

Analysis of Systemic Risk in the Chinese Insurance Market Based on Reinsurance Networks

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Abstracts

Since the financial crisis in 2008, regulators around the world have been committed to understanding and mitigating the potential systemic risks brought by the insurance industry, focusing on the risk transmission field within the insurance industry. This paper focuses on the possible transmission relationship of systemic risk in China's insurance market through the reinsurance network from the perspective of macro-prudential, discusses the accumulation and contagion effect of systemic risk over time, and puts forward suggestions on the macro-prudential supervision of China's insurance industry.

Keywords: insurance, systemic risks, network perspective

INTRODUCTION

Since the financial crisis in 2008, the insurance industry, as the main business of risk management, had received a great deal of attention. Regulators around the world had been working to understand and mitigate the potential systemic risks posed by the insurance industry, with a focus on areas of risk transmission within the insurance industry. Most scholars have analyzed the potential sources and transmission channels of systemic risk in the insurance industry, with the most likely channel for spillover systemic risk from the insurance industry being reinsurance business.

This paper focuses on the possible systemic risk transmission relationships in the Chinese insurance market through the reinsurance network under a macro-prudential perspective, explores the accumulation and contagion effects of systemic risk over time, analyzes the impact of systemic risk contagion through the reinsurance channel in Chinese insurance market, and provides some suggestions for the macro-prudential regulation of insurance in China.

This paper is organized as follows: section 2 provides a literature review; section 3 explains the importance of reinsurance network; section 4 describes the current situation of the Chinese reinsurance market; section 5 analyzes the network topology characteristics of the reinsurance market, and reveals how systemic risk propagates and accumulates through the reinsurance network; section 6 simulates the propagation of risk through the reinsurance network in the insurance market when a shock occurs, based on the Ising model; section 7 discusses the policy recommendations.

LITERATURE REVIEW

Reinsurance is an important tool used by the insurance industry to transfer risk. The reinsurance market has strengthened the linkages between financial institutions and further amplified the systemic risk in the financial market. Acharya et al. (2009) proposed that reinsurance strengthened the linkages among financial institutions and further amplified the systemic risk in financial markets. Cummins et al. (2014) argued that the financial crisis or bankruptcy of reinsurers would lead to the destabilization of the entire property insurance market, causing insurance market failure, which in turn would bring damage to the entire financial system and even the real economy. Park and Xie (2014) confirmed that centrally located reinsurers had higher systemic risk. Kanno (2016) constructed an insurance network model based on the maximum entropy principle and analyzed the structure of the insurance network. Wang L. (2017) showed that from the perspective of risk contagion in insurance business, domestic and foreign reinsurers were systemically important; small direct insurers and some reinsurers with a higher share of ceded premiums had systemic vulnerability; however, for Chinese insurance industry, the possibility of systemic risk occurring due to reinsurance underwriting business was not high. Niu X. and Wu X. (2019) pointed out that in recent years, due to their close ties with other insurance companies, some of the larger and more complex domestic insurance institutions were in the central position in the reinsurance network species and played a pivotal role in the stability and stability of Chinese overall financial system and its ability to serve the real economy. Li F. et al. (2022) developed a network-based contagion model to investigate reinsurance strategy from a macro-prudential perspective, showing a U-shaped relation with economic losses caused by risk spillovers. Other influential works include Berdin et al. (2017), Chen H. et al. (2020), Jourde T. (2022).

THE IMPORTANCE OF REINSURANCE IN INSURANCE INDUSTRY

Reinsurance, as an important risk transfer instrument and risk management mechanism, serves the following functions: (1) it disperses and transfers part of the risks underwritten by the reinsurance institution, thus realizing the apportionment of sub-risk; (2) it helps control the risk liability and uses the financial compensation function of insurance to compensate for the losses incurred by the reinsurance institution due to insurance risks; (3) it enables the reinsurance institution to expand its underwriting capacity; fourthly, it reduce the operating costs of the sub-insurance agency. However, this process of business and activity can also lead to increased interconnectedness among insurance institutions and an increasing aggregation of risks among reinsurers, which can easily create systemic risks within the insurance market through reinsurance business if a crisis occurs in any one or more institutions. Risk diversification and restructuring mechanisms based on reinsurance contracts have become a global network that transcends national borders. The risk transfer mechanism of reinsurance also exists to provide a quick route of contagion for potential risk shocks and the consequences of magnifying potential insurance risks. Such internal risk transmission channels and modalities have become an important concern for global regulators.

Reinsurance stands on the top of the insurance network. Risk spillovers from the reinsurance can lead to financial instability due to risk contagion within the wider insurance industry, and may even have spillover effects and negative externalities on the economy as a whole. When the International Association of Insurance Supervisors (IAIS) conducts systemic importance assessments, reinsurance is considered as an important factor in assessing risk transmission among insurance institutions. As Acharya et al. (2009) argued, "reinsurance markets increase

the interconnectedness of the system in an exponential manner and may therefore increase systemic risk across the market". Indeed, credit risk from counterparties in reinsurance transactions has been an important issue in their risk diversification and transmission, and ceding companies are increasingly using special termination clauses with rating triggers in their reinsurance contracts for risk mitigation purposes. This practice may actually exacerbate the problem of "Reinsurance Spiral". If a reinsurer's rating is lower below a certain threshold, the clause will allow the major players to cancel the reinsurance policy, thus weakening an already weak reinsurer and triggering a "reinsurance spiral", leading to a greater likelihood of systemic risk.

Research has shown that reinsurance can generate systemic risk by increasing the interconnectedness of risks through leverage and increasing contagion between insurance institutions. Therefore, the study of systemic risk in insurance is crucial to the study of reinsurance business linkage networks.

CURRENT SITUATION OF REINSURANCE BUSINESS IN CHINA

In order to analyze the impact of risk shocks on the reinsurance market, it is critical to understanding the current situation of China's insurance reinsurance business. This section will analyse Chinese current situation in the insurance industry market from the following perspectives: the reinsurance institutions、the structure of ceded premium, and the reinsurance payout ratio.

