent. At present, the construction of credit system in China does not have the relevant qualifications. Second, our reform in the economic market has not been completely completed. We still have a lot of room for improvement in the transparency of information in the securities market. And there is a big discrepancy between the stock price held by many listed companies and the actual price. Credit Portfolio View Model, Credit Metrics Model and KMV Model will use the data of China's securities market in the testing process, but the imperfect information of capital market will lead to the restriction of the use of these models. However, at present,

China is stepping up the development and reform of the capital market, and the relevant systems are gradually being improved. Therefore, this creates conditions for the use of these models to a great extent.

At present, China can't use some advanced foreign technical means in credit evaluation, so it is necessary to integrate the existing risks of some commercial banks in China and consider them from various aspects, so as to work out a set of evaluation system suitable for China. According to some research findings above, because the Credit Metrics model and Credit Risk+ model are based on the enterprise credit rating database, they have no good practical effect in China, so they cannot be adopted. As an extension of Credit Metrics model, Credit Portfolio View model needs to fully consider some macroscopic influences, but there are too many variables of macroeconomic factors, which lack relative stability and accuracy. Therefore, it is not applicable to the current situation in China. KMV is also difficult to apply in China in a certain form. However, because this model combines the most theories, it is used most at the beginning of its establishment, and it is convenient for people to operate. At the same time, it can be measured under various conditions, and it is more accurate in obtaining relevant data. And with the continuous improvement and construction of market economy in China, KMV is constantly undergoing renewal, so this model is a good choice for China at present.

4. Credit Risk Assessment Based on KMV Model

Based on the above research on the income of commercial

banks, it is not difficult to find that they occupy an important position in economic markets, but there is little research on their credit risk. Therefore, this paper conducts a research on the credit risk of commercial banks based on KMV model. The corresponding research data comes from the annual financial statements and the annual stock market data statements of each research bank.

4.1. Define the Object of Study

If only China Merchants Bank (03968) is taken as the research object in the risk research of commercial banks, the default distance and the corresponding probability of the bank can be calculated by the comprehensive analysis of data and the construction of KMV model, but the research object is too

single and there is no control group, so the research results will have no practical effect. Based on the consideration of this problem to the research on China Merchants Bank, this paper also includes the research on the four major commercial banks in Hong Kong stocks, namely Shengjing Bank (02066), Harbin Bank (06138), Qingdao Bank (03866) and Chongqing Bank (01963). After comprehensive analysis and research comparison of five banks, this paper specifically analysed the credit risk of China Merchants Bank, and puts forward some suggestions on the existing risks. The sample selection time is from January 1, 2018 to December 31, 2018, and the relevant data used in the research are derived from the annual financial statements of banks in 2018. The relevant data involved in the research are shown in the following table.

Table 3. Financial Statements of Five Major Commercial Banks.

Name	Stock price (yuan)	Total liabilities (100 million yuan)	Total share capital (100 million yuan)	Total assets (100 million yuan)
China Merchants Bank	10.67	4253.88599	89.8162	46161.5991
Shengjing Bank	8.8	7999.13547	76.9668	8016.28500
Harbin bank	4.52	5110.03309	23.9956	5448.51268
Bank of Qingdao	6.46	257294348	62.5871	2872.35254
Bank of Chongqing	7.42	3885.14992	47.2705	4198.07987

Data source: NetEase Financial Annual Financial Statements.

4.2. Model Index Selection

4.2.1. Determination of Risk-free Interest Rate r

The coefficient r used in the calculation of this paper is the annual interest rate of regular deposits and withdrawals implemented in China in 2018 (because the research time interval is 2018), and the specific value of this coefficient is 1.5%.

4.2.2. Determination of Time Parameter T

As mentioned above, this research spans one year, from the beginning to the end of 2018, and mainly studies the default distance and probability of the five major commercial banks in 2018.

4.2.3. Determination of Equity Value

The listed places of the five commercial banks selected in the study are all Hong Kong, and the calculation of their total stock value should be based on the local calculation method, which involves the total share capital of the bank and the closing stock price of the calculation day. The specific calculation method is: comprehensive market value of stocks = total shares of the bank * closing stock price of the calculation day.

