Proceedings of Business and Economic Studies, 2024, Volume 7, Issue 1
http://ojs.bbwpublisher.com/index.php/PBES
Online ISSN: 2209-265X
Print ISSN: 2209-2641

Systematic Risk Analysis of Listed Financial Institutions from the Perspective of Complex Network

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Abstract: Based on the complex network theory, this paper studies the systemic financial risks in China's financial market. According to the industry classification of the China Securities Regulatory Commission in 2012, the daily closing prices of 45 listed financial institutions are collected and the daily return rates of each financial institution are measured according to the logarithmic return rate calculation formula. In this paper, the risk spillover value ΔCoVaR is used to measure the contribution degree of each financial institution to systemic risk. Finally, the relationship between the risk spillover value ΔCoVaR and the node topology index of the risk transmission network is investigated by using a regression model, and some policy suggestions are put forward based on the regression results.

Keywords: Complex network; Systemic risk; GARCH model

Online publication: February 25, 2024

1. Introduction

With the continuous development of China, the horizontal development of the economy is more extensive, the vertical development is deepening, the domestic economy of various industries and sectors of the business interaction overlap, and the supply chain before and after the link is more closely linked, and the economic development enters into the "new normal." Together with the deep adjustment of the global economy and the deep-rooted economic contradictions accumulated in China for a long time, which resulted in the intertwining and folding of domestic and foreign dividing lines, the financial risks gathered rapidly. With the consequences of the prediction of the gradual deterioration of the U.S. subprime crisis in 2007 as a trigger, the impact of it ultimately spread to the entire global market, which further led to the outbreak of the global skills crisis [1]. Although the consequences of the financial crisis have gradually faded in recent years, there are serious obstacles to economic recovery, with different countries experiencing different economic and financial crises, serious damage to the real economy, difficulties in the transformation and upgrading of traditional industries, and the need for emerging industries to further stabilize their market position. Systemic risk, also known as non-diversifiable risk, refers to the risk that all institutions in the entire market suffer economic losses at the same time due to the influence and changes of multiple factors. Although financial institutions, as participants in the market, have a certain impact on the market due to their economic activities, they are not sufficient to reduce systemic risk. Systemic risk is caused by a combination of factors and cannot be eliminated by diversification. Regulators and scholars around the world have gradually realized the importance of systemic risk, and have shifted their research direction from individual or certain financial institutions to the overall study of macrofinance, while the concept of international financial regulation has gradually shifted from micro-financial regulation to macro-financial regulation.

As far as the current development of the domestic economy is concerned, the supervision of financial institutions in China has mainly focused on the supervision of individual large-scale institutions or certain important industries, especially before the outbreak of the financial crisis, and China has not paid enough attention to the chain reaction of risks triggered by the linkage of financial institutions and industries [2]. However, with the increasing degree of social and financial liberalization in China and the accelerated advancement of economic globalization, various resources are integrated, various financial industries penetrate each other, and financial institutions gradually form a large network, i.e., the network of financial institutions. In the report of the 19th National Congress, it was repeatedly emphasized the need to continuously promote the deepening of the reform of the financial system, establish a sound financial regulatory system, and prevent and resolve systemic financial risks [3]. Therefore, for preventing and resolving systemic financial risks, measuring and analyzing financial risks from the perspective of the financial risk network as a whole, and integrating complex network theory to analyze the structure of the financial risk network can help us better understand systemic financial risks, explore the financial institutions that are more important to the financial system, study the financial risk propagation paths, and better target the systemic financial risks to provide a better understanding of systemic financial risks. It is of great significance to prevent and resolve systemic financial risks.

2. Systemic risk measurement of listed financial institutions in China

2.1. Systemic financial risk in a complex network perspective

Complex networks are networks with some or all of the properties of self-organization, self-similarity, attractors, small worlds, and scale-free. The main research includes the formation mechanism, topological properties, evolutionary laws, and stability of the structure of the network. The node level includes degree, median centrality, clustering coefficient, global efficiency, and average path length. With the continuous development of the financial industry and the continuous improvement of the financial system, financial institutions have gradually blurred the transaction barriers between each other, increased the relevance of financial transactions, and the chain reaction of financial risk is more and more intense, leading to a “too big to fail” problem in financial institutions, so we introduce the complex network theory into the study of systemic financial risk. From the perspective of a financial network, it is reasonable to examine the network topology and contagiousness of financial institutions regarding the stability of the financial market and the triggering factors of systemic financial risks, to prevent and resolve systemic financial risks. In this paper, the correlation coefficient matrix between financial institutions is used to construct the risk propagation network, and then the topological properties of the risk propagation network are analyzed by using the indicators of complex networks, and the node characteristics are discussed to study the stability of the financial system.