Information of Reinsurance Institutions

Prior to China's accession to WTO, there was only one reinsurance company in China, China Re. Since 2003, with the continuous opening up of Chinese insurance industry, it has been developing with great potential, attracting major professional reinsurance institutions all around the world to set up branches in China, such as Munich Re and Swiss Re, etc. These foreign reinsurance institutions entered the Chinese reinsurance market and undertook a large amount of ceded reinsurance business. After the financial crisis in 2008, China accelerated the establishment of Chinese reinsurance institutions in view of the growing demand for risk diversification in the domestic insurance industry, and established PICC Re, Qianhai Re and China Agricultural Re. Up to now, there are 15 reinsurance institutions in the Chinese insurance market, including 8 foreign professional reinsurance institutions and 7 Chinese professional reinsurance institutions¹.

Structure of Ceded and Ceding Premium

The data shows that by the end of 2020, the total scale of premiums ceded from the original insurance market in China was 244.183 billion, accounting for 5.68% of the original insurance premium, rising up 2.12% from the previous year. The scale of ceded premium from property and casualty (non-life) insurers remained stable relatively (as shown in Figure 1). The life insurance industry's ceded premium rate was slightly 2% above the global life insurance

¹ Although China Re Group has established China Life Reinsurance and China Property Reinsurance to operate life insurance and non-life insurance reinsurance business respectively, according to the data in the China Insurance Yearbook, China Re Group still handles reinsurance business separately and is therefore also considered a reinsurance agency.

average, while the non-life insurance industry's average ceded premium rate was 8.4% above the global average².

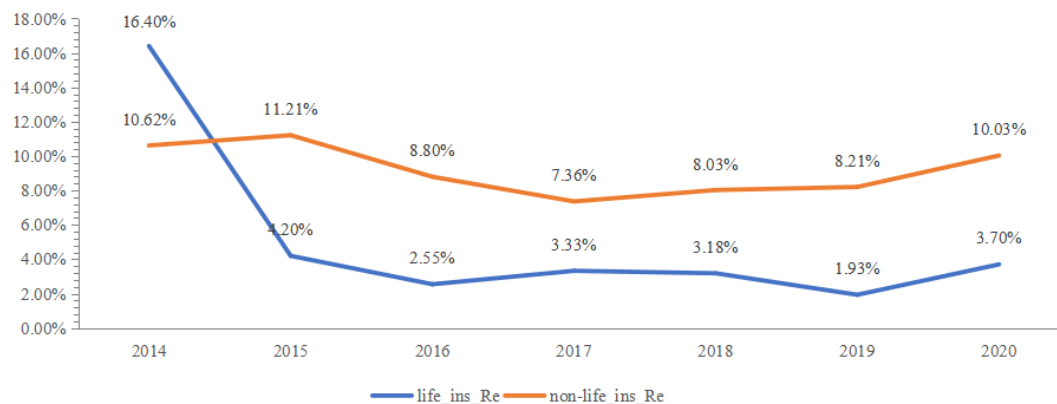


Figure 1 Comparison of ceded premium ratio between life and non-life industry in China

Data source: the Yearbook of China's Insurance (2015-2021), compiled and mapped by the author³

From the perspective of premium structure, the scale of reinsurance premium has increased from about RMB 120 billion in 2013 to more than RMB 320 billion in 2020, increasing by more than 2.69 times and with an annual average growth rate of 13.16% within 8 years in domestic reinsurance market. In terms of ceded-out business, the ceded-out premium of original insurance companies accounted for 75.69%, and that of professional reinsurance companies accounted for 24.31%. By 2020, the ceded premium of professional reinsurance companies was 297.377-billion-yuan, accounting for 87.76% of the ceded business. The ceded premium of original insurance companies was 41.495-billion-yuan, accounting for 12.24% of the ceded premium (see Figure 2). It can be seen that China's reinsurance business is mainly underwritten by domestic professional insurance institutions, with a relatively low level of internationalization, far behind the world average. From the perspective of change trend, the proportion of premium ceded by Chinese-funded professional reinsurance institutions had been descending year by year since 2017, and slightly increased in 2020 (see Figure 3). The reason may be that as China continued to promote economic globalization, the insurance industry had always played a leading role in the opening up of the financial industry. With the comprehensive opening up of the insurance industry, international reinsurance institutions had accelerated their deployment in China, bringing more abundant funds and advanced management experience to the reinsurance market in China.

² Data source: Compiled from "Swiss Re sigma: Global Market Trends".

³ As the insurance industry started to implement the new accounting standards in 2012, they were fully implemented in 2014. This led to inconsistencies in the calibre of reinsurance statistics prior to 2014, so only data from 2014 onwards was selected for comparable analysis in this paper. In the modelling, the current year data was used for modelling and therefore the comparability of the results is not affected.

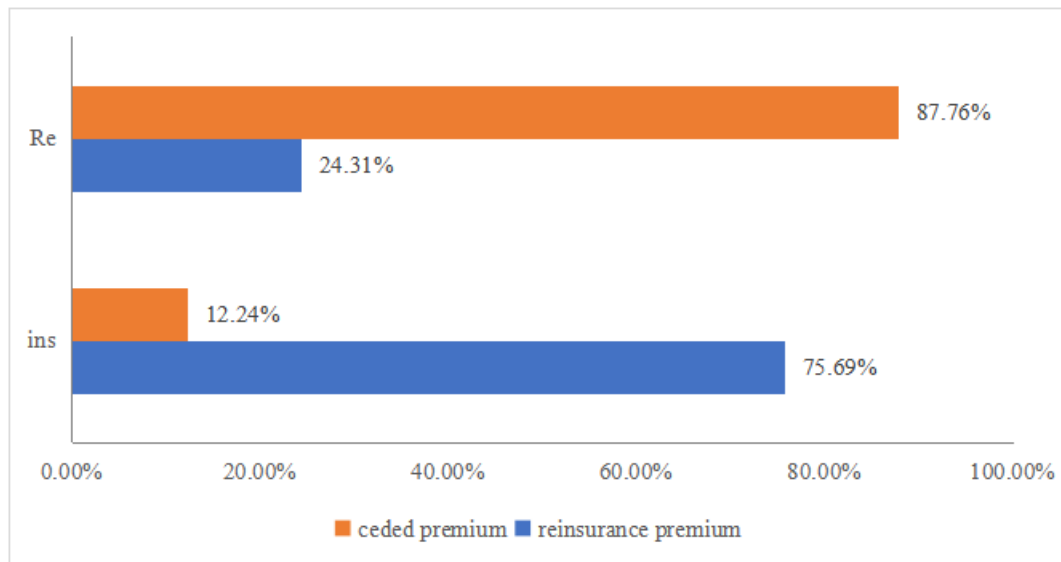


Figure 2 the ratio of premium underwritten by original insurance company and professional reinsurance company

Data source: the Yearbook of China's Insurance (2015-2021), compiled and mapped by the author.