4.2.4. Determination of Default Point

A variety of factors should be considered in setting the default point. According to a large number of literatures, the default point in KMV risk assessment of banks is generally set as the sum of 50% of the current external debt cost and the fixed debt cost of banks. However, the fixed liability costs of the five major commercial banks were not found in the related investigation of this paper. There is

only a certain explanation for the total liabilities, and the default point is set as the total liabilities cost of designated banks in this study.

4.3. Empirical Analysis

4.3.1. The Calculation of the Volatility of Bank Stock Value

At present, there are many ways to calculate the volatility of stock value in the world, and this paper chooses the moving average calculation method with more accurate calculation results. The calculation of volatility involves the calculation of the arithmetic average value of the daily closing stock price of the bank one year before the calculation period. The calculation model assumes that the fluctuation of the daily closing stock price of the bank conforms to the normal distribution model, excluding the bank's normal vacation, the number of stock trading days in the whole year is about 250 days, and the common formula is as follows:

Stock return rate: $u_i = \ln \frac{S_i}{S_i - 1}$, where S_i is the closing

share price of the bank on the first day;

Daily volatility of stock value:

$$\sigma = \sqrt{\frac{1}{n-1} \sum_{i=1}^n (U_i - \bar{U})^2}, \quad \bar{U} = \frac{1}{n} \sum_{i=1}^n u_i$$

Annual volatility of stock value: $\sigma_E = \sigma \sqrt{\theta}$, where θ value is 250. The final concrete results are shown in the first and second columns of Table 4 below.

Table 4. Five Banks σ , σ_E And V_E The value of.

Name	σ	σ_E	V_E
China Merchants Bank	0.032124	0.49734	72.116 billion
Shengjing Bank	0.025687	0.39243	56.242 billion
Harbin bank	0.016238	0.25123	32.146 billion
Bank of Qingdao	0.023128	0.36142	26.572 billion
Bank of Chongqing	0.015327	0.23986	24.813 billion

4.3.2. The Bank's Stock Market Value (V_E) Calculation

The calculation of this value involves the closing stock price and the total share capital of the bank on the specified calculation day, which is shown as follows: V_E = closing stock price on the

specified calculation date * total share capital. The specific calculation results are shown in the third column of Table 4.

It can be seen from Figure 1 and Figure 2 that China Merchants Bank has the highest volatility of 0.032124 (day) and 0.49734 (year), while Chongqing Bank has the lowest volatility of 0.015327 (day) and 0.23986 (year). The average value of the five banks is 0.022243 (day) and 0.34756 (year). Comparing the data, we can find that China Merchants Bank has greater stock volatility than the other four major banks, the price of its stock is extremely unstable, but the volatility of Chongqing Bank's stock is relatively small, and the development of its stock is relatively stable.

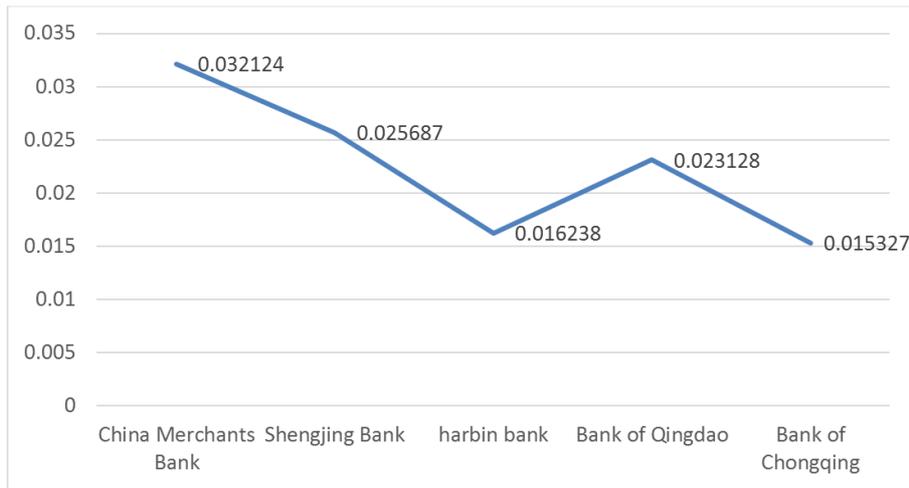


Figure 1. Daily volatility of stock value.

