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Research Article

Multiplex Networks of the Guarantee Market: Evidence from China

Shouwei Li and Shihang Wen

School of Economics and Management, Southeast University, Nanjing 211189, China

Correspondence should be addressed to Shihang Wen; wenzhanyao@gmail.com

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We investigate a multiplex network of the guarantee market with three layers corresponding to different types of guarantee relationships in China. We find that three single-layer networks all have the scale-free property and are of disassortative nature. A single-layer network is not quite representative of another single-layer network. The result of the betweenness centrality shows that central companies in one layer are not necessarily central in another layer. And the eigenvector centrality has the same result of the betweenness centrality except the top central company.

1. Introduction

The global financial crisis of 2007–2009 has shown how interconnected the global financial system is. Financial institutions' interconnections can serve as a channel for systemic risk and have been directly linked to the stability of financial systems. Network analysis has contributed to characterizing, understanding, and modeling financial institutions' interconnections, which is gaining popularity across academics, regulators, and policymakers.

There are a lot of studies on financial networks and systemic risk (see, e.g., Allen and Gale [1]; Nier et al. [2]; May and Arinaminpathy [3]; Gai et al. [4]; Li [5]; Li and He [6]; Georg [7]; Sachs [8]; Sensoy and Tabak [9]; Aymanns and Georg [10]; Acemoglu et al. [11]; Chen et al. [12]; Betz et al. [13]; Li et al. [14]; Li and Sui [15]; González-Avella et al. [16]; Sensoy et al. [17]; Christiano Silva et al. [18–21]; Silva et al. [22].), while financial institutions interact in just one way in most of these studies. In fact, financial institutions interact in many ways. Such a situation is best modeled with a multiplex network, where a multiplex network is made up with several layers, each of them composed of all relations of the same type and modeled with a simple network [23]. Multiplex networks can explicitly incorporate multiple channels of connectivity and constitute the natural environment to describe systems interconnected through different categories of connections [24]. Mapping out the structure of complex systems as a monoplex network could lead to missing relevant information [25]. For example, Poledna et al. [26] find that modeling contagion using each layer independently can lead to an underestimation of systemic risk. Therefore, the multiplex network method is useful in improving our understanding of complex systems by taking such multilayer features into account.

The theory of multiplex networks is in its early stages and has been introduced within the last three years to analyze the structure of financial systems [27]. The study of financial multiplex networks has only appeared recently. Empirical analyses of the financial multiplex networks of Colombia, UK, Mexico, Italy, Europe, and USA are provided by León et al. [28], Langfield et al. [29], Molina-Borboa et al. [30], Bargigli et al. [31], Aldasoro and Alves [32], and Musmeci et al. [33], respectively.

León et al. [28] investigate a multiplex network of Colombian sovereign securities settlements corresponding to the three sovereign securities' trading and registering environments and find that the multiplex network has some features, such as sparse, inhomogeneous, scale-free, ultra-small-world, and clustered. Langfield et al. [29] construct the multiplex network of the UK interbank market and find that the network of interbank exposures exhibits a core-periphery structure and the funding network has less of a core-periphery structure. Molina-Borboa et al. [30] analyze the persistence and overlap of relationships between banks in a multiplex network of the Mexican banking system, where the multiplex network includes five layers, namely, collateralized loans between banks, new deposits and loans, securities, outstanding deposits, and loans and derivatives. Bargigli et al. [31] analyze the Italian interbank multiplex network by transaction type and by maturity and find that layers have different topological properties and persistence over time. Aldasoro and Alves [32] adopt data on interbank exposures broken down by both maturity and instrument type to investigate structures of the multiplex network of large European banks and find that the network presents positive correlated multiplexity and a high similarity between layers. Musmeci et al. [33] analyze structural properties of the multiplex network of US stock markets, which includes four layers corresponding, respectively, to linear, nonlinear, tail, and partial correlations among a set of financial time series. They find that some features are unique to the multiplex structure and would not be visible otherwise by the separate analysis of the single-layer networks.

In recent years, China's listed companies widely adopt different forms of guarantee to form a complex guarantee circle, which reduces the difficulty of corporate finance to a certain extent. But this also provides risk contagion channels among listed companies. Generally, listed companies who require guarantees tend to have relatively poor performance and relatively large financial risk. Once a listed company has bankruptcy risk, it may result in risk contagion among listed companies through guarantee connections and even lead to systemic risk. Since 2012, the frequency of China's guarantee circle crisis is increasing, such as, the guarantee circle crisis in Zhejiang, Shanghai, Shandong, and other places.