2.2. Sample selection and data source

Based on the industry classification of the Securities and Futures Commission (SFC), this paper collects the daily closing prices of the stocks of 45 listed financial institutions from January 1, 2012, to December 31, 2021, for data analysis. This paper is mainly based on the following considerations: firstly, the sample coverage is wide enough to be representative of the financial system; secondly, the period is long enough to minimize the chance generated by the time series; thirdly, the cut-off date is close to the present time, which is scientifically sound for guiding the reality; and lastly, the sample of the collected data covers a wide enough range of industries and has a complete distribution of the industries. Divided according to the 2012 SEC "Industry Classification of Listed Companies," this paper selected 45 listed financial institutions [4].

Based on the given closing prices of the stocks of the financial institutions, the return of each financial institution is calculated, and the daily return of the financial institutions is tabulated by the first-order logarithmic difference of the closing prices of the stocks concerning the definition of Ding and Wu in the paper [5]:

$$R_i = 100 \times \ln\left(\frac{P_t}{P_{t-1}}\right) \qquad (1)$$

where R_i is the rate of return of the listed financial institution and P_t is the closing price on day t.

The rate of return of the financial system is a description of the overall return situation in the financial system. However, due to the importance of each financial institution in the financial system being different, the degree of return impact should also have different weights. This paper defines the rate of return of the financial system through the aforementioned table, gives the 45 listed financial institutions the average daily return weighted to get, and the calculation formula is:

$$R_t^s = \sum_i \frac{w_t^i}{\sum_i w_t^i} R_t^i \qquad (2)$$

where w is the number of the outstanding share capital of each financial institution and R is the stock return of each financial institution.

All data used in this paper were obtained from Wind Information and Csmar Economic and Financial Research Database.

2.3. Metrics of ΔCoVaR values

A GARCH (1,1) model was constructed for the Bank of China, for which the regression equation GARCH (1,1) takes the form of $GARCH = C(1)+[C(2)\times RESID(-1)^2]+[C(3)\times GARCH(-1)]$, and the parameter estimation is shown in **Table 1**.

Table 1. Parameter estimation of the GARCH model for the Bank of China

Variable	Coefficient	Std. error	z-Statistic	Prob.
Variance equation				
C	0.064801	0.003103	20.88051	0.0000
$RESID(-1)^2$	0.139452	0.007227	19.29672	0.0000
GARCH(-1)	0.832088	0.005968	139.4182	0.0000
R-squared	0.000000	Mean dependent var	-3.16E-07	
Adjusted R-squared	0.000412	S.D. dependent var	1.407480	
S.E. of regression	1.407190	Akaike info criterion	3.033198	
Sum squared resid	4811.847	Schwarz criterion	3.040353	
Log-likelihood	-3682.335	Hannan-Quinn criteria	3.035799	
Durbin-Watson stat	2.014928			

This regression equation is significant from the *P* value in **Table 1** and the resulting equation is $GARCH = 0.064801 + [0.139452 \times RESID(-1)^2] + [0.832088 \times GARCH(-1)]$. This mean value equation is then used to generate the predicted sequence, which is substituted into the equation:

$$VaR_t^{zg} = rzg_t - q(0.05)\delta_t \tag{3}$$

where rzg_t is the mean of one step forward in forecasting and δ_t is the conditional variance of one step forward in forecasting. The mean equation for the return of the financial system is constructed based on a similar process: $GARCH = 0.020859 + [0.069372 \times RESID(-1)^2] + [0.924494 \times GARCH(-1)]$.

Similarly, this mean value equation is used to make a predicted sequence and then substitute it into the equation:

$$CoVaR_t^{zg} = rsys_t - q(0.05)\delta_t^{sys} \tag{4}$$

This leads to the corresponding CoVaR value of the Bank of China of -0.157025. The data of 45 listed financial institutions are substituted into this model, which leads to the CoVaR value of them. The contribution of each financial institution to the systemic risk is further calculated as the ΔCoVaR.

3. Risk transmission networks and systemic financial risk

3.1. Selection of regression indicators

To investigate the impact of network topology on systemic financial risk, this paper fits regressions to the values of systemic risk indicators of each financial institution and the values of indicators of each complex network topology, to measure the degree of impact. In this paper, CoVaR is used as an explanatory variable, and ΔCoVaR is used as a measure of the degree of contribution of each financial institution to systemic risk. This paper selects the influence factors from the network structure parameters and the financial data of financial institutions by referring to the previous study for the measure of systemic risk influence factors and the selection of regression equation indicators [6], in which the network structure parameters include financial institutions' node degree, intermediary centrality Betweenness_Centrality (B_C), Closeness_Centrality (C_C), and Average Shortest Path Length (ASL). The company's financial data include Return on Equity (ROE) and Equity Multiplier (M). The above indicators are considered in the regression equation.