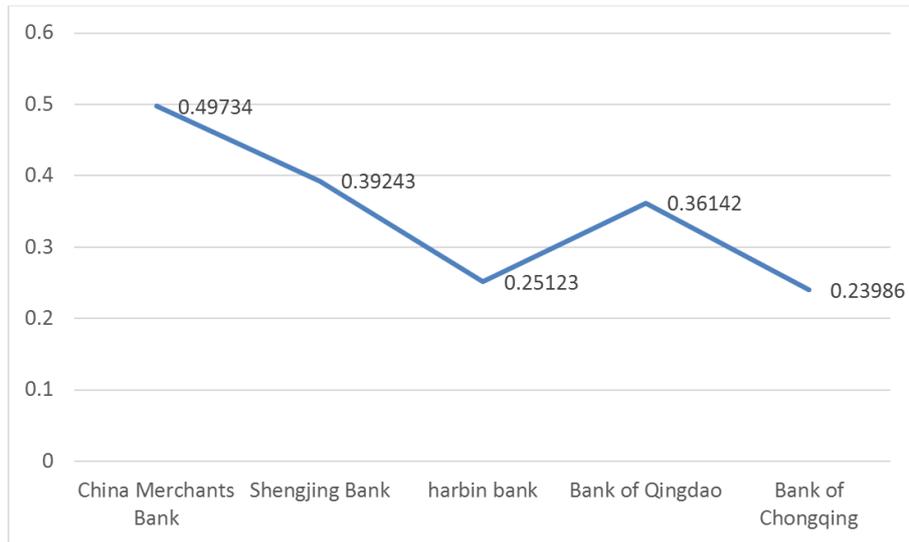


Figure 2. Annual volatility of stock value.

4.3.3. Calculation of Bank Default Point DP

In this study, the bank's default point is defined as the bank's total debt cost, and DP is used to represent the bank's default

point in the following. The relevant data are derived from the annual financial statements of major banks, and the specific set values are as follows.

Table 5. The default point (DP) of five banks is 100 million yuan.

Default point	China Merchants Bank	Shengjing Bank	Harbin bank	Bank of Qingdao	Bank of Chongqing
DP/ 100 million yuan	4253.88599	7999.13547	5110.03309	2572. 94348	3885.14992

The above table reflects the overall debt costs of major banks, which are 425.388599 billion yuan for China Merchants Bank, 799.913547 billion yuan for Shengjing Bank, 511.003309 billion yuan for Harbin Bank, 388.514992 billion yuan for Chongqing Bank and 257.294348 billion yuan for Qingdao Bank. On the whole, the total debt cost of China Merchants Bank is not very high. Compared with the other four banks, its credit risk is not very high.

4.3.4. Market Value of bank Assets V_A with Its Volatility σ_A
Calculation of

According to KMV model, the market value of bank assets V_A , and its volatility σ_A , the calculation formula is:

$$V_A = \frac{V_E + DPe^{-rT}N(d_2)}{N(d_1)} \tag{1}$$

$$\sigma_A = \frac{V_E \sigma_E}{V_A N(d_1)} \tag{2}$$

$$d_1 = \frac{\ln(\frac{V_A}{DP}) + (r + \frac{\sigma_A^2}{2})T}{\sigma_A \sqrt{T}} \tag{3}$$

$$d_2 = d_1 - \sigma_A \sqrt{T} \tag{4}$$

will V_A And σ_A The expression of, and then use MATLAB software to calculate, the final results can be obtained as shown in Table 6 below.

Table 6. Five Banks V_A And σ_A value.