In this paper, we investigate structures of the multiplex network of the guarantee market in China, which would be conducive to preventing risk contagion in the guarantee market. The study on financial multiplex networks is still preliminary. Existing empirical study on financial multiplex networks only analyzes sovereign securities markets, interbank markets, and stock markets. Therefore, this paper contributes to the literature on financial multiplex networks. Second, we study different segments of the guarantee market by guarantee types, and this would help to understand the economics of guarantee market infrastructures as the collective function of several layers of interaction between financial institutions.

The rest of the paper is organized as follows. Section 2 presents the guarantee multiplex network and the data set. Section 3 presents the results of single-layer networks. Section 4 presents the results of multiplex networks. And the conclusion is drawn in Section 5.

2. Guarantee Multiplex Network and Data Description

2.1. Guarantee Multiplex Network. We consider a guarantee market consisting of N listed companies and m different types of guarantee relationships. We can adopt the multiplex network to describe the structure of the guarantee market. A network consisting of a type of relationship can be described by a adjacency matrix. Moreover, the structure of the guarantee market can fully be described by the set of adjacency matrices, which is given as follows:

$$A = \left\{A^{[1]}, A^{[2]}, \ldots, A^{[m]}\right\}, \quad (1)$$

where $A^{[\theta]} = \{a_{ij}^{\theta}\}$, with $a_{ij}^{\theta} = 1$ if there is the θ type guarantee relationship between listed company i and listed company j; otherwise $a_{ij}^{\theta} = 0$.

If we consider the amount of the guarantee, we can fully describe the structure of the guarantee market by the set of weighted adjacency matrices,

$$W = \left\{W^{[1]}, W^{[2]}, \ldots, W^{[m]}\right\}, \quad (2)$$

where $W^{[\theta]} = \{W_{ij}^{\theta}\}$ and W_{ij}^{θ} denotes the amount of the θ type guarantee. In this paper, we only analyze unweighted multiplex networks of the guarantee market in China.

2.2. Data Description. In this paper, we investigate guarantee relationships of listed companies in China, where the data used stem from the Wind database and the time interval is from 2005 to 2015. The Wind database is a leading integrated service provider of financial data in China. In order to simplify data processing, we regard guarantee relationships of subsidiaries as their parent companies'. Besides, if there are more than one guarantee contract between two companies, we assumed that there is only one edge between these companies.

There are 8 types of guarantee relationships among listed companies, namely, joint liability guarantee (JLG), guaranteed guarantee (GUG), credit guarantee (CRG), counter guarantee (COG), general guarantee (GEG), mutual guarantee (MUG), mortgage guarantee (MOG), and pledge guarantee (PLG). Table 1 shows numbers of companies and guarantee relationships from 2005 to 2015. Although various guarantee relationships all play an important role in corporate finance, there are some differences among them. In fact, from Table 1, we can obtain the numbers of the 8 types of guarantee relationships from 2005 to 2015, where the numbers of JLG, GUG, CRG, COG, GEG, MUG, MOG, and PLG are 26126, 1705, 710, 106, 3402, 204, 1121, and 551, respectively. It can be seen that the numbers of JLG, GUG, and GEG are the largest three. Therefore, in this paper, we investigate a multiplex network with three layers corresponding, respectively, to JLG, GUG, and GEG. Due to the different time period of guarantees, in this paper we construct networks based on all data from 2005 to 2015 without special instructions.

3. Structure Analysis of Single-Layer Networks

We first investigate topological structures of the three single-layer networks. Figure 1 shows the distributions of degrees of nodes of the JLG network, the GUG network, and the GEG network. It can be seen that degree distributions of these three networks follow a power law, and corresponding exponents are 3.2200, 2.9000, and 2.8900, respectively. Therefore, three single-layer networks all have the scale-free property. This result means that there is a very strong heterogeneity of the

Table 1: Numbers of companies and guarantee relationships from 2005 to 2015.

