Research on the Correlation of China's Financial Systemic Risk Based on Granger Causality Test

Shiru Lan[1], Jin Li[1(✉)], Yanxin Wang[2(✉)], and JiaoTian[3]

[1] Hunan Sany Polytechnic College, Langli Industrial Park, Changsha County, Changsha 410129, Hunan, People's Republic of China
goldliclass@163.com

[2] Chongqing University of Technology, Hongguang Road 69, Banan District, Chongqing 400054, People's Republic of China
412677263@qq.com

[3] Southwest University of Political Science and Law, No. 301, Baosheng Avenue, Yubei District, Chongqing 401120, People's Republic of China

Abstract. In this paper, the ARMA-GARCH model is constructed to estimate the heteroscedasticity, so as to eliminate the impact of non-systematic risk on the model. On this basis, the Granger causality test is carried out. Finally, this paper empirically studies the Granger causality correlation between 22 financial institutions in China. The results show that the correlation between Chinese financial institutions is gradually increasing; the Granger causality correlation within the bank is the largest, that is, the most prone to systemic risk contagion; the securities sector is the most infectious to the banking sector; the insurance sector is not only the industry that is least prone to internal risk contagion, but also the industry that is least likely to spread risk to other financial sectors.

Keywords: Systemic risk · Granger causality · ARMA-GARCH

1 Introduction

Different from the traditional method of studying the contagion of financial systemic risk, the ARMA-GARCH model is used to estimate the heteroscedasticity of the sequence to remove the influence of non-systemic risk on the model, and then the Granger causality test is used to detect the correlation between institutions and the direction of contagion. Most scholars like to use the GARCH model to estimate the heteroscedasticity of the sequence, and less use the ARMA-GARCH model. However, the default data of the standard GARCH model obeys the normal distribution, and most of the financial time series data in practice often show bias [1]. Therefore, our research on China 's financial industry here enriches this aspect.

J. Yen et al. (Eds.): ICBIS 2023, AHCS 14, pp. 677–685, 2023.
https://doi.org/10.2991/978-94-6463-198-2_70

2 ARMA-GARCH and Inspection

2.1 ARMA-GARCH Model

Because ARMA-GARCH model is composed of ARMA model and GARCH model. Since the ARMA model can eliminate the autocorrelation of the data, and the GARCH model can eliminate the conditional heteroscedasticity of the data, here we couple them to preprocess the data to prepare for the test of Granger causality.

ARMA-GARCH model [2, 3] is composed of the mean equation of ARMA (p, q) model and the conditional variance equation of GARCH (m, s) model, its basic form is as follows:

$$R_t = c + \sum_{i=1}^{p} \varphi_i R_{t-i} + \sum_{j=1}^{q} \theta_j \varepsilon_{t-j} + \varepsilon_t \tag{1}$$

$$\sigma_t^2 = \alpha_0 + \sum_{i=1}^{m} \alpha_i \varepsilon_{t-i}^2 + \sum_{j=1}^{s} \beta_j \sigma_{t-j}^2 \tag{2}$$

where, σ_t^2 is the conditional variance, $c = \mu\left(1 - \sum_{i=1}^{p} \varphi_i\right)$, $\varepsilon_t = \sigma_t \mu_t$, $i.i.d$, α_0, α_i, β_j $(i = 1, \cdots p,\ j = 1, \cdots q)$ is the parameter to be estimated, Eq. (1) is the mean equation of ARMA-GARCH model, and Eq. (2) is the conditional variance equation of ARMA-GARCH model.

Since the ARMA model is for stationary sequences, for non-stationary time series, the ARMA model cannot be directly applied, and differential processing is required to become a stationary sequence.

2.2 ADFTest

Time series is generally divided into stationary time series and non-stationary time series. If the statistical law of time series changes with time, we call it non-stationary time series, otherwise it is stationary time series. ADF is a DF test that extends DF from AR(1) to AR(p). Therefore, this paper intends to use ADF to test the stationarity of time series.

AR(p) model:

$$y_t = c + \alpha_1 y_{t-1} + \alpha_2 y_{t-2} + \cdots + \alpha_p y_{t-p} + \varepsilon_t \tag{3}$$

where, c is a constant, α_i is a constant coefficient, and ε_t is a random interference sequence with mean value of 0 and variance of σ^2. Convert Eq. (3) into difference form as follows:

$$\Delta y_t = c + \rho y_{t-1} + \sum_{i=2}^{p} \varphi_i y_{t-(i-1)} + \varepsilon_t \tag{4}$$

where $\rho = \left(\sum_{i=1}^{p} \alpha_i\right) - 1$, $\varphi_i = -\sum_{j=i+1}^{p} \alpha_j$. Then ADF test is to test hypothesis:

$$H_0 : \rho = 0;\ H_1 : \rho = 1 \tag{5}$$

where H_0 is the original hypothesis (or zero hypothesis) and H_1 is the alternative hypothesis.

