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Integrated risk study for Chinese commercial banks with fuzzy comprehensive appraisal method

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Abstract: The Basel Capital Accord II proposes that commercial banks should supervise not only credit risk but also market risk, liquidity risk and operational risk. Using the fuzzy comprehensive appraisal method based on the Basel Capital Accord II, this paper measures the integrated risk of Chinese commercial banks. Our results indicate that the average values of the four types of risks are higher than the integrated risk of the four risks, indicating an overestimated whole risk. Our results illustrate the importance of considering the correlation between the different risk sources in order to efficiently allocate financial resources.

Keywords: integrated risk of commercial bank; fuzzy comprehensive appraisal; R-cluster analysis; principal component analysis.

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1 Introduction

With the increase in complexity of financial transactions, commercial banks face an integrated risk of credit, market, operation and so on. There are strong correlations among these risks. The conventional method of measuring individual risks ignores the correlations, and thus does not fully reflect the true level of risk exposure of the bank. In addition, Basel II (Basel Committee on Banking Supervision, 2006) proposes measuring the risks in an integrated manner.

Although the commercial banks in China have improved the measurement of credit, market, operational and liquidity risks, these risks are usually measured independently and in an isolated manner. This paper measures the integrated risk of Chinese commercial banks. According to the *Banker* magazine, Industrial and Commercial Bank of China (ICBC) and China Construction Bank (CCB) represent large commercial banks in China. China Merchant Bank (CMB) and Shanghai Pudong Development Bank (SPDB) are regarded as the representative of Chinese publicly traded commercial banks. In this paper, we will measure the integrated risk of the four commercial banks using the fuzzy comprehensive appraisal method. From this paper, we can draw a conclusion that the mean value of the four risks will be higher than the integrated risk of the four risks considering the correlations between risks. This means the whole risk will be overestimated. This is not conducive to the allocation efficiency of financial resources.

The remainder of the paper is organised as follows. The research model is formulated in Section 3, and the empirical analysis is provided in Section 4. In Section 5, we offer the summary and conclusions.

2 Literature review

In the risk research area of commercial banks, many scholars have conducted much research regarding all kinds of risks. However, in recent years, both integrated risks and comprehensive appraisals are beginning to be studied. Frankel and Rose (1996) developed a probit model of currency crashes in a large sample of developing countries. Their use of annual data permitted them to make a comprehensive appraisal with these variables (such as the composition of external debt) that were available only at that frequency. Rosenberg and Schuermann (2006) constructed the integrated risk distribution for a typical, large, internationally active bank using the method of copulas. He and Zhang (2001) established a risk pre-warning system for commercial banks with an integrated evaluation method. Zhang and Huang (2003) analysed factors for financial risk

evaluation, obtained the indexes weights with hierarchical analysis and valued the risk of integrated financial systems with a comprehensive appraisal method. Chen (2003) introduced several statistical methods of risk rating. Chi et al. (2009) set up an early warning model of commercial banks' risk based on a comprehensive appraisal and principal component analysis.

Many of the above approaches did not study the integrated risks of credit, market, liquidity and operation. This paper will measure the credit, market, operational and liquidity risks as a whole faced by the Chinese commercial banks using fuzzy comprehensive appraisal and an objective analysis method. Different from others, our study includes operational risk in the integrated risk. Without operational risk data in the annual report of Chinese commercial banks, this paper tries to measure the operational risk of the commercial banks indirectly.

3 Research model

3.1 Primaries of the integrated risk indexes

According to the requirements of 'risk evaluation system of commercial banks (interim)' and 'commercial bank regulatory risk core index (interim)' (China Banking Regulatory Commission, 2004, 2005) in China, we selected 13 indexes from the four aspects of the credit, market, operational and liquidity risks in view of the indexes selection principles and expert opinions. X_1, X_2, X_3 and X_4 represented the four kinds of risks, respectively. (X_{11}, X_{12}, X_{13}, X_{14}, X_{15}, X_{16}), (X_{21}, X_{22}), (X_{31}) and (X_{41}, X_{42}, X_{43}, X_{44}) represented the second-layer indexes (see Table 1). Table 1 presents the different risks' indexes and the limit for each index.