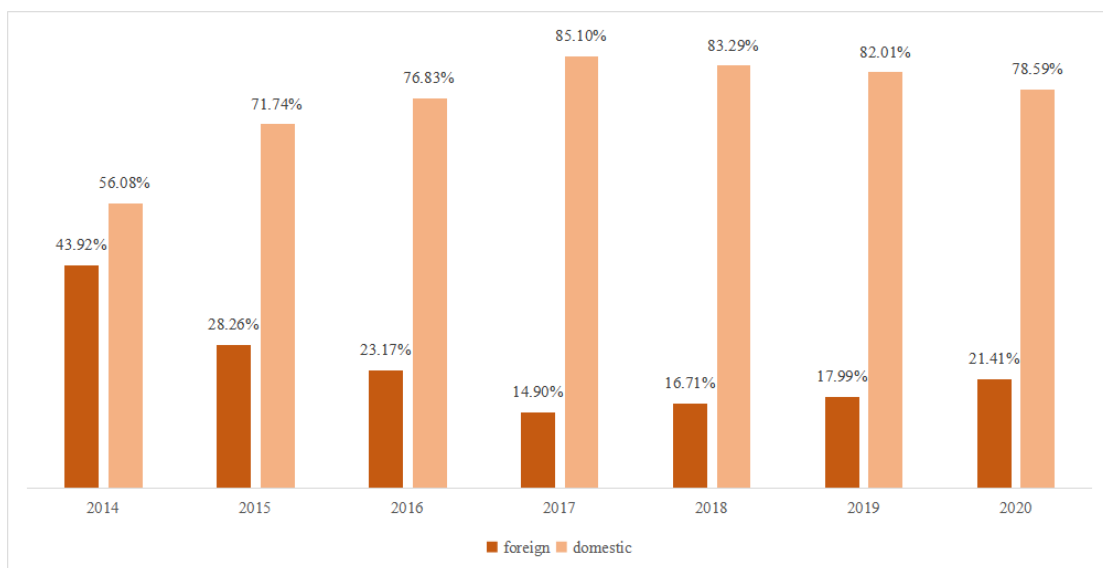


Figure 3 the ratio of premium underwritten by foreign and domestic reinsurance company

Data source: the Yearbook of China's Insurance (2015-2021), compiled and mapped by the author.

Reinsurance Payout in the Chinese Insurance Industry

The reinsurance payout ratio has always been an important indicator of the stability of the reinsurance system (as shown in Figure 4). Reinsurance payout ratio was generally stable except for 2016 when it was extremely high. The data shows that non-life reinsurance payout ratio is higher than life insurance. There was an abnormal payout from Hannover Re in 2015 and 2016, which led to higher payout ratio of life reinsurance market as a whole. The life reinsurance payout ratio remained at around 50% and the property reinsurance payout ratio remained at around 55%, excluding the Hanover accident.

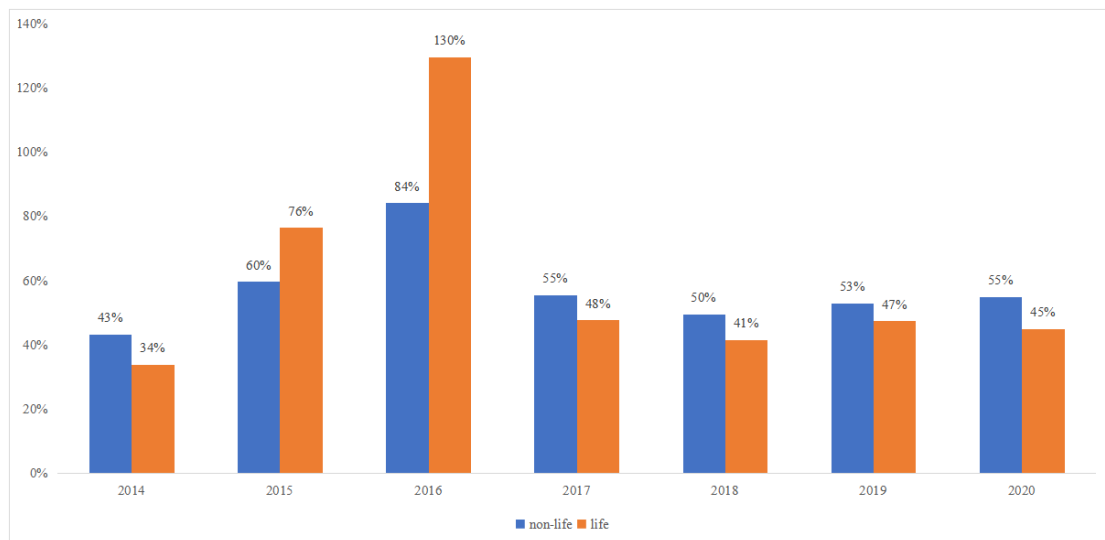


Figure 4 reinsurance payout ratio between life and non-life insurance in China

Data source: the Yearbook of China's Insurance (2015-2021), compiled and mapped by the author.

It is obvious that most of reinsurance contracts in the Chinese insurance industry originates from domestic primary insurance institutions, while the international business is mainly completed or ceded by international (professional) insurance institutions. In terms of ceded-out premium, primary insurance companies are mainly the risk ceded-out party and professional reinsurance companies are mainly the ceded-in party. Foreign reinsurers are gradually becoming the main ceded-in agents in the market, and China's original insurers are also actively involved in the reinsurance industry, with relatively small premium sizes making the correlation between the businesses relatively weak.