The ADF test is divided into three cases. If the original assumptions of the three cases are the same, that is, the sequence contains the unit root, but the alternative assumptions of the three cases are different [1].

3 Granger Causality Test Model

In order to better investigate the characteristics of financial systemic risk contagion, this paper not only measures the contagion among financial institutions, but also studies the dynamic direction of contagion. Therefore, we mainly use correlation and causality to measure and detect the size and direction of systemic risk contagion among financial institutions. Firstly, ARMA-GARCH model is constructed to estimate heteroscedasticity to eliminate the impact of unsystemic risks on the model. On this basis, the time series of Granger causality test [4] is $R_{it} = \tilde{R}_{it} \big/ \sigma_{it}$, where σ_{it} is the heteroscedasticity estimated by ARMA-GARCH model.

Assume that R_{it} and R_{jt} are stationary time series and establish the model:

$$\begin{cases} R_{it} = \sum_{i=1}^{q} \alpha_i R_{t-i} + \sum_{j=1}^{q} \beta_j R_{t-j} + \varepsilon_{1t} \\ R_{ji} = \sum_{j=1}^{p} \gamma_j R_{t-j} + \sum_{i=1}^{p} \delta_i R_{t-i} + \varepsilon_{2t} \end{cases} \tag{6}$$

$$\begin{cases} R_{it} = \sum_{i=1}^{q} \alpha_i R_{t-i} + \varepsilon_{1t} \\ R_{jt} = \sum_{j=1}^{p} \delta_j R_{t-j} + \varepsilon_{2t} \end{cases} \tag{7}$$

where $\varepsilon_{1t}, \varepsilon_{2t}$ is white noise and uncorrelated. The value of β_j, δ_i in the equation set (6) will have the following four cases, and the corresponding Granger causality also has four cases:

(1) If $\beta_j = 0,\ \delta_i \neq 0\ (i = 1,\ 2 \cdots q,\ j = 1,\ 2 \cdots p)$ in equation set (6), R_{it} is Granger causality of R_{jt};
(2) If $\beta_j = 0,\ \delta_i = 0\ (i = 1,\ 2 \cdots q,\ j = 1,\ 2 \cdots p)$ in equation set (6), then R_{it} and R_{jt} are not Granger causality;
(3) If $\beta_j \neq 0,\ \delta_i = 0\ (i = 1,\ 2 \cdots q,\ j = 1,\ 2 \cdots p)$ in equation set (6), then R_{jt} is the Granger causality of R_{it};
(4) If $\beta_j \neq 0,\ \delta_i \neq 0 (i = 1,\ 2 \cdots q,\ j = 1,\ 2 \cdots p)$ in equation set (6), R_{it} and R_{jt} are Granger causality.

Before testing Granger causality, we first put forward two sets of assumptions:

$$\begin{matrix} H_{10} : \beta_j = 0 \\ H_{11} : \beta_j \neq 0 \end{matrix}\ j = 1,\ 2,\ \cdots q$$

$$\begin{matrix} H_{20} : \delta_j = 0 \\ H_{21} : \delta_j \neq 0 \end{matrix} \; j = 1,\ 2,\ \cdots q$$

Then record that the sum of squares of regression residuals of Eq. (6) is ESS (m, l) and ESS (q, p) respectively; Record that the sum of squares of regression residuals of Eq. (7) is ESS (l) and ESS (q) respectively, then construct statistics:

$$F_1 = \frac{\left(ESS(l) - ESS(m,\ l)\big/ m\right)}{ESS(m,\ l)\big/ (n - m - l - 1)} \sim F(m,\ n - m - l - 1) \tag{8}$$

$$F_2 = \frac{\left(ESS(p) - ESS(q,\ p)\big/ q\right)}{ESS(p,\ q)\big/ (n - p - q - 1)} \sim F(q,\ n - p - q - 1) \tag{9}$$

Given the setting level α, Critical value F_α found. Then we can draw the following conclusions:

(1) If $F_1 \leq F_\alpha,\ F_2 > F_\alpha$, accept the hypothesis H_{10} and H_{21}, and reject the hypothesis H_{20}, that is, R_{it} is the Granger causality of R_{jt};
(2) If $F_1 > F_\alpha,\ F_2 \leq F_\alpha$, reject H_{10}, accept H_{11} and H_{20}, that is, R_{jt} is the Granger causality of R_{it};
(3) If $F_1 > F_\alpha,\ F_2 > F_\alpha$, reject H_{10} and H_{20}, accept H_{11} and H_{21}, that is, R_{it} and R_{jt} are Granger causality each other.