Table 1 Primary indexes of the integrated risk

Sort	*Index*	*Limit*
Credit risk (X_1)	Non-performing loan ratio(X_{11})	5%
	Estimated loan loss ratio (X_{12})	3%
	Mortgage loans ratio (X_{13})	25%
	NPL provisioning coverage ratio (X_{14})	75%
	Ratio of the largest single loan (X_{15})	10%
	Ratio of 10 largest loans (X_{16})	50%
Market risk (X_2)	Risk-sensitive ratio of interest rate (X_{21})	1 best
	Accumulated foreign exchange exposure positions ratio (X_{22})	20%
Operational risk (X_3)	The volatility of non-interest expenditure(X_{31})	40%
Liquidity risk (X_4)	Reserve requirement ratio (X_{41})	13.5%
	Liquidity ratio (X_{42})	25%
	Loan-deposit ratio (X_{43})	75%
	Inter-bank borrowings ratio (X_{44})	4%

We used the 2005–2008 volatility of non-interest expenditure calculated by the top-down expenditure approach to represent the index of operational risk. Though this substitution cannot value the precise operational risk, it can make a rough comparison of operational risk between commercial banks.

Then we will determine the integrated risk indexes of these commercial banks.

3.2 Determination of the integrated risk indexes

Because of the different dimensions between these indexes, the data will be dealt with dimensionless method.

3.2.1 Dimensionless method of indexes

The formulas of dimensionless method are $X' = X_i/X_m$ with the forward indexes and $X' = X_m/X_i$ with the backward indexes. Let X' = dimensionless indexes, X_i = true value and X_m = limit value in Table 1.

These index data in the 2008 annual report of the four banks are dealt with this dimensionless method and the dimensionless data of the integrated risk indexes are given in Table 2. ICBC, CCB, SPDB and CMB stand for Industrial and Commercial Bank of China, China Construction Bank, Shanghai Pudong Development Bank and China Merchant Bank, respectively.

Table 2 Dimensionless data of integrated risk indexes

Index	*ICBC*	*CCB*	*SPDB*	*CMB*
Non-performing loan ratio (X_{11})	2.18	2.26	4.13	4.50
Estimated loan loss ratio (X_{12})	1.44	1.48	1.98	1.76
Mortgage loans ratio (X_{13})	2.07	2.16	1.82	1.51
NPL provisioning coverage ratio (X_{14})	1.74	1.75	2.57	2.98
Ratio of the largest single loan (X_{15})	3.45	2.72	3.38	1.88
Ratio of 10 largest loans (X_{16})	2.45	2.41	2.06	1.56
Risk-sensitive ratio of interest rate (X_{21})	0.93	0.93	0.97	0.92
Accumulated foreign exchange exposure positions ratio (X_{22})	2.28	6.47	1.39	1.73
The volatility of non-interest expenditure (X_{31})	1.01	1.56	0.94	0.95
Reserve requirement ratio (X_{41})	1.07	1.07	1.00	1.00
Liquidity ratio (X_{42})	1.33	2.11	2.21	1.73
Loan-deposit ratio (X_{43})	1.33	1.30	1.03	1.01
Inter-bank borrowings ratio (X_{44})	6.15	50.00	3.57	1.14

3.2.2 Cluster analysis of indexes

After the non-dimension, we will do correlation analysis on these data with the SPSS software to get the correlative matrix of the risk indicators. The correlative matrix is presented in Table 3. The result indicates that there are strong correlations between some of the risk indicators.

Table 3 The correlative matrix of the risk indicators

	Non-performing loan ratio (X_{11})	*Estimated loan loss ratio (X_{12})*	*Mortgage loans ratio (X_{13})*	*NPL provisioning coverage ratio (X_{14})*	*Ratio of the largest single loan (X_{15})*	*Ratio of 10 largest loans (X_{16})*	*Risk-sensitive ratio of interest rate (X_{21})*	*Accumulated foreign exchange exposure positions ratio (X_{22})*	*Reserve requirement ratio (X_{41})*	*Liquidity ratio (X_{42})*	*Loan-deposit ratio (X_{43})*	*Inter-bank borrowings ratio (X_{44})*	*The volatility of non-interest expenditure (X_{31})*
Non-performing loan ratio (X_{11})	1												
Estimated loan loss ratio (X_{12})	0.879	1											
Mortgage loans ratio (X_{13})	−0.936	−0.666	1										
NPL provisioning coverage ratio (X_{14})	0.989	0.798	−0.975	1									
Ratio of the largest single loan (X_{15})	−0.471	−0.061	0.626	−0.578	1								
Ratio of 10 largest loans (X_{16})	−0.924	−0.633	0.983	−0.971	0.741	1							
Risk-sensitive ratio of interest rate (X_{21})	0.158	0.605	0.159	0.008	0.714	0.231	1						

Table 3 The correlative matrix of the risk indicators (continued)