Name	Value of bank's assets V_A (100 million yuan)	Volatility of bank's asset returns σ_A
China Merchants Bank	5271.2456	0.10934
Shengjing Bank	8934.9874	0.03989
Harbin bank	6143.7589	0.02069
Bank of Qingdao	3456.5732	0.05987
Bank of Chongqing	4745.4981	0.02018

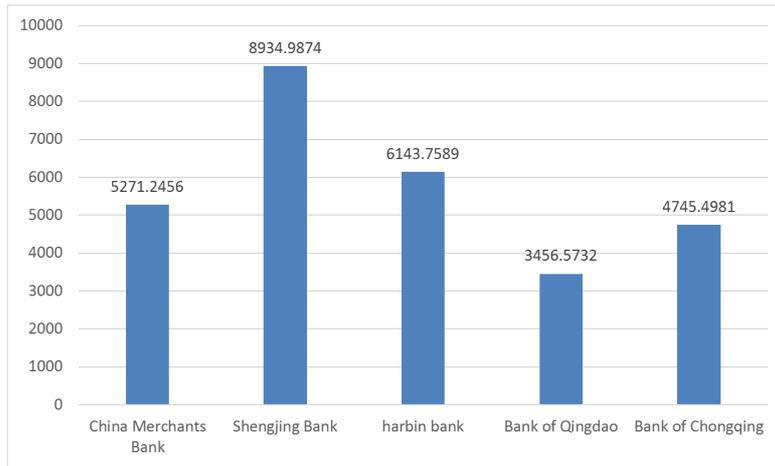


Figure 3. Value of bank's assets.

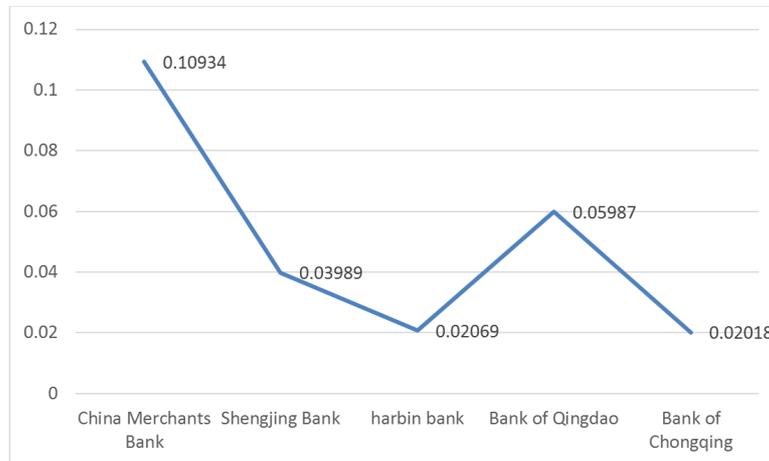


Figure 4. Volatility of bank's asset returns.

Figure 3 and Figure 4 intuitively show the comparison of asset market value and return volatility of the five major banks. Shengjing Bank has the highest asset market value of 893.49874 billion yuan, while its asset return volatility ranks third, indicating that the bank's return volatility is relatively small compared with its market value, and its development is relatively stable. In contrast, the market value of China Merchants Bank's assets ranks the third with 527.12456 billion yuan, and the maximum volatility of its income is 0.10934, which indicates that the income of China Merchants Bank fluctuates greatly and the development of the bank is extremely unstable.

4.3.5. Calculation of Default Distance (DD) and Default Probability (EDF)

The prediction of bank default risk can be realized by calculating the default distance and default probability. The calculation results can accurately show the relative distance between the market asset value and DP and the probability of default in the calculation period. The two major indicators are calculated as follows:

Default distance:

$$DD = \frac{V_A - DP}{V_A \sigma_A} \tag{5}$$

Default probability:

$$EDF=1-N(DD) \tag{6}$$

The final calculation results are shown in Table 7.

Table 7. Default Distance (DD) and Default Probability (EDF) of Five Banks.