The predominant relationship between professional reinsurers and direct insurance companies is unidirectional and vertical, i.e. professional reinsurers generally do not purchase reinsurance sold by the original insurer or have relatively small volumes of this business, and there is little correlation between professional reinsurers and the few horizontal interconnectedness that may exist between reinsurers. To some extent, such a network structure limits the potential impact of unexpected risks on the insurance industry as a whole, and the likelihood that traditional reinsurance activities will have a negative and potentially systemic impact on the industry as a whole is low. Even if it does, it is likely to be limited in the insurance industry.

ANALYSIS OF THE STRUCTURE OF CHINESE REINSURANCE NETWORK BASED ON THE PRINCIPLE OF MAXIMUM ENTROPY

As it is difficult to obtain accurate data on reinsurance contracts directly, this paper uses the principle of maximum entropy and simulates Chinese network connections in the insurance market through complex network, analyzing the network structure characteristics related to reinsurance network at two levels: life insurance and non-life insurance (property and casualty insurance) respectively.

Model Setting

Kanno (2016) proposed an insurance network model based on the principle of maximum entropy to study the optimal structure of insurance networks (see Kanno, 2016). This model has been used by several scholars in the study of reinsurance networks (e.g. Wang L., 2015; Niu X. et al., 2019; Lu S. et al., 2022), and widely proved its validity by the academic researchers. In this paper, we draw on the model proposed by Kanno (2016) to establish an optimal stable reinsurance network structure, and analyse the position of each institution in Chinese reinsurance network and its importance to the network under this structure, so as to analyse the propagation path of systemic risk and the cumulative effect of systemic risk over time through this network.

Data Sources and Data Processing

Data for this article is extracted from the Yearbook of China's Insurance published from 2015 to 2021. According to the business characteristics engaged in by insurance institutions, the institutions can be classified into two types: life insurance (mainly engaged in life insurance business) and non-life insurance institutions (mainly engaged in property and casualty insurance business). In accordance with the business characteristics of insurance institutions and the relevant requirements of the China Banking and Insurance Regulatory Commission for data reporting, health insurance business is consolidated into life insurance business and short-term business in the accident insurance category is included in the calculation of non-life insurance (property insurance) business, as the volume and amount of casualty reinsurance business is very small, it can be ignored. At the end of 2020, the data set includes a total number of 188 insurance institutions⁴, of which 89 are life insurance institutions (including 5 special health insurance institutions, 3 special pension insurance institutions and 2 mutual insurance institutions), 87 are non-life insurance institutions (including 5 special agricultural insurance institutions) and 12 professional reinsurance institutions.

We select several items and data from the yearbook, including the name of each insurance institution, assets and liabilities, ceded premiums (contractual cessions, temporary cessions, amortized cession expenses and amortized cession benefits), ceded premiums (contractual cessions, temporary cessions and cession benefits expenses) and payout ratio. In order to consider the balance of the data, this paper is based on the number of all companies in 2020. If the company has not been established in previous years, the data of its previous years will be defaulted to zero; if there is a change in the shareholding or legal entity of the company, we use the latest company name for data processing and modelling analysis. If the volume of a company's ceding business is zero or close to zero, it will be excluded.

Using the reinsurance premium data of each insurance institution, we analyze the life and non-life insurance markets' structure separately using the model developed by Kanno (2016) to find out the optimal bilateral reinsurance correlation matrix for each year for the non-life and life

⁴ As Shun Lee Reinsurance (China) Limited and Korea Reinsurance Company Shanghai Branch will only join the Chinese insurance market in 2019 and 2020 respectively, they are excluded from the model due to their timing and low volume of facultative business and premium amount; life insurance institution China Law Life changed its shareholding in 2017 and changed its name to Xiaokang Life, and non-life insurance institution Guangdong Energy Property Insurance Self-Insurance Co. Ltd. was established in November 2017, but they are excluded as they both have zero volume of reinsurance business in the statistics, and the rest of the institutions are included in the model.

insurance markets, and then explore the time-varying characteristics of the optimal network structure of the insurance market in China. The data processing and model solving in this paper is mainly based on python 3.7.

Characteristic of the Optimal Network Structure

Node Degree and Degree Distribution:

The degree of a node in a network is the number of connections or edges between this node and other nodes. Degree analysis in insurance market networks provides an understanding of the degree of connectivity of an insurance institution in the insurance network, and therefore the number of insurance institutions associated with that insurance institution. The degree distribution is the distribution function of the degrees of the nodes in a network, i.e. the probability that the degree of a node in the network is exactly a certain value. The degree distribution of the reinsurance network for the life and non-life insurance markets in China is plotted using python 3.7 (see Figure 5 for details).

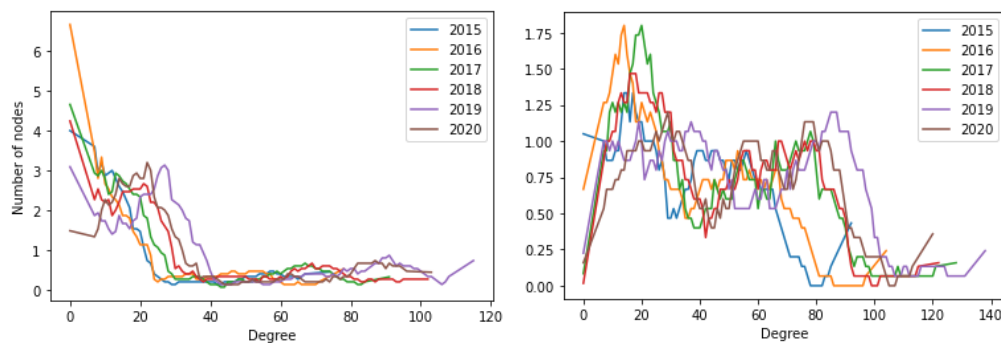


Figure 5-degree distribution for life (left) and non-life (right)

It can be seen from the degree distribution in Figure 5, the degree of connectivity between companies in the model becomes stronger over time for both life and non-life reinsurance networks, which can also be obtained by increasing the average degree of the nodes. Similarly, the graph above shows that the non-life reinsurance network is more connected to each other through reinsurance contracts than the life reinsurance network. This also means that risks in the non-life insurance market are more likely to be transmitted through the reinsurance channel relative to the life insurance market.