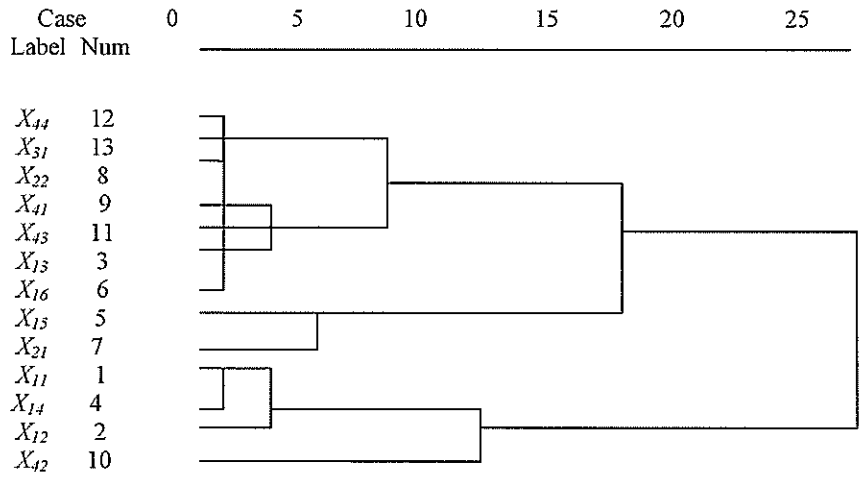
	Non-performing loan ratio (X_{11})	*Estimated loan loss ratio (X_{12})*	*Mortgage loans ratio (X_{13})*	*NPL provisioning coverage ratio (X_{14})*	*Ratio of the largest single loan (X_{15})*	*Ratio of 10 largest loans (X_{16})*	*Risk-sensitive ratio of interest rate (X_{21})*	*Accumulated foreign exchange exposure positions ratio (X_{22})*	*Reserve requirement ratio (X_{41})*	*Liquidity ratio (X_{42})*	*Loan-deposit ratio (X_{43})*	*Inter-bank borrowings ratio (X_{44})*	*The volatility of non-interest expenditure (X_{31})*
Accumulated foreign exchange exposure positions ratio (X_{22})	–0.655	–0.607	0.684	–0.636	–0.100	0.541	–0.266	1					
Reserve requirement ratio (X_{41})	–0.992	–0.930	0.893	–0.962	0.359	0.869	–0.280	0.687	1				
Liquidity ratio (X_{42})	0.313	0.567	0.000	0.218	–0.039	–0.095	0.555	0.301	–0.356	1			
Loan-deposit ratio (X_{43})	–0.996	–0.916	0.899	–0.971	0.425	0.890	–0.235	0.627	0.996	–0.393	1		
Inter-bank borrowings ratio (X_{44})	–0.618	–0.521	0.690	–0.616	–0.051	0.547	–0.156	0.993	0.638	0.404	0.579	1	
The volatility of non-interest expenditure (X_{31})	–0.630	–0.559	0.682	–0.619	–0.083	0.537	–0.212	0.998	0.657	0.359	0.597	0.998	1

Then we will eliminate some indexes which have strong correlations. Here we use R-cluster analysis. Clustering means to divide all the data into different clusters. R-cluster analysis is a classification method based on the correlation coefficients or the distance between different indexes. Here we use squared Euclidean [$\Sigma(X_i - Y_i)^2$; see Verma, 2013]. We can get the indexes classification and distance cluster combine. Table 4 and Figure 1 indicate the classification results between these indexes with R-cluster analysis.

Table 4 Indexes classification with R-cluster analysis

Case	*12 clusters*	*11 clusters*	*10 clusters*	*9 clusters*	*8 clusters*	*7 clusters*	*6 clusters*	*5 clusters*
Non-performing loan ratio (X_{11})	1	1	1	1	1	1	1	1
Estimated loan loss ratio (X_{12})	2	2	2	2	2	2	1	1
Mortgage loans ratio (X_{13})	3	3	3	3	3	3	2	2
NPL provisioning coverage ratio (X_{14})	4	4	4	1	1	1	1	1
Ratio of the largest single loan (X_{15})	5	5	5	4	4	4	3	3
Ratio of 10 largest loans (X_{16})	6	6	6	5	3	3	2	2
Risk-sensitive ratio of interest rate (X_{21})	7	7	7	6	5	5	4	3
Accumulated foreign exchange exposure positions ratio (X_{22})	8	8	8	7	6	6	5	4
Reserve requirement ratio (X_{41})	9	9	9	8	7	3	2	2
Liquidity ratio (X_{42})	10	10	10	9	8	7	6	5
Loan-deposit ratio (X_{43})	11	9	9	8	7	3	2	2
Inter-bank borrowings ratio (X_{44})	12	11	8	7	6	6	5	4
The volatility of non-interest expenditure (X_{31})	12	11	8	7	6	6	5	4