Name	Default distance (DD)	Probability of Default (EDF)
China Merchants Bank	1.6427	0.073496
Shengjing Bank	1.7324	0.054876
Harbin bank	3.0213	0.002375
Bank of Qingdao	2.2368	0.028742
Bank of Chongqing	3.3428	0.000988

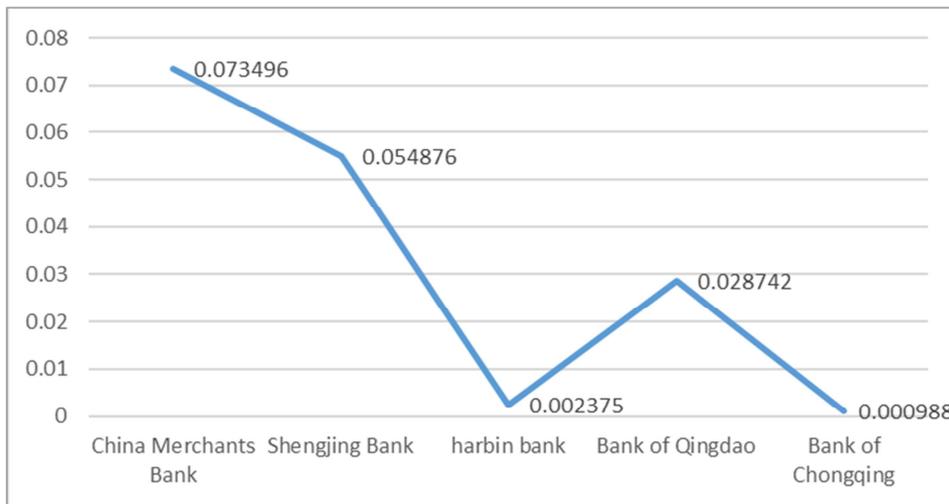


Figure 5. Expected default frequency (EDF).

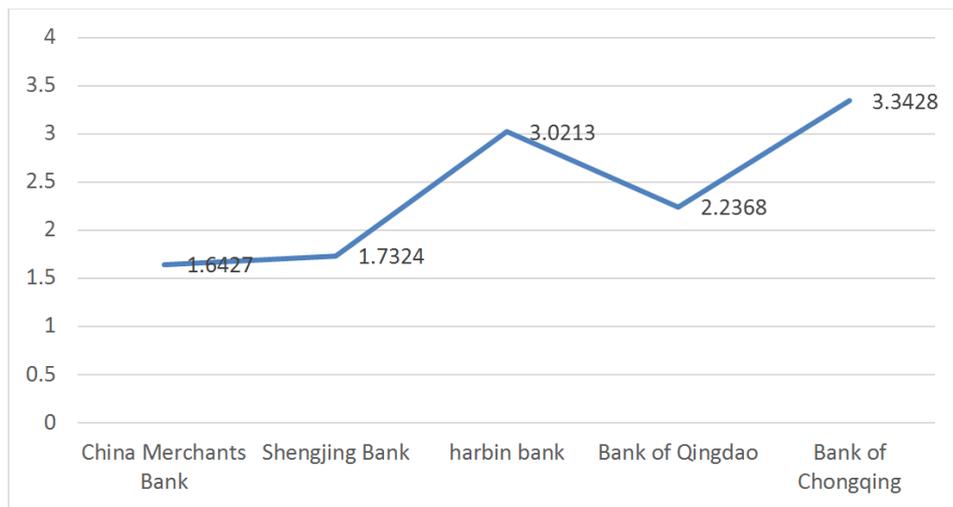


Figure 6. Default distance (DD).

It can be seen from the above figure that in the comparison of default distance and probability among the five banks, the minimum default distance of China Merchants Bank is 1.5059, and the maximum expected default probability is 0.073496. To a certain extent, China Merchants Bank is prone to credit risk, and the bank should take corresponding preventive measures against this situation.

In addition to the calculation of the above two indicators, the credit risk of the five major banks can be evaluated more comprehensively by the risk rating systems of Moody's and Standard & Poor's (S&P). The two systems are respectively launched by their corresponding companies, and the risk estimation efficiency of the system has been recognized by most international banks, which is mainly used for the probability budget of bank default. The application of two systems in five banks can reflect the credit risk of each bank more accurately. Table 8 shows the credit rating comparison table of the two major evaluation systems, while Table 9 shows the credit rating results of the five major banks.