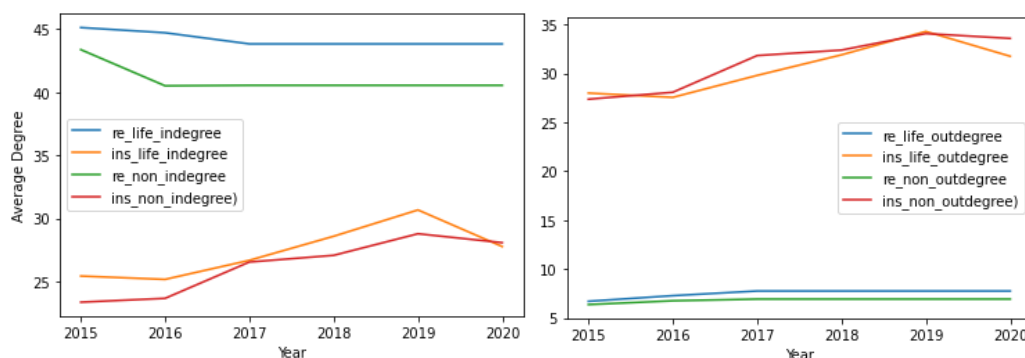


Figure 6 average in and out degree of life and non-life insurance

Given that reinsurance premiums are divided into ceded and ceded-out premiums, a reinsurance directed network was constructed based on the reinsurance bilateral connection matrix. The results of the model show that professional reinsurers are more likely to take in risk from the original insurer than to cede risk. They also show that professional reinsurers rarely share risk with each other, which is generally consistent with the results discussed in the existing literature⁵. In addition, life insurers are more likely to take in risk than non-life insurers, and non-life insurers are more likely to take out risk. This is mainly reflected in the fact that life insurers are more likely to take in than non-life insurers, and the opposite is true in terms of taking out. This finding is consistent with the structure of the reinsurance market in practice, where professional reinsurers generally choose to underwrite reinsurance sold by the original insurer due to the relatively vertical network of the reinsurance market, with the possibility of a few horizontal linkages between professional reinsurers, but these are very weak. In terms of the time dimension, the number of reinsurers receiving facultative business has been relatively stable, with a sudden drop between 2015 and 2016 mainly due to the increment of the reinsurers.

Network Centrality:

The centrality indicator captures the importance of insurance (reinsurance) institutions in the market. In this paper, we select eigenvector centrality and betweenness centrality to analyze the importance of the insurers(reinsurers).

The eigenvector centrality is used as an important indicator of the influence of the node in the overall network. Based on the previous ideas of network construction, a reinsurance network for the life and non-life insurance was established and analyzed for eigenvector centrality and betweenness centrality as well as temporal changes (see Figure 7 and 8 for details).

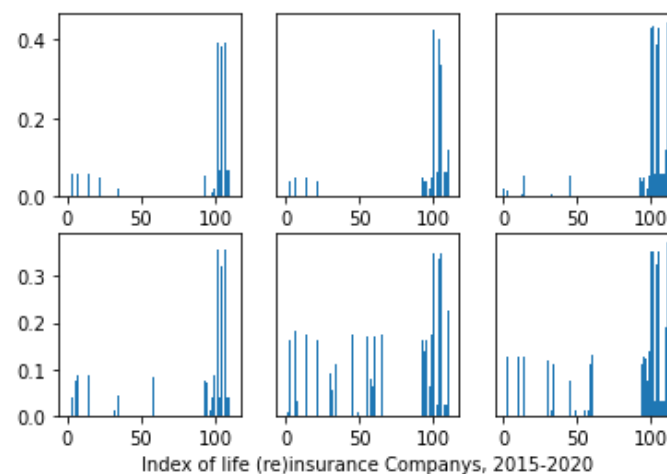


Figure 7 the eigenvector centrality of the life insurers in the insurance market (2015-2020)

Figure 7 shows the change in the eigenvector centrality of the life reinsurance market from 2015 to 2020. the first row shows 2015, 2016 and 2017 respectively, and the second row shows 2018, 2019 and 2020 respectively. 0-97 are the original insurer codes and 98-111 are the

⁵ International Association of Insurance Supervisors (IAIS), *Reinsurance and financial stability[R]*, Basel: International Association of Insurance Supervisors, 2012: 10.

reinsurer codes. As can be seen from Figure 7, over time, the risk concentration of the life insurance reinsurance market presents a process from concentration to relative dispersion. From the perspective of space, concentration means that in the life insurance reinsurance market, after risk exchanges, market risk is mainly shared by several large insurance companies and professional reinsurance companies; Diversification refers to that, compared with the situation in which the market risks were mainly concentrated in professional reinsurance institutions in 2015, after five years of development, the main market risk pattern has changed into multiple large insurance companies and professional reinsurance companies sharing market risks. In terms of time, with the development of the market, the risks assumed by each risk-bearing entity are increasing, and the number of risk-bearing entities has also increased, and the degree of risk concentration has decreased, showing a certain trend of diversification.

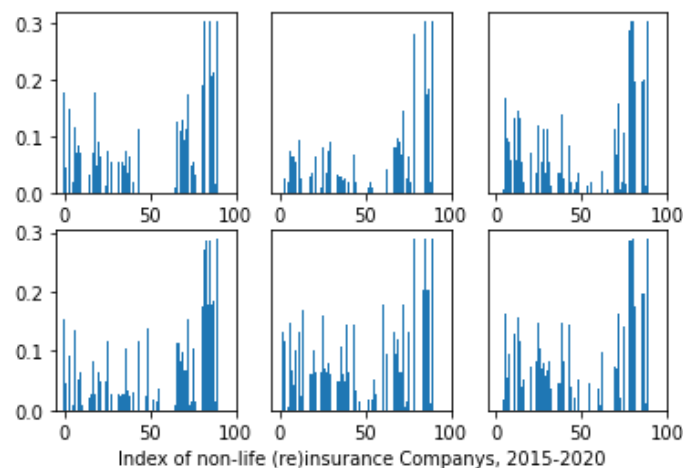


Figure 8 the eigenvector centrality of the non-life insurers in the insurance market (2015-2020)

It is slightly different from the situation of life insurance companies, as shown in Figure 8. The horizontal axis 0 to 76 in the figure is the code of non-life insurance institutions, and 77 to 89 is the code of reinsurance institutions. From the perspective of space, in the reinsurance network of non-life insurance, the risk concentration showed a trend of gradually sharing to the whole market from 2015 to 2020, and the relative scores between nodes were relatively close. Although a large number of risks are still concentrated in professional reinsurance companies, their risk allocation is more average than that of life insurance reinsurance networks. This indicates that the non-life insurance reinsurance network is more likely to have the risk caused by the default of the reinsurance contract than the life insurance reinsurance network, thus inducing the systemic risk, which spreads in a waterfall manner in the whole non-life insurance market.