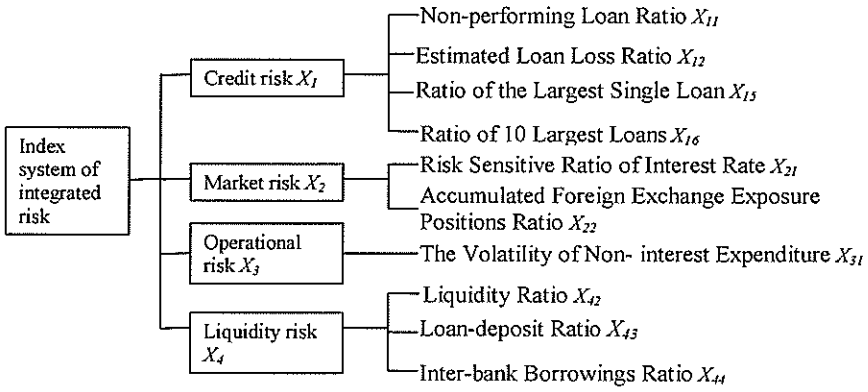
Figure 1 Rescaled distance cluster combine



There is the strongest relation between X_{11} and X_{14}. X_{13} and X_{16} belong to the same category. X_{31} and X_{44} are in the same category. There is some relation between X_{41} and X_{43}.

Considering the representation and correlation of these indexes, we set up the index system of the integrated risk in Figure 2 according to the result of R-cluster analysis.

Figure 2 Integrated risk index system of commercial banks



3.3 Indexes weights of integrated risk

This paper will get the index weights of the integrated risk with objective principal component analysis. Principal component analysis is a method of reduction of dimension. Multiple variables are reduced to a small number of variables (called principal components) through this method. If we use the random variable $X = (X_1, X_2, \ldots, X_p)^T$ to describe the research objects, then we can get the linear transformations of X with the principal component analysis:

$$\begin{cases} Z_1 = \mu_{11}X_1 + \mu_{12}X_2 + \ldots + \mu_{1p}X_p \\ Z_2 = \mu_{21}X_1 + \mu_{22}X_2 + \ldots + \mu_{2p}X_p \\ \quad\quad \ldots\ldots\ldots \\ Z_q = \mu_{q1}X_1 + \mu_{q2}X_2 + \ldots + \mu_{qp}X_p \end{cases}$$

In the linear transformations of X, Z_1, Z_2,..., Z_q are the principal components. μ_{ij} ($i = 1, 2, \ldots, q, j = 1, 2, \ldots, p$) is the coefficient of the principal components (see Jolliffe, 2002). With the SPSS software, principal component analysis is used on the dimensionless data of the index system. Then, we can get the coefficient matrix of the principal component score. The result is given in Table 5.

Table 5 Coefficient matrix of principal component score

Indexes	*The coefficient of principal component*		
	1	*2*	*3*
Non-performing loan ratio (X_{11})	–0.173	–0.112	0.083
Estimated loan loss ratio (X_{12})	–0.157	0.053	0.220
Ratio of the largest single loan (X_{15})	0.047	0.423	0.041
Ratio of 10 largest loans (X_{16})	0.153	0.238	0.024
Risk-sensitive ratio of interest rate (X_{21})	–0.045	0.330	0.274
Accumulated foreign exchange exposure positions ratio (X_{22})	0.156	–0.161	0.161
The volatility of non-interest expenditure (X_{31})	0.153	–0.153	0.187
Liquidity ratio (X_{42})	–0.020	–0.046	0.442
Loan-deposit ratio (X_{43})	0.171	0.096	–0.121
Inter-bank borrowings ratio (X_{44})	0.150	–0.139	0.208

Table 5 is the result of the principal component analysis method. From Table 5, we can get three principal components. Let Z stand for comprehensive principal component. According to the coefficient matrix of the principal component score, we can get the linear combination between the principal components and the early risk warning indexes. The coefficients of the principal components are the contribution rate of each index to the principal components. Based on the contribution rate of each index to the principal components, we can get equations (1)–(4):

$$\begin{aligned} Z_1 = &-0.173X_{11} - 0.157X_{12} + 0.047X_{15} \\ &+ 0.153X_{16} - 0.045X_{21} + 0.156X_{22} \\ &+ 0.153X_{31} - 0.02X_{42} + 0.171X_{43} + 0.15X_{44} \end{aligned} \tag{1}$$