4 Empirical Analysis

4.1 Data Collections

The daily stock price is the most conducive to reflect the daily trading volume, so this section mainly selects Shanghai and Shenzhen. The stock data of 22 financial institutions listed on the local A-share market are studied, mainly from the Resset database (www.resset.cn). Due to the data time provided by the database and the limitations of institutions, this paper only considers the data from 2008 to 2017, including 14 banking industries, 3 insurance industries and 5 securities industries [5]. Figure 1 is the trend chart of the average closing price of the banking, insurance and securities industries. From the chart, it can be seen that the closing prices of the three industries are convergent.

In order to highlight the index fluctuation more, the first order difference processing of the data is as follows: $\tilde{R}_{it} = 100(\ln p_{it} - \ln p_{it-1})$, where p_{it} is the closing price of institution i in period t, and $\tilde{R}_{it}$ is the index yield of institution i. Table 1 shows the return rate statistics of banking, insurance and securities industries statistics of all institutions in each industry. It can be seen from the table that the kurtosis is greater than 3, the skewness (except for China Life Insurance, Minsheng Bank, Ping An Bank, Bank of China and CITIC Bank) is negative, and the yield data shows the characteristics of peak fat tail and left bias; It can be seen from Jarque bera statistics and p-value that the return rate does not obey normal distribution.

In order to obtain Granger causality among financial institutions, it is first necessary to test whether the data obtained are stationary series. This paper mainly judges the stability of the sequence by ADF test. Table 2 shows the ADF test results of Bank of

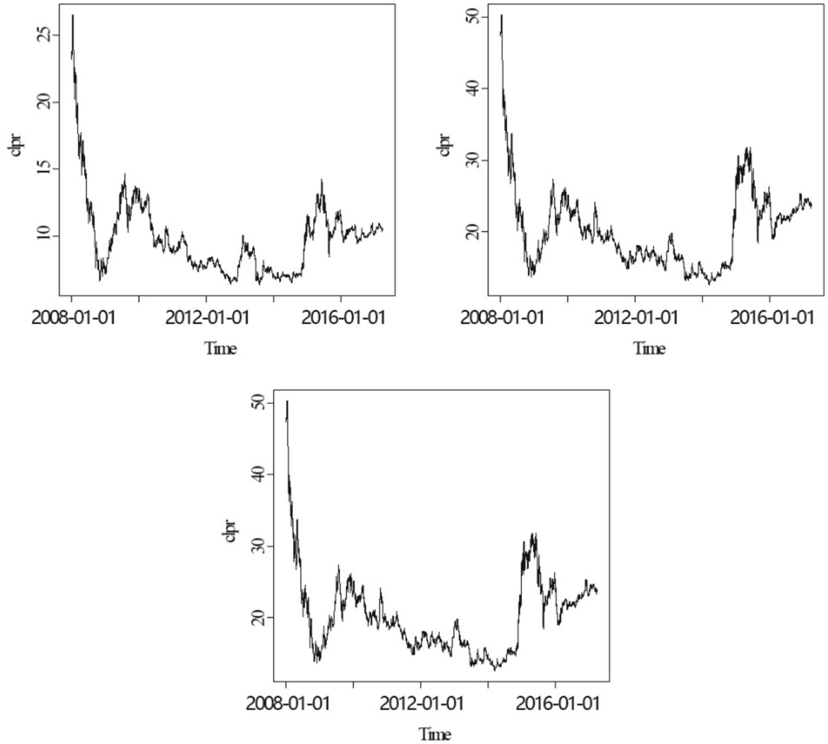

Fig. 1. Trend chart of average closing price: Banking industry (left); Insurance industry (middle); Securities Industry (right)

Table 1. Statistical Table of Yield

Statistics	Banking	Insurance	Securities
Minimum	(−12.9309, −10.5361)	(−10.5441, −10.5402)	(−15.2980, −10,5534)
Maximum	(9.5542, 9.68)	(9.5460, 9.5634)	(9.5536, 9.6049)
Mean	(−0.0269, 0.0094)	(−0.0237, −0.0069)	(−0.0192, −0.0164)
Variance	(1.8982, 6.6795)	(4.0555, 4.3536)	(5.6909, 7.2244)
Standard deviation	(1.3777, 2.5845)	(2.0138, 2.0866)	(2.3856, 2.6879)
Skewness	(−0.4343, 0.1382)	(−0.1615, 0.2224)	(−0.3212, −0.0716)
Kurtosis	(5.1704, 14.3596)	(4.9583, 6.3056)	(4.6004, 5.1705)
Jarque-bera Statistics	(3778.654, 29153.015)	(3465.283, 5617.412)	(3041.020, 3778.655)
P-value	(0, 0)	(0, 0)	(0, 0)