Table 8. Comparison between EDF values of Moody's and Standard & Poor's (S&P) and KMV models.

EDF	Standard & Poor's	Moody
0.020-0.045	≥AA	≥Aa2
0.045-0.105	AA/A	A1
0.105-0.195	A/BBB+	Baa1
0.195-0.405	BBB+/BBB-	Baa3
0.405-0.725	BBB-/BB	Ba1
0.725-1.015	BB/BB-	Ba3
1.015-1.435	BB-/B+	B1
1.435-2.025	B+/B	B2
2.025-3.455	B/B-	B3

Table 9. Credit Rating Results of Five Banks.

	Standard & Poor's	Moody
China Merchants Bank	AA/A	A1
Harbin bank	2AA	2Aa2
Bank of Chongqing	2AA	≥Aa2
Shengjing Bank	AA/A	A1
Bank of Qingdao	2AA	2Aa2

It can be seen from Table 9 that, except China Merchants Bank and Shengjing Bank, whose credit rating is Grade II, the other three banks are all Grade I. This result coincides with the calculation results of default distance and probability of the five major banks, which further shows that China Merchants Bank has great credit risk.

5. Conclusions and Countermeasures

5.1. Conclusion

Looking at many related literatures at home and abroad, the research on the evaluation of bank credit risk in China started later than that in other countries. Foreign advanced countries have set up a proprietary default database for bank default, which can accurately analyse bank credit risk. However, at present, the credit risk assessment in our country can only borrow the calculation of the distance of violation to get the

value of default probability, and there is a big error in the calculation process, which can not be practically applied to the prevention and control system of bank credit risk. In this paper, the KMV model is used to predict the risk of five major commercial banks in China, and the research conclusions are as follows:

First, the application of this model proves that there is a negative correlation between default distance and default probability. To a certain extent, the default probability increases with the decrease of default distance. The calculation results show that compared with other four major banks, China Merchants Bank has greater credit risk, and certain preventive measures should be taken;

Secondly, based on the application of KMV model, the credit evaluation of Moody's and Standard & Poor's system of the five major banks is further carried out. The data show that China Merchants Bank is only rated as second-class among the five major commercial banks studied, and its credit risk problem cannot be ignored. In view of the problems existing in the credit risk of commercial banks, this paper puts forward some opinions on the supervision index of credit risk, personnel control and bank development.

5.2. Countermeasures and Suggestions

At present, the factors affecting the credit risk of commercial banks can be divided into macro-factors and micro-factors. The macro-factors mainly include national macro-control policies and China's economic development state, while the micro-factors are many internal factors of city commercial banks. It is mainly affected by the factors such as its capital turnover, loan-to-deposit ratio of capital, loan interest and net profit of banks. Under normal circumstances, risks can be regulated to the greatest extent. In order to ensure the development of commercial banks, we should try our best to avoid the credit risks they face. Specific suggestions for the development of commercial banks are as follows:

5.2.1. Improve the Capital Turnover and Loan-to-Deposit Ratio of Commercial Banks

According to the research on the annual reports of five major commercial banks in 2018, it is found that the capital turnover of China Merchants Bank is only about 11.0%, Shengjing Bank is 14.2%, Harbin Bank is 12.6%, Qingdao Bank is 15.2%, and Chongqing Bank is 12.1%. Therefore, aiming at the risk pre-control of the five major commercial banks, we should strengthen the control of the capital turnover of China Merchants Bank, minimize the investment of various high-risk projects, ensure the capital flow in a more reasonable state, and avoid the huge losses caused to the bank.