3.2 Descriptive statistics

For the selection of regression variables, descriptive statistics for each regressor are shown in **Table 2**:

Table 2. Descriptive statistics of major variables

Variable name	Mean value	Maximum value	Minimum value	Standard deviation	Skewness	Kurtosis
Delta_CoVaR	-7.1145	-1.8826	-13.7025	3.2526	-0.1872	2.0656
Degree	1.9556	4.0000	1.0000	0.8779	0.6972	2.8663
Betweenness_Centrality	189.7556	495.0000	0.0000	191.2723	0.3724	1.4394
Closeness_Centrality	1.1491	1.3915	0.8204	0.1225	-0.2684	2.7342
Short_Path	0.8800	1.2189	0.7186	0.0997	0.9209	4.2163
ROE	0.0208	0.1184	-0.5882	0.1440	-3.4389	14.1455
M	7.6556	14.3925	1.0350	4.1441	0.0849	1.4721

According to the information of the indicators in **Table 2**, it can be seen that the maximum value of ΔCoVaR is -1.8826, and the minimum value is -13.7025, with a large difference in the extreme value, which indicates that in the financial market system consisting of the 45 listed financial institutions, each financial institution does not have the same degree of contribution to the systemic risk, i.e., there is a significant difference in the risk spillover effect, and each financial institution's position in the financial market is unequal. This is in line with the actual situation of the market. From the value of ΔCoVaR, each financial institution hurts systemic risk, i.e., the business situation of each financial institution has a downturn phenomenon for the whole financial system, but generally speaking, it exists in a relatively small range. From the value of each index of the complex network, each financial institution shows strong connectivity and high tightness, indicating that the correlation between each financial institution is relatively close, and the way of financial risk propagation is dominated by conduction rather than diffusion, i.e., the financial institutions influence the whole financial market by influencing other financial institutions. The global efficiency Elogb value is 0.1936, indicating that the overall risk propagation efficiency is relatively low. In addition, the financial data of each financial institution shows that the average return on assets of each financial institution has a maximum value of 0.1184 and a minimum value of -0.5882, which is within a reasonable range, but because of the different composition of the assets of each financial institution, the financial position of each financial institution is not equal to the status of the systemic financial risk.

3.3. Regression model building and analysis

In this paper, panel data were used to conduct a regression analysis of ΔCoVaR, the financial risk spillover value of this risk propagation network, to study the degree of influence of each topological indicator on systemic risk, and the regression model set up in this paper is:

$$\Delta CoVaR = \alpha_i + \beta_2 Degree_i + \beta_3 B\_C + \beta_4 C\_C + \beta_5 ASL + \beta_6 ROE + \beta_7 M + \omega$$

where $\Delta CoVaR$ represents the risk spillover value, *Degree* represents the node degree of each financial institution, *B_C* represents the value of median centrality of each financial institution, *C_C* represents the value of tight centrality of the financial institutions, *ASL* represents the average shortest path of the financial institutions, *ROE* represents the return on equity of the financial institutions, *M* represents the equity multiplier of the financial institutions, α_i represents the constant term, and ε represents the error term. The regression results are shown in **Table 3**.

Table 3. ΔCoVaR regression model parameter estimation

Variable	Coefficient	Std. error	t-Statistic	Prob.
C	-110.8467	41.99853	-2.639300	0.0120
DEGREE	-1.085585	0.545263	1.156960	0.0761
B_C	-0.000775	0.003078	-0.251862	0.7025
C_C	-48.36172	19.20024	2.518808	0.0161
ASL	50.97295	22.73112	2.242430	0.0308
ROE	4.454046	2.529295	1.760983	0.0863
M	0.417226	0.090791	4.595467	0.0000

R-squared	0.578187	Mean dependent var	-7.114511
Adjusted R-squared	0.511585	S.D. dependent var	3.252631
S.E. of regression	2.273157	Akaike info criterion	4.622251
Sum squared resid	196.3552	Schwarz criterion	4.903287
Log-likelihood	-97.00064	Hannan-Quinn criteria.	4.727018
F-statistic	8.681216	Durbin-Watson stat	2.082867
Prob (F-statistic)		0.000006	

According to the estimation results of the regression model, the node degree (Degree) of financial institutions, the tight centrality C_C, and the average shortest path length (ASL) have a significant effect on the ΔCoVaR of each financial institution, while the median centrality B_C does not have a significant effect in relative terms. Considering that the negative value of ΔCoVaR represents the impact of financial institutions on other financial institutions and the financial market as a whole, the smaller the value of ΔCoVaR is, the greater the intensity of the impact of the financial institution is, the greater the potential for loss is, and the higher the relative position of the financial institution in the financial system is. For the analysis of financial indicators of financial institutions, it seems that the return on assets ROE and equity multiplier M have a significant effect on the ΔCoVaR, and the return on assets and equity multiplier are the direct factors that can affect the volatility of the rate of return of financial institutions, in line with the economic reality.