Table 2. ADF Test

		Bank of China		Haitong Securities		Ping An	
		t statistics	P*	t statistics	P*	t statistics	P*
ADF Test		−11.20945	0.000	−11.90114	0.000	−59.84032	0.0001
	1% significant level	−3.432114		−3.432110		−3.432100	
	5% significant level	−2.862205		−2.862203		−2.862199	
	10% significant level	−2.567168		−2.567167		−2.567164	

Table 3. Estimation Results of ARMA-GARCH Model

Coefficient	μ	ϕ_1	ϕ_2	θ_1	θ_2	α_0	α_1	β_1
Parameter	4.2316	−0.5183	−0.7792	0.4897	0.7580	0.2079	0.0164	0.1401

China, Ping An of China and Haitong Securities. Secondly, ARMA (p, q) model is used to eliminate the autocorrelation of financial series and GARCH (1,1) model is used to eliminate the heteroscedasticity of financial series. Table 3 shows the estimated results of the ARMA-GARCH model of BOB. The above data processing is ready for the Granger causality test in the next section.

4.2 Granger Causal Network

This section examines the Granger causality between 22 Chinese financial firms [6, 7]. Due to the large time span, wedivides the time into three sample periods (2008–2009, 2010–2014, 2015–2017), and uses (8) and (9) to conduct Granger causality test on 22 financial institutions. See Table 4, Table 5 and Table 6 for some results. It can be seen from the table that at the significance level of 5%, BOB is the Granger causality of ICBC, while ICBC is not the Granger causality of BOB. Therefore, a directed line segment is used to connect BOB to ICBC, but ICBC has no direction to BOB. The Granger causality between any two financial institutions is tested in this way. The Granger causality network diagram can be drawn by taking the financial institutions as nodes and the causality as directed lines.

Figure 2 shows the Granger causality network diagrams of 2008–2009, 2010–2014 and 2015–2017 respectively. It is calculated that the correlation degree of China's financial system in these three periods is 98, 108 and 112 respectively, which indicates that the correlation degree between China's financial institutions is gradually increasing.

Table 4. Granger causality test in 2008–2009

Original hypothesis	degree of freedom	F statistics	p-value
Bank of Beijing is not Granger of ICBC	(1, 727)	7.25552	0.0008
ICBC is not Granger of BOB	(1, 727)	1.02666	0.3587

Table 5. Granger Causality Test 2010–2014

Original hypothesis	degree of freedom	F statistics	p-value
Bank of Beijing is not Granger of ICBC	(1, 1824)	6.04545	0.0024
ICBC is not Granger of BOB	(1, 1824)	0.67053	0.5116

Table 6. Granger Causality Test 2015–2017

Original hypothesis	degree of freedom	F statistics	p-value
Bank of Beijing is not Granger of ICBC	(1, 821)	3.31292	0.0370
ICBC is not Granger of BOB	(1, 821)	2.21528	0.1099

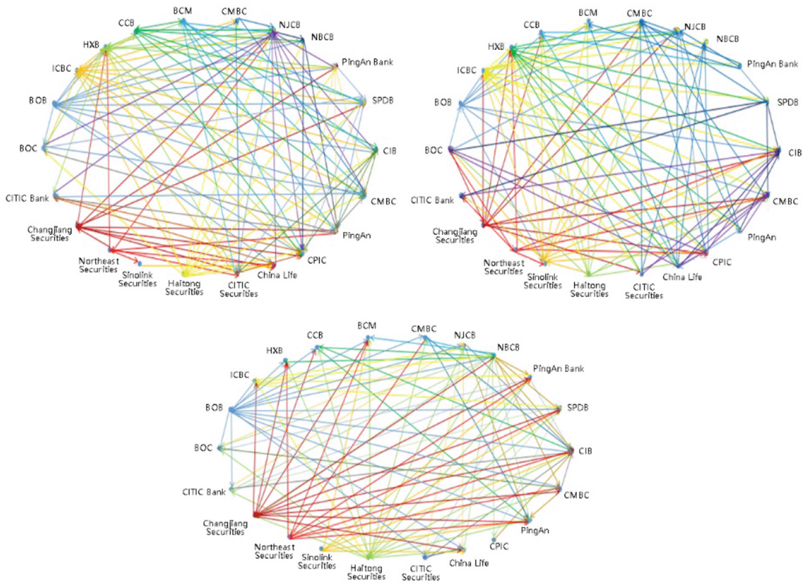

Fig. 2. Granger causality test chart: 2008–2009 (left); 2010–2014 (right); 2015–2017 (bottom)