In terms of betweenness centrality, the betweenness centrality of the reinsurance network is shown in Figure 9. As with the eigenvector centrality, the betweenness centrality of the reinsurance network in the life insurance market is also concentrated in several large original insurance companies and professional reinsurance companies. Such results show that if the crisis occurs in small life insurance institutions, as long as there is no fatal impact on these large insurance institutions and professional reinsurance institutions, there is a great chance that large insurance institutions and professional reinsurance institutions will become effective risk

blocking points and isolate risks from other institutions. However, just like the two sides of the coin, if the crisis occurs in these large insurance institutions and professional reinsurance institutions, its intermediary effect will amplify the impact of the crisis, make the crisis spread quickly to the entire network, and bring fatal damage to the entire insurance market. This also confirms that IMF, BIS and FSB (2009), Geneva Association (2010) and IAIS (2010) put forward the characteristics of measuring the scale and interrelation of systemic risk.

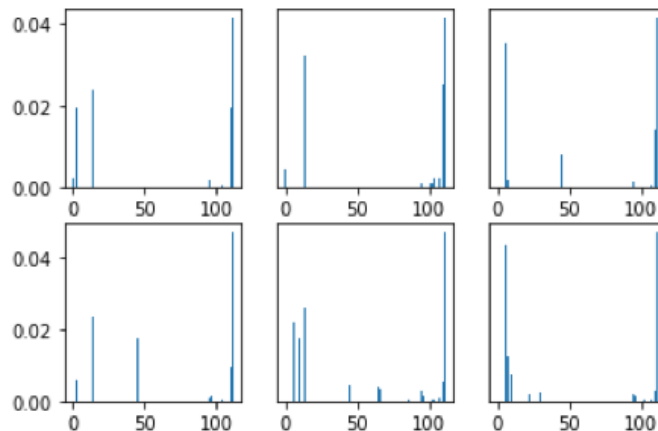


Figure 9 the betweenness centrality of the life insurers in the insurance market (2015-2020)

Analysis of the intermediary centrality of the reinsurance network in the non-life insurance market (shown in Figure 10) is compared to the reinsurance network in the life insurance market. While specialist reinsurers take on some intermediary functions, the main network intermediaries are concentrated in the non-life primary insurers. This suggests, on the one hand, that risk sharing in the non-life network is more balanced and that when a crisis arises in one institution, the entire network can assume the risk in a balanced manner. But on the other hand, it also indicates that non-life market networks have fewer risk-blocking points compared to life market networks, and that in the event of a large-scale risk outbreak, most institutions in the network would be affected by the shock and thus have a higher likelihood of systemic risk. This is closely related to the business activities engaged in by non-life insurance institutions. Some credit guarantee businesses could be potential triggers of systemic risk.

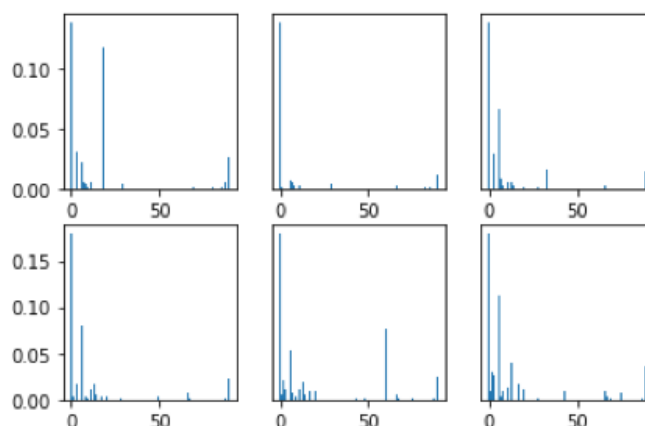


Figure 10 the betweenness centrality of the non-life insurers in the insurance market (2015-2020)

In summary, this paper solves the bilateral reinsurance connection matrix using the maximum entropy principle. The constructed reinsurance network shows that the reinsurance network in China's life insurance market is characterised by a high degree of risk concentration and obvious risk blocking points. Among them, the risk blocking points are mainly large life insurance primary insurers and professional reinsurers. The advantage of this network structure is that if a shock occurs at a non-betweenness node (an institution with low betweenness centrality), the betweenness node may form an effective barrier to absorb and block the risk. The disadvantage, however, is that if a shock occurs at the point of betweenness, it may spread throughout the network of the life insurance market, thereby inducing systemic risk. In contrast, our non-life market reinsurance network has a low concentration of risk, but relatively few risk-blocking points. The advantage of such a network is that risks are more evenly distributed across the network and the stability of the network is not easily broken by shocks to individual nodes. However, the disadvantage is that if shocks occur on a large scale at some of the nodes at the same time, the network lacks an effective blocking mechanism, which could lead to a large-scale outbreak of crisis and systemic risk.

IMPACT OF SHOCK OCCURRENCE ON SYSTEMIC RISK IN INSURANCE NETWORKS

Due to the internal fragility of the insurance industry, the insurance market itself is very sensitive to adverse shocks, and it is easy to cause systemic risks under the joint action of internal and external factors. In order to further study the impact of the reinsurance network structure on the systemic risk when the impact occurs, this paper introduces Ising model to describe the correlation degree of nodes in the reinsurance network when the impact occurs.