At the same time, it is found that the loan-to-deposit ratio of the five major commercial banks are 48.2% for China Merchants Bank, 49.8% for Shengjing Bank, 49.2% for Harbin Bank, 60.3% for Qingdao Bank, and 57.3% for Chongqing Bank. By contrast, China Merchants Bank has the lowest proportion and Qingdao Bank has the highest, which directly reflects the fact that China Merchants Bank has low

capital utilization rate. In view of this phenomenon. Commercial banks should increase the utilization rate of funds of China Merchants Bank, and try to increase the operating rate of funds while ensuring low credit risk. It can be realized by expanding the scale of operation. We should pay attention to the reduction of expenses, maximize our own operating profit, and at the same time, help to reduce the probability of default and the occurrence of credit risk.

5.2.2. Strengthen the Training of Employees' Risk Awareness

China is now in a period of steady economic growth. Various monetary policies and financial strategies are beneficial to the investment and construction of enterprises, and the interest rate of related construction projects is low. The reform of tax system has created many opportunities for the development of enterprises. In order to speed up the development of commercial banks, banks, especially China Merchants Bank, should increase the training of employees' credit risk awareness to ensure that all foreign loans of banks can be recovered, and increase the credit evaluation and real-time supervision of lending enterprises, so as to prevent enterprises from defaulting, ensure the absolute safety of the overall funds of banks, and avoid huge economic losses caused by non-compliance of lending enterprises. When employees are responsible for lending to enterprises, special attention should be paid to the nature and economic strength of enterprises, which can strengthen the loans to enterprises supported by the state and reduce the loans to enterprises with higher capital risks.

5.2.3. Absorb Professional Risk Management Talents

In addition to the training of employees' risk awareness, more references should be made to professional and technical personnel. Based on this demand, commercial banks can increase the training of credit risk knowledge for employees, explain relevant knowledge to employees through professional institutions and organizations, increase the training of professional talents, or increase direct reference to professional talents. In addition, banks can also increase cooperation with internationally renowned enterprises and introduce foreign advanced talents on the basis of cooperation. The combination of internal talent introduction and external talent introduction is bound to bring a large number of specialized personnel to the bank, which can effectively make great contributions to the bank's credit risk prevention work, and the bank's external credit rating is bound to increase.

5.2.4. Promote Inter-bank Cooperation and Establish a Common Default Risk

At present, there is no credit risk database of major banks in China, and there are many problems in risk pre-control. Based on this situation, commercial banks can increase mutual cooperation among various types of banks, speed up the collection of bank credit data, and gradually speed up the construction of default database on the basis of information collection. The speed of information dissemination among

banks will be greatly increased, and the information cost will be reduced. The losses caused by information asymmetry can be avoided to a certain extent, and the credit rating of banks will be rapidly improved. Generally speaking, it takes at least five years to establish a complete credit risk database. It took fifteen years to complete the risk database of Moody's, an international high-grade credit company, which covers the credit information of 100,000 enterprises. Based on the calculation of the default distance of each major enterprise, the probability of default is calculated, and the corresponding enterprise default database is constructed. According to the credit and plan of the company, the company has introduced a more accurate credit evaluation system. On the other hand, with the development of commercial banks in China, there are many enterprises in China, and it takes a long time to establish a complete enterprise credit information database. In order to minimize the time consumed, we can accelerate the collection of information by increasing the cooperation of banks and establish a corresponding default database, and carry out effective and rapid credit risk assessment for many enterprises in China.