$$\begin{aligned} Z_2 = &-0.112X_{11} + 0.053X_{12} + 0.423X_{15} \\ &+ 0.238X_{16} + 0.33X_{21} - 0.161X_{22} \\ &- 0.153X_{31} - 0.046X_{42} + 0.096X_{43} - 0.139X_{44} \end{aligned} \tag{2}$$

$$\begin{aligned} Z_3 = &0.083X_{11} + 0.22X_{12} + 0.041X_{15} \\ &+ 0.024X_{16} + 0.274X_{21} + 0.161X_{22} \\ &+ 0.187X_{31} + 0.442X_{42} - 0.121X_{43} + 0.208X_{44} \end{aligned} \tag{3}$$

$$Z = 0.549Z_1 + 0.2274Z_2 + 0.2236Z_3 \tag{4}$$

Substituting equations (1)–(3) into equation (4), we have equation (5):

$$\begin{aligned} Z = &-0.102X_{11} - 0.025X_{12} + 0.131X_{15} \\ &+ 0.143X_{16} + 0.112X_{21} + 0.085X_{22} \\ &+ 0.091X_{31} + 0.077X_{42} - 0.089X_{43} + 0.097X_{44} \end{aligned} \tag{5}$$

Equation (5) is the equation of the linear relationship between comprehensive principal component and the early risk warning indexes. That is the index contribution degree to

the comprehensive principal component. The coefficient in equation (5) is the weight of each index. For comparing conveniently, the coefficients of equation (5) are normalised. The normalised procedure is as follows:

1 Add up all the absolute values of the coefficients. $s = \sum_{i=1}^{4} \sum_{j} |a_{ij}|$, where a_{ij} is the coefficient of the indexes in equation (5).

2 Calculate separately the absolute value sum of each index's coefficient in the first layer. s_i, $i = 1, 2, 3, 4$.

- Weight of first-layer index: $w_i = s_i / s$, $i = 1, 2, 3, 4$.
- Weight of second-layer index: $w_{ij} = |a_{ij}| / s_i$.

We get the normalised indexes weights of the integrated risk in Table 6. Table 6 presents the normalised indexes weights of different layers' indexes.

Table 6 Normalised indexes weights of integrated risk

First-layer index	*Weight*	*Second-layer index*	*Weight*
Credit risk (X_1)	0.4215	Non-performing loan ratio (X_{11})	0.2538
		Estimated loan loss ratio (X_{12})	0.0621
		Ratio of the largest single loan (X_{15})	0.3267
		Ratio of 10 largest loans (X_{16})	0.3574
Market risk (X_2)	0.2065	Risk-sensitive ratio of interest rate (X_{21})	0.5676
		Accumulated foreign exchange exposure positions ratio (X_{22})	0.4324
Operational risk (X_3)	0.0956	The volatility of non-interest expenditure (X_{31})	1.0000
Liquidity risk (X_4)	0.2764	Liquidity ratio (X_{42})	0.2940
		Loan-deposit ratio (X_{43})	0.3367
		Inter-bank borrowings ratio (X_{44})	0.3693

In this table, we can see that the weight of credit risk (X_1) is the biggest and the weight of operational risk is the smallest. The ratios of ten largest loans (X_{16}) are the most important variables in the credit risk. The weight of X_{21} is higher than that of X_{22}. The weight of inter-bank borrowings ratio (X_{44}) is higher than that of the others.

3.4 Elements sets

Elements sets include index set, weight set, evaluation set and subjection degree matrix. These sets are given by vectors (see Chi et al., 2009). We use these sets to calculate the early warning factors of different risks and integrated risk.

- Index set: The first-layer index set:

$$X = (X_1, X_2, X_3, X_4) \tag{6}$$

- The second-layer index set:

$$X_1 = (X_{11}, X_{12}, X_{15}, X_{16}) \tag{7}$$

$$X_2 = (X_{21}, X_{22}) \tag{8}$$

$$X_3 = (X_{31}) \tag{9}$$

$$X_4 = (X_{42}, X_{43}, X_{44}) \tag{10}$$

- Weight set: According to Table 6, we can get equations (11)–(15). The first-layer index weight set:

$$w = (w_1, w_2, w_3, w_4) = (0.42,\ 0.21,\ 0.10,\ 0.28) \tag{11}$$

- The second-layer index weight set:

$$w_1 = (w_{11}, w_{12}, w_{15}, w_{16}) = (0.25,\ 0.06,\ 0.33,\ 0.36) \tag{12}$$

$$w_2 = (w_{21}, w_{22}) = (0.57,\ 0.43) \tag{13}$$

$$w_3 = (w_{31}) = (1) \tag{14}$$

$$w_4 = (w_{42}, w_{43}, w_{44}) = (0.29,\ 0.34,\ 0.37) \tag{15}$$

- Evaluation set:

$$V_m = (V_1,\ V_2, V_3, V_4) \tag{16}$$

V_m represents the different grade of risk. '1' means non-risk, '2' light risk, '3' middle risk and '4' serious risk.