Model and Parameter Setting

The Ising model is a classical binary random variable graph model in statistical physics named after the physicist Ernst Ising⁶. In this paper, each node of the network corresponds to a participant in the reinsurance network (either the original insurer or a professional reinsurer), the edges represent the reinsurance relationship between the participants, and the joint probability distribution of risk occurrence at the network nodes takes the form of the joint distribution of the multivariate Bernoulli distribution in Dai et al. (2013).

$$p_I(y) = P[I_1 = y_1, \dots, I_n = y_n] = \exp \left(\sum_{i \in V} \theta_i y_i + \sum_{(i,j) \in E} \theta_{ij} y_i y_j - A(\theta) \right) \quad (\text{E. 1})$$

where $y \in \{0,1\}^n$ is whether a claim occurs for each insurance agency⁷ and $\theta = (\theta_{ij})_{i \in V, (i,j) \in E}$ is the unassigned adjacency matrix of the nodes, i.e. the connectivity between the nodes inscribed by the bilateral reinsurance connectivity matrix solved in the previous section, or $\theta_{ij} = 1$ if there is connectivity between the nodes, or $\theta_{ij} = 0$ if there is no connectivity. It follows that the Ising model satisfies the binary Markov property. The normalization function $A(\bullet)$ in Equation 4-1 satisfies

⁶ For details see Denuit M, Robert C Y. Conditional mean risk sharing in the individual model with graphical dependencies[J]. *Annals of Actuarial Science*, 2022, 16(1): 183-209.

⁷ For simplicity, this paper does not discuss the payout relationship between the different lines of insurance of the various insurers and reinsurers, but simply uses the overall company payout ratio as the overall payout situation.

$$A(\theta) = \log \sum_{y \in \{0,1\}^n} \exp \left(\sum_{i \in V} \theta_i y_i + \sum_{(i,j) \in E} \theta_{ij} y_i y_j \right) \quad (\text{E. 2})$$

Although the Ising model does not provide a unique solution in numerical simulations, the model can help us understand the interdependence between nodes when a risk shock occurs through the correlation coefficient matrix diagram. This paper therefore uses the model to analyse the correlation between the nodes in the reinsurance network of the Chinese life and non-life markets when a shock occurs and how strongly the linkages are. The Ising correlation coefficient can be positive, negative or zero, and is sensitive to the dependence between the two institutions in a stochastic state. This correlation coefficient is limited by the univariate Bernoulli distribution probability function. If ρ_{ij} denotes the correlation coefficient between I_i and I_j , then

$$\max \left\{ -\sqrt{\frac{p_i p_j}{(1-p_i)(1-p_j)}}, -\sqrt{\frac{(1-p_i)(1-p_j)}{p_i p_j}} \right\} \leq \rho_{ij} \leq \sqrt{\frac{p_i \vee p_j (1-p_i \wedge p_j)}{p_i \wedge p_j (1-p_i \vee p_j)}} \quad (\text{E. 3})$$

In E. 3, $p_i = \Pr(I_i = 1)$, $p_j = \Pr(I_j = 1)$.

Risk Contagion and Blocking Relationships in Reinsurance Networks

Using the reinsurance correlation matrix data of the life and non-life insurance market and the payout ratio of insurance institutions obtained previously, the Ising model is substituted to solve the Ising correlation coefficient between different insurance institutions, so as to obtain a correlation coefficient matrix, and then we use python and complex network model to analyze the correlation of nodes in the network when different markets are facing shocks. In general, we analyze the infectious effects of systemic risk in different time dimensions. In this paper, the results are visualized as thermal charts of life insurance and non-life insurance markets respectively.

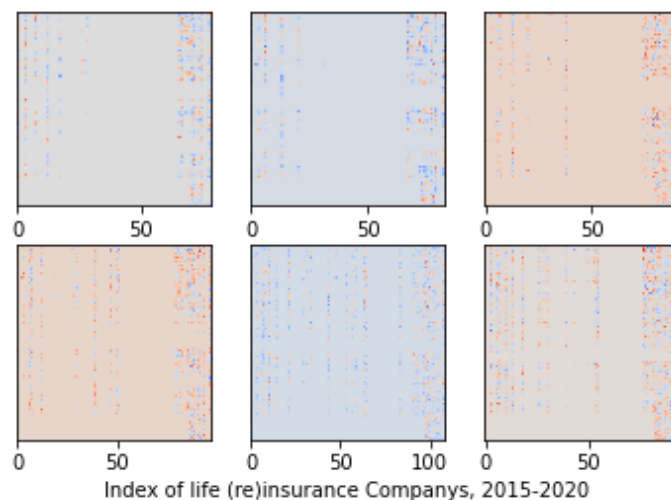


Figure 11 heat map of the Ising correlation coefficient for life insurance (2015-2020)

Note: From left to right, top to bottom, in order from 2015 to 2020. The horizontal coordinates 0-98 are life insurance institutions and 99-111 are specialist reinsurance institutions.

Figure 11 shows the correlation between nodes in the reinsurance network of the life insurance market from 2015 to 2020. As can be seen from the above figure, the increasing density of the Ising correlation coefficient in China's life insurance market from 2015 to 2020 indicates that the degree of risk correlation in the reinsurance network is increasing, and accordingly, the risk contagion effect is also increasing. It is readily apparent from the above graph that when shocks occur, a large number of life insurers in the life insurance network are associated with professional reinsurers, with a higher degree of correlation between large life insurers and smaller life insurers, and a lower degree of risk correlation between smaller insurers and larger insurers. This is consistent with the findings of intermediary centrality in the previous section 4. Without consideration of the impact of the type of risk, if the risk occurs in a small insurance institution, large insurance institutions and specialist reinsurers are able to effectively prevent the spread of the risk and act as a blocking point for the risk. Conversely, if a crisis occurs in a large insurance institution or a professional reinsurer, there is lack of effective risk-blocking points in the network to prevent the widespread spread of the crisis, thus allowing the crisis to spread rapidly through the network and thus triggering systemic risk in the network, which is largely consistent with Park and Xie's (2014) study.