References

- [1] Zhang Wei, Li Yushuang. Credit Risk Assessment and Application of Personal Microfinance Based on Logistic Regression Model [J]. *Financial Theory and Practice*, 2003 (01): 33-38.
- [2] Tan Yanzhi, Zhang Yundong. An evaluation study based on the relationship between credit risk and unemployment rate —— Taking the non-performing loans of banks in China, Japan and the United States as an example [J]. *Management Review*, 2013 (7).
- [3] Chen Jiali. P2P online loan personal credit risk assessment model research-based on hybrid Drosophila neural network method [J]. *Friends of Accounting*, 2013 (21): 32-35.
- [4] Shen Yonghua. Construction of credit risk evaluation index system of listed companies [J]. *Journal of neijiang normal University*, 2015 (12): 65-69.
- [5] Ling Jianghuai, Liu Yanmei. Research on Credit Risk Assessment of Jinzhou Bank Based on KMV Model [J]. *Cooperative Economy and Technology*, 2016 (7): 59-62.
- [6] Zhang Fan. Constructing the credit risk evaluation model of small and micro enterprises based on CFaR [J]. *Accounting Monthly*: 2017 (5): 23-28.
- [7] Panpan Zhang, Zhou Xinmiao. Research on Internet Financial Credit Risk Assessment Based on BP Neural Network Model [J]. *Science and Technology Innovation*, 2017 (16): 338-338.
- [8] Zhang Jingui, Hou Yu. Research on Credit Risk Evaluation and Risk Management of SMEs under Supply Chain Finance Model [J]. *Journal of Central University of Finance and Economics*, 2017 (12): 36-45.
- [9] Yang Xiuyun, Jiang Yuanyuan, Duan Zhenzhen. Credit risk assessment of development finance from the perspective of default distance [J]. *Financial Theory and Practice*, 2018 (5).

- [10] Ma ruowai, Zhang Wei. credit risk assessment of commercial bank customers based on unbalanced samples-taking listed companies as an example [J]. financial theory and practice, 2016, No. 468 (07): 55-61.
- [11] Zhang Dabin, Zhou Zhigang, Liu Wen, Jiao Peng. Research on Bank Credit Risk Assessment Based on KMV Model [J]. Cooperative Economy and Technology, 2017 (7): 59-62.
- [12] Beixi Si. Data Processing in Model of the Bank Credit Risk Assessment Based on Asset Assessment [J]. Applied Mechanics and Materials, 1993, 707: 493-496.
- [13] Jacoby, Fowler. The Application of WN Based on PSO in Bank Credit Risk Assessment [C]// International Conference on Artificial Intelligence & Computational Intelligence. IEEE Computer Society, 2005.
- [14] Meyer, Yeager. Credit risk assessment of the microfinance industry in Nigeria: an application to Accion Microfinance Bank Limited (AMFB) [J]. Applied Physics Letters, 2006, 98 (1): 1-2.
- [15] Pesola. Assessment Research of Credit Risk in Commercial Bank Based on Fuzzy-VaR [C]// International Conference on Management & Service Science. IEEE, 2008.
- [16] Saunders. Recent developments in consumer credit risk assessment [J]. European Journal of Operational Research, 2009, 183 (3): 1447-1465.
- [17] Hoggarthetal. Multiple classifier application to credit risk assessment [J]. Expert Systems with Applications, 2013, 37 (4): 3326-3336.
- [18] David W, DavidT. Genetic algorithm-based heuristic for feature selection in credit risk assessment [J]. Expert Systems with Applications, 2015, 41 (4): 2052-2064.
- [19] Atlman. A hybrid ensemble approach for enterprise credit risk assessment based on Support Vector Machine [J]. Expert Systems with Applications, 1968, 39 (5): 5325-5331.
- [20] Ohlson. Credit Risk Assessment and Relationship Lending: An Empirical Analysis of German Small and Medium-Sized Enterprises [J]. 1989, 45 (2): 194-213.
- [21] Zmijewski. Credit risk assessment model for Jordanian commercial banks: Neural scoring approach [J]. Review of Development Finance, 1994, 4 (1): 20-28.
- [22] Mcquown. Non-negative matrix factorization with sparseness constraints for credit risk assessment [C]// IEEE International Conference on Grey Systems & Intelligent Services. IEEE, 2005.
- [23] Arora, et al. A Least Squares Fuzzy SVM Approach to Credit Risk Assessment [M]// Bio-Inspired Credit Risk Analysis. Springer Berlin Heidelberg, 2009.
- [24] Cao. APPLICATION OF ANT COLONY OPTIMIZATION TO CREDIT RISK ASSESSMENT [J]. New Mathematics and Natural Computation, 2012, 04 (01): 107-122.
- [25] Korablev, Dwyer. Risk Management for Central Banks and Other Public Investors || Risk mitigation measures and credit risk assessment in central bank policy operations [J]. 2017, 10.1017/CBO9780511575716 (8): 303-339.