- Subjection matrix: The first-layer index subjection:

$$\text{Matrix } R = (R_1, R_2, R_3, R_4)^{\mathrm{T}} \tag{17}$$

- The second-layer index subjection degree matrix:

$$R_1 = (r_{11}, r_{12}, r_{15}, r_{16})^{\mathrm{T}} \tag{18}$$

$$R_2 = (r_{21}, r_{22})^{\mathrm{T}} \tag{19}$$

$$R_3 = (r_{31})^{\mathrm{T}} \tag{20}$$

$$R_4 = (r_{42}, r_{43}, r_{44})^{\mathrm{T}} \tag{21}$$

The subjection degree of forward index is calculated by

$$r_{ij}(V_1) = \begin{cases} 0, & v_0 \le x \le v_2 \\ \dfrac{x - v_2}{v_3 - v_2}, & v_2 \le x \le v_3 \\ 1, & v_3 \le x \le v_4 \end{cases} \tag{22}$$

$$r_{ij}(V_2)=\begin{cases}0, & v_0 \le x \le v_2 \\ \dfrac{v_3-x}{v_3-v_2}, & v_2 \le x \le v_3 \\ 0, & v_3 \le x \le v_4\end{cases} \tag{23}$$

$$r_{ij}(V_3)=\begin{cases}0, & v_0 \le x \le v_1 \\ \dfrac{x-v_1}{v_2-v_1}, & v_1 \le x \le v_2 \\ 0, & v_0 \le x \le v_1\end{cases} \tag{24}$$

$$r_{ij}(V_4)=\begin{cases}1, & v_0 \le x \le v_1 \\ \dfrac{v_2-x}{v_2-v_1}, & v_1 \le x \le v_2 \\ 0, & v_2 \le x \le v_4\end{cases} \tag{25}$$

The subjection degree of backward index is calculated by

$$r_{ij}(V_1)=\begin{cases}1, & v_0 \le x \le v_1 \\ \dfrac{v_2-x}{v_2-v_1}, & v_1 \le x \le v_2 \\ 0, & v_2 \le x \le v_4\end{cases} \tag{26}$$

$$r_{ij}(V_2)=\begin{cases}0, & v_0 \le x \le v_1 \\ \dfrac{x-v_1}{v_2-v_1}, & v_1 \le x \le v_2 \\ 0, & v_2 \le x \le v_4\end{cases} \tag{27}$$

$$r_{ij}(V_3)=\begin{cases}0, & v_0 \le x \le v_2 \\ \dfrac{v_3-x}{v_3-v_2}, & v_2 \le x \le v_3 \\ 0, & v_3 \le x \le v_4\end{cases} \tag{28}$$

$$r_{ij}(V_4)=\begin{cases}0, & v_0 \le x \le v_2 \\ \dfrac{x-v_2}{v_3-v_2}, & v_2 \le x \le v_3 \\ 1, & v_3 \le x \le v_4\end{cases} \tag{29}$$

In the above, x means X_{ij} and v_i (i = 0, 1, 2, 3, 4) means the boundary value of each risk grade according to the limit in Table 1. The definite v_i (i = 0, 1, 2, 3, 4) is given by

Table 7. V_i ($i = 0, 1, 2, 3, 4$) means the degree of different risks. According to the limit in Table 1, 'risk evaluation system of commercial banks (interim)' and 'commercial bank regulatory risk core index (interim)' (China Banking Regulatory Commission, 2004, 2005), the boundary values of each risk grade are presented in Table 7.

Table 7 The boundary value of each risk grades

Index	*Non-risk* (V_1)	*Light risk* (V_2)	*Middle risk* (V_3)	*Serious risk* (V_4)
Non-performing loan ratio (X_{11})	≤5	(5, 8)	(8, 10)	≥10
Estimated loan loss ratio (X_{12})	≤3	(3, 6)	(6, 15)	≥15
Ratio of the largest single loan (X_{15})	≤9	(9, 12)	(12, 15)	≥15
Ratio of 10 largest loans (X_{16})	≤45	(45, 55)	(55, 65)	≥65
Risk-sensitive ratio of interest rate (X_{21})	(1, 1.05)	(1.05, 1.1)	(1.1, 1.15)	(1.15, 1.2)
Accumulated foreign exchange exposure positions ratio (X_{22})	≤18	(18, 25)	(25, 40)	≥40
The volatility of non-interest expenditure (X_{31})	≤40	(40, 50)	(50, 60)	≥60
Liquidity ratio (X_{42})	≥30	(20, 30)	(15, 20)	≤15
Loan-deposit ratio (X_{43})	≤70	(70, 80)	(80, 85)	≥85
Inter-bank borrowings ratio (X_{44})	≤4	(4, 6)	(6, 8)	≥8

In the elements set, r means the subjection degree between index and risk. The nearer r_{ij} closes to 1, the higher degree x belongs to V. The nearer r_{ij} closes to 0, the lower degree x belongs to V.