4. Conclusions and policy recommendations

4.1. Conclusions

This paper investigates the systemic financial risk in China's financial market based on the complex network theory, collects the closing prices of 45 listed financial institutions, conducts step-by-step modeling and data analysis, and measures the risk spillover value of financial institutions by using the GARCH model, which is used to measure the degree of contribution of each financial institution to the systemic risk. Finally, a regression model was used to examine the relationship between the ΔCoVaR and the node topology indicators of the risk propagation network.

In the study, it is found that in the ranking of the contribution to the value of ΔCoVaR, most real estate companies are in the front, some securities companies are in the second place, trust institutions and insurance institutions are in the middle of the ranking, while the banking industry is more stable. This paper suggests that it may be due to the restrictions on the real estate market in recent years, which to a certain extent affects the real estate company's earnings volatility, so its earnings appear unstable. As real estate market regulations strengthen, residents' attitudes toward real estate consumption gradually shift. Consequently, the pace of real estate market development seems to slow down, leading to fluctuations in earnings for real estate companies. The fluctuation of the real estate company's earnings also further aggravates the systemic risk of triggering, so a balanced approach is required to control and maintain the stability of the real estate market. The banking system is more backward. Considering that the data for measuring systemic risk in this paper are mainly stock prices, the riskiness of the banking system is mainly reflected in the capital supply chain, China has always been a bank-dominated financial system, and the banks and other submarkets have become increasingly close to each other, the spread of risk in the banking system mainly affects the financial system as a whole by affecting other submarkets, which also affects the systemic risk spillover of the banking sector to a certain extent.

The influence coefficients of the node degree distribution, meso-centrality, and tight centrality on the ΔCoVaR are negative, indicating that when the values of the degree distribution, meso-centrality, and tight centrality are larger, the intensity of the influence of the financial institutions is greater, and the absolute value of the ΔCoVaR is greater. Simultaneously, referring to the significance of the two indexes in the structure of the network, the larger the two indexes are, the greater the intensity of the node is, and the higher the importance of this node to the network is. The ASL is directly proportional to the ΔCoVaR, indicating that when the average path is longer, the value of the ΔCoVaR is larger, and the absolute value is smaller, i.e., when the average path of financial institutions' risk propagation is longer, the impact of financial institutions on the financial system as a whole and systemic risk is weaker. Financial institutions are located in the more marginal position in the risk propagation network. From the perspective of the impact coefficient, the larger the return on assets and equity multiplier is, the larger the size of the financial institution is, the better the investment effect is, and the more corresponding shareholders' dividends are. On the other hand, there is also a relatively high liquidity risk, and the financial institutions are in a more central position for the risk propagation network.

4.2. Policy recommendations

Firstly, based on this paper's measure of the contribution to systemic risk, most real estate firms are at the top of the list, some securities firms are at the bottom, trusts, and insurance institutions are in the middle of the list, and the banking sector is stable. The real estate market should strictly control its business and reduce the volatility of the real estate market through a variety of financial regulatory means. Especially in recent years, under the impact of the new crown epidemic, small and medium-sized real estate enterprises and even various types of small and medium-sized financial institutions in the industry have had a large-scale impact, so how to save them and the business of the real estate market and reasonably control the real estate market volatility is an important means of preventing and resolving systemic risk.

Secondly, because the banking and securities industries are at the core of the financial risk transmission network, financial market supervision should strengthen the supervision of indirect finance such as investment and financing. Particularly, it is necessary to guard all kinds of large-scale financial institutions, including the banking and securities industries, as the first line of defense to prevent systemic risks and intervene promptly, and split and reorganize financial institutions caught in the predicament of being "too big to fail." It is also necessary to protect the interests of depositors and investors and promote the smooth operation of the economy.

Finally, concerning the impact of node degree, average path length, and tight centrality on the ΔCoVaR of the financial risk propagation network, a complete systematic risk assessment mechanism should be established, and the network topology indicators mentioned above should be taken into account as the factors affecting the assessment results, which will help to provide timely and early warnings and prevent and mitigate systematic risks.

Disclosure statement

The author declares no conflict of interest.

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