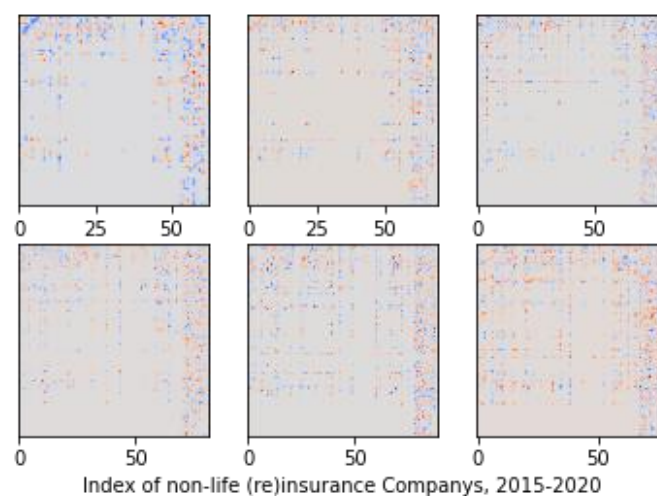


Figure 12 heat map of the Ising correlation coefficient for non-life insurance (2015-2020)

Note: From left to right, top to bottom, in order from 2015 to 2020. The horizontal coordinates 0-76 are non-life insurance institutions and 77-89 are specialist reinsurance institutions.

Turning to the Ising correlation coefficient heat map for the non-life reinsurance network (shown in detail in Figure 12), there is an increasing degree of correlation and risk transfer relationships in the non-life network, too. However, unlike the life reinsurance network, the non-life reinsurance network has a very high degree of correlation between large, small or professional reinsurers, and therefore the non-life reinsurance network lacks an effective risk blocking point. In the event of a shock, it is more likely to spread throughout the network, but because the risks are relatively dispersed, it is less likely to result in a large-scale crisis.

Loss Distribution of Reinsurance Network Values

In this section, we focus on the distribution of losses in the reinsurance network, which is depicted by the multivariate Bernoulli joint probability distribution on the Ising model. The total value of the insurance market is the sum of the values of all insurers in the market. When a market shock occurs randomly, the total loss incurred by the entire insurance market through the reinsurance network can be considered as the magnitude of the systemic risk. Figure 13 shows the probability density function of market value loss when the life insurance market is subject to a random shock in a time-varying state.

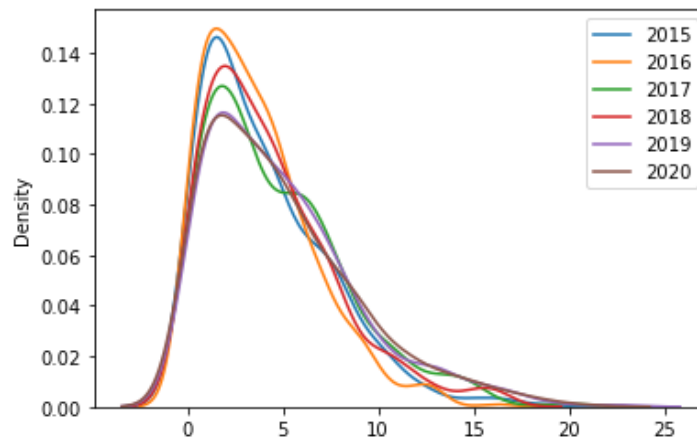


Figure 13 density function of the probability of loss of value in life insurance (2015-2020)

As can be seen in Figure 13, the peak in the number of market value losses due to random shocks has been decreasing year by year, indicating that the risk has been effectively diversified as the life reinsurance network expanded. However, the probability distribution gradually takes on a thick-tailed character, indicating that a small probability event, if it occurs, has a considerable impact on the overall market value. Although the network structure allows for effective risk diversification and avoids single point concentrations of risk, the probability of large losses increases over time, as reflected by the thickening tails of the density function, reflecting the accumulation of risk in the time dimension within the life reinsurance market.

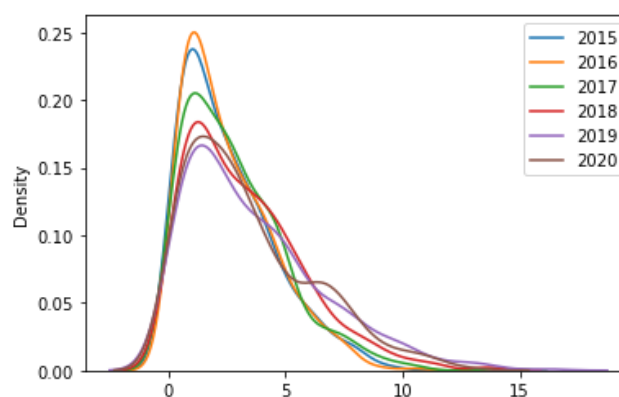


Figure 14 density function of the probability of loss of value in non-life insurance (2015-2020)

The probability density function of market value loss of non-life reinsurance network is shown in Figure 14. Similar to the life insurance market, with the continuous expansion of the

reinsurance network, its peak value has basically declined year by year (possibly due to the impact of the COVID-19 epidemic, it will pick up slightly in 2020). At the same time, it also shows a fat tail over time, reflecting the continuous accumulation of risks over time. Unlike the life insurance market, the overall market risk of the non-life insurance market is higher than that of the life insurance market, but the tail thickness is thinner than the reinsurance network of the life insurance market. This shows that the risk sharing efficiency of non-life insurance reinsurance network is higher than that of life insurance reinsurance network, which makes it more tolerant of risk. However, the non-life insurance reinsurance network lacks effective risk blocking institutions, which increases the risk of the overall collapse of the network when a large number of institutions on the network are impacted at the same time.

POLICY RECOMMENDATIONS

The previous analysis shows that macro-prudential supervision of the insurance industry is necessary in order to avoid systemic risks in the insurance industry. Specifically, one is to focus on counter-cyclical regulation and the reasonable use of counter-cyclical adjustment tools, such as attention to tightening reinsurance underwriting conditions to reduce risk accumulation when the market is irrationally booming; the second is to focus on mitigating the adverse impact of external shocks. The results of the analysis show that the lack of blocking points in the reinsurance network of China's property insurance market makes it extremely easy for risks to spread rapidly. Regulators should pay attention to close coordination between macro-prudential and micro-prudential, and do a good job of supervising the solvency of property insurance institutions to avoid a large-scale liquidity shortage, which would affect the stability of the insurance market. Third, the supervisors should focus on the conduct regulation of systemically important insurance institutions to avoid collective irrationality. For example, supervisors should curb irrational investments by insurance institutions, excessive expansion of the "asset side" and blind investment and financing in the capital market; and curb excessive concentration in the insurance market and the pursuit of "too big to fail".

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