Let

$$B_1 = w_1 * R_1 \tag{30}$$

$$B_2 = w_2 * R_2 \tag{31}$$

$$B_3 = w_3 * R_3 \tag{32}$$

$$B_4 = w_4 * R_4 \tag{33}$$

and $\lambda = (1, 2, 3, 4)$. Then, we can get the early warning factors of different risks and integrated risks:

Early warning factor of credit risk:

$$\beta_1 = \lambda * B_1^{\mathrm{T}} \tag{34}$$

Early warning factor of market risk:

$$\beta_2 = \lambda * B_2^{\mathrm{T}} \tag{35}$$

Early warning factor of operational risk:

$$\beta_3 = \lambda * B_3^{\mathrm{T}} \tag{36}$$

Early warning factor of liquidity risk:

$$\beta_4 = \lambda * B_4^{\mathrm{T}} \tag{37}$$

Early warning factor of integrated risk:

$$\beta = w*(\beta_1, \beta_2, \beta_3, \beta_4)^{\mathrm{T}} \tag{38}$$

4 Empirical analysis

Here, empirical analysis means that we will calculate the integrated risk of four Chinese commercial banks with fuzzy comprehensive appraisal method. According to the above calculated method, we can get the warning factors of different risks in ICBC firstly.

Based on the 2008 data of Chinese commercial banks in Table A1 and the calculated method of the indexes subjection degree expressed by equations (22)–(29), we can get the subjection degree of every risk.

Credit risk subjection degree:

$$R_1 = (r_{11}, r_{12}, r_{15}, r_{16})^{\mathrm{T}} = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{pmatrix}$$

Market risk subjection degree:

$$R_2 = (r_{21}, r_{22})^{\mathrm{T}} = \begin{pmatrix} 0.54 & 0.46 & 0 & 0 \\ 1.00 & 0.00 & 0 & 0 \end{pmatrix}$$

Operational risk subjection degree:

$$R_3 = (r_{31})^{\mathrm{T}} = (0.06,\ 0.94,\ 0,\ 0)$$

Liquidity risk subjection degree:

$$R_4 = (r_{42}, r_{43}, r_{44})^{\mathrm{T}} = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{pmatrix}$$

Then we put the weight and subjection degree of each risk into equations (30)–(33):

$$B_1 = w_1 * R_1 = (0.25,\ 0.06,\ 0.33,\ 0.36) * \begin{pmatrix} 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{pmatrix} = (1,\ 0,\ 0,\ 0)$$

$$B_2 = w_2 * R_2 = (0.57,\ 0.43) * \begin{pmatrix} 0.54 & 0.46 & 0 & 0 \\ 1.00 & 0.00 & 0 & 0 \end{pmatrix} = (0.74,\ 0.26,\ 0,\ 0)$$

$$B_3 = w_3 * R_3 = 1 * (0.06,\ 0.94,\ 0,\ 0) = (0.06,\ 0.94,\ 0,\ 0)$$

$$B_4 = w_4 * R_4 = (0.29,\ 0.34,\ 0.37) * \begin{pmatrix} 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{pmatrix} = (1,\ 0,\ 0,\ 0)$$

According to equations (34)–(38), we calculate the early warning factor of each risk.

Early warning factor of credit risk:

$$\beta_1 = \lambda * B_1^{\mathrm{T}} = (1,\ 2,\ 3,\ 4) * (1,\ 0,\ 0,\ 0)^{\mathrm{T}} = 1$$

Early warning factor of market risk:

$$\beta_2 = \lambda * B_2^{\mathrm{T}} = (1,\ 2,\ 3,\ 4) * (0.74,\ 0.26,\ 0,\ 0)^{\mathrm{T}} = 1.2622$$

Early warning factor of operational risk:

$$\beta_3 = \lambda * B_3^{\mathrm{T}} = (1,\ 2,\ 3,\ 4) * (0.06,\ 0.94,\ 0,\ 0)^{\mathrm{T}} = 1.944$$