Table 7. Granger causality between financial sectors

	2008–2009			2010–2014			2015–2017		
	Banking	Insurance	Securities	Banking	Insurance	Securities	Banking	Insurance	Securities
Banking	45	10	15	40	1	5	67	23	8
Insurance	4	0	1	25	2	0	12	0	3
Securities	31	9	1	35	4	3	23	10	4

Note: 22 financial institutions in the figure are CITIC Bank, Bank of China BOC, Bank of Beijing BOB, Industrial and Commercial Bank of China ICBC, Huaxia Bank HXB, China Construction Bank CCB, Bank of Communications BCM, Minsheng Bank CMBC, Bank of Nanjing NJCB, Bank of Ningbo NBCB, Ping An Bank, SPDB, Industrial Bank CIB, China Merchants Bank CMBC, Ping An, China Pacific CPIC CITIC Securities, Haitong Securities, Sinolink Securities, Northeast Securities.

In order to more clearly describe the Granger causality among financial sectors, the Granger causality of three financial sectors in three sample periods is given here, as shown in Table 7.

It can be seen from Table 7 that the internal correlation of Bank of China has always been at a high level, both the financial crisis repair period (2008–2009: 45 Granger causality) and the current period (2015–2017: 67 Granger causality) remain high correlation, indicating that systemic risk contagion is most likely to occur within banks [8]. The securities sector has the most Granger linkages to the banking sector, with 31, 35 and 23 for the three periods, indicating that the securities sector has the greatest impact on the banking sector relative to the insurance sector. Whether it is internal Granger causality or Granger causality with other sectors, the Granger causality correlation degree of the insurance sector is the weakest, and even the Granger causality correlation degree between the sectors is 0, so the insurance sector is not only the industry that is the least prone to internal risk contagion, but also the industry that is the least prone to risk contagion to other financial sectors [9].

5 Conclusions

From the results of empirical analysis, we can draw the following conclusions: (1) The correlation between Chinese financial institutions is gradually increasing; (2) Granger within the bank has the largest causality, which is most prone to systemic risk contagion; (3) Granger from the securities sector to the banking sector has the most contacts, which has the greatest impact on the banking sector; (4) The insurance sector has the least Granger contact with other financial sectors, and its internal Granger contact is also the smallest. Therefore, the insurance sector is not only the industry most vulnerable to internal risk contagion, but also the industry most vulnerable to risk contagion to other financial sectors.

Acknowledgment. Young Scientists Fund of the National Natural Science Foundation of China (71903018); Youth Fund for Humanities and Social Sciences Research of the Ministry of Education

(18YJC790148); Supported by Hunan Provincial Education Information Technology Key Program (HNETR22042); Supported by Hunan Provincial Excellent Project of Ideological and Political Work in Colleges and Universities (22JP113).

References

1. Shi Daimin Apply time series analysis Beijing: Higher Education Press, 2011
2. Yang Qi, Cao Xianbing Analysis and forecast of stock price based on ARMA-GARCH model Practice and Understanding of Mathematics, 2016, 46 (6): 80-86
3. Wang Bo Empirical analysis of Shanghai stock index based on ARMA-GARCH model Science, Technology and Engineering, 2012, 12 (5): 1219–1221
4. Gao Bo, Ren Ruoen Evaluation of the Systemic Importance of Financial Institutions Based on Granger Causal Network Model Management Review, 2013, 25 (6): 3-10.
5. Kaminsky G L,Reinhart C M.The Twin Crisis: The Causes of Banking and Balance of Payments Problems. American Economic Review.1998(3):473-500.
6. Schwarcz S L. Systemic Risk. George Town Law Journal. 2008, 97: 193-1767.
7. De Bandt O, Hartmann P. Systemic Risk: A Survey. Social Science Electronic Publishing, 2000.
8. Glasserman P, Young H P. How likely is contagion in financial networks? Journal of Banking & Finance, 2015, 50(2120): 383-399.
9. Gray D F, Jobst A. New directions in financial sector and sovereign risk management. Journal of Investment Management, 2010, 8(1): 23-38.