Early warning factor of liquidity risk:

$$\beta_4 = \lambda * B_4^{\mathrm{T}} = (1,\ 2,\ 3,\ 4) * (1,\ 0,\ 0,\ 0)^{\mathrm{T}} = 1$$

The early warning factor of integrated risk:

$$\beta = w * (\beta_1, \beta_2, \beta_3, \beta_4)^{\mathrm{T}} = (0.42,\ 0.21,\ 0.10,\ 0.28) * (1,\ 1.26,\ 1.94,\ 1)^{\mathrm{T}} = 1.1443$$

In the same way, we can get the early warning factor of risk in the other three commercial banks. The values are given in Table 8. In the table, β_i (i = 1, 2, 3, 4) means the warning factors of different risks and β' means the mean value of these four risk warning factors. β is the warning factor of integrated risk. The bigger the value of β_i, β' or β is, the higher the risk is. Table 8 presents the calculated results among these Chinese commercial banks.

Table 8 Early warning factor of risk in banks

	ICBC	*CCB*	*SPDB*	*CMB*
Credit risk (β_1)	1.0000	1.0000	1.0000	1.0000
Market risk (β_2)	1.2622	1.0000	1.4756	1.0000
Operational risk (β_3)	1.9440	1.0000	3.2550	3.2980
Liquidity risk (β_4)	1.0000	1.2793	1.1135	1.0960
Mean value (β')	1.3016	1.0698	1.7110	1.5985
Integrated risk (β)	1.1443	1.0577	1.3452	1.2462

From Table 8, we can see the risk degrees of CCB and ICBC are lower than those of SPDB and CMB, especially β_3. It indicates that SPDB and CMB faced bigger operational risks in 2008. In Table 8, β' means the mean value of these four risk warning factors ignoring the correlations between risks and β is the warning factors of the integrated risk

considering the correlations between risks. From Table 8, we can also see that β' is higher than β in all Chinese commercial banks. This means, if we ignore the correlations between risks, the whole risk will be overestimated. Then we can draw a conclusion that the result of many kinds of risks studied as a whole is better than simply the sum of all the risks. Without considering the correlation between these risks, the simple linear weighted sum of these risks will expand the integrated risk.

5 Conclusion

Based on the structure of fuzzy comprehensive appraisal method, this paper calculated the integrated risk warning factors of four Chinese commercial banks. The paper also tried to measure the integrated risk including operational risk, even though the exact data for operational risk are not obtainable due to the privacy of banks.

In Table 8, the risk degrees of CCB and ICBC are lower than those of SPDB and CMB. In addition, from this form, we can see that the mean value of the four risks ignoring the correlations will be higher than the integrated risk of the four risks. This means the whole risk will be overestimated. This is not beneficial to the allocative efficiency of financial resources.

Because of the correlation between different kinds of risks, we should study these kinds of risks as a whole. Without considering the influence of correlation, future research results can easily depart from reality. For this reason, we should consider the correlation among different risks when we study the risks faced by commercial banks.

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Appendix A

Table A1 The original data of the four Chinese commercial banks in 2008. The limits are according to the requirements of 'risk evaluation system of commercial banks (interim)' and 'commercial bank regulatory risk core index (interim)' (China Banking Regulatory Commission, 2004, 2005)

	ICBC	*CCB*	*SPDB*	*CMB*	*Limit*
Non-performing loan ratio (X_{11})	2.29	2.21	1.21	1.11	<5%
Estimated loan loss ratio (X_{12})	2.0866	2.0226	1.5151	1.7078	<3%
Mortgage loan ratio (X_{13})	51.70	54.06	45.46	37.81	>25%
NPL provisioning coverage ratio (X_{14})	130.15	131.58	192.49	223.29	>75%
Ratio of the largest single loan (X_{15})	2.90	3.68	2.96	5.31	<10%
Ratio of 10 largest loans (X_{16})	20.40	20.72	24.3	32.14	<50%
Risk-sensitive ratio of interest rate (X_{21})	1.0731	1.0746	1.0329	1.0919	1 best
Accumulated foreign exchange exposure positions ratio (X_{22})	8.77	3.09	14.34	11.53	<20%
The volatility of non-interest expenditure (X_{31})	49.44	32.01	52.98	52.55	<50%
Reserve requirement ratio (X_{41})	14.5	14.5	13.5	13.5	>13.5%
Liquidity ratio (X_{42})	33.3	52.74	55.24	43.14	>25%
Loan-deposit ratio (X_{43})	56.4	57.77	72.85	74.17	<75%
Inter-bank borrowings ratio (X_{44})	0.65	0.08	1.12	3.52	<4%