Year	Number of companies	JLG	GUG	CRG	COG	GEG	MUG	MOG	PLG
2005	1869	1522	135	48	8	154	37	32	20
2006	1772	1424	104	42	6	199	40	30	6
2007	1619	1207	134	66	8	181	43	35	11
2008	1508	1184	123	36	12	120	29	39	17
2009	1291	967	120	34	14	119	23	46	15
2010	2808	1834	395	271	25	170	13	88	108
2011	2643	1937	379	176	29	96	19	86	24
2012	3661	3019	83	6	4	494	0	155	51
2013	4354	3618	78	15	0	545	0	199	88
2014	4900	4102	99	13	0	613	0	184	100
2015	6150	5312	55	3	0	711	0	227	111

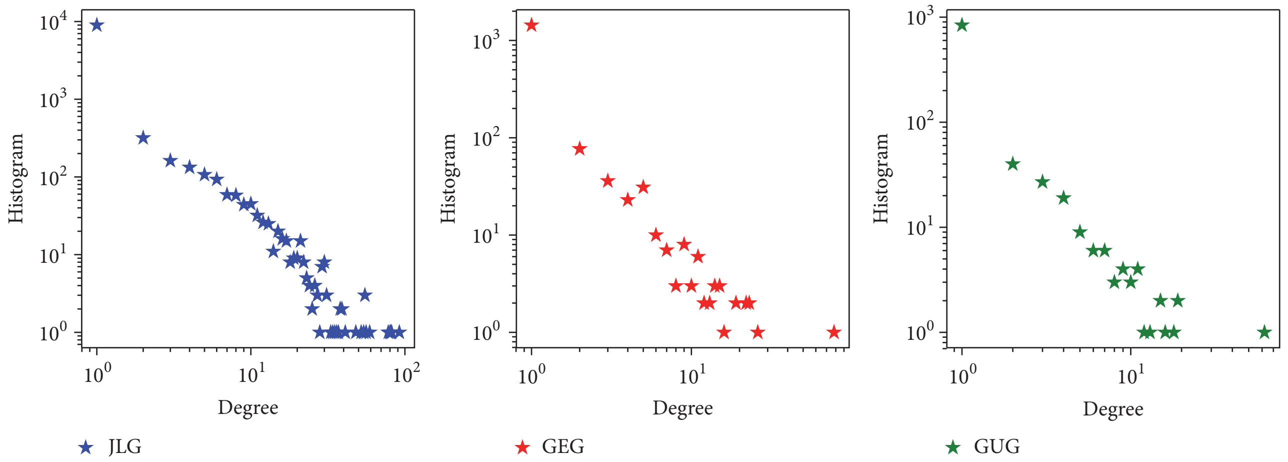


Figure 1: Distribution of degrees of nodes of single-layer networks.

single-layer networks, with few important hubs and many nodes with low degree. This means that few listed companies are at the heart of the guarantee market in China. If these listed companies go bankrupt, it is likely to lead to the break of the guarantee chain, which may lead to regional financial crisis.

Next we analyze degree correlations of the three single-layer networks, which can be measured by the following formula [34]:

$$r = \frac{M^{-1}\sum_i j_i k_i - \left[M^{-1}\sum_i (1/2)\left(j_i + k_i\right)\right]^2}{M^{-1}\sum_i (1/2)\left(j_i^2 + k_i^2\right) - \left[M^{-1}\sum_i (1/2)\left(j_i + k_i\right)\right]^2}, \quad (3)$$

where j_i, k_i are the degrees of the nodes at the ends of the ith edge, with $i = 1, 2, \ldots, M$. This formula measures whether a node of high degree at one end of a link prefers a node of high degree (assortative mixing, $r > 0$) or low degree (disassortative mixing $r < 0$) at the other end. According to this formula, we can obtain that r values of JLG, GUG, and GEG networks are -0.3000, -0.1780, and -0.1670, respectively. This indicates that the three single-layer networks are of disassortative nature; that is, companies of high degrees tend to be connected to companies with low degrees. The possible reason for this is that companies tend to find companies with high credit for guarantee, where companies with high credit usually have high degrees. Therefore, it is necessary to identify the so-called systemically important listed companies, which would adversely affect large parts of the guarantee network in case of their bankruptcies.

4. Structure Analysis of Multiplex Networks

4.1. Similarity Analysis. In this section, we focus on analyzing the similarity between different layers, where the similarity analysis assesses to what extent a layer is representative of the other. We adopt the Jaccard similarity J to analyze network similarity, where the Jaccard similarity is the probability of observing a link in a network conditional on the observation of the same link in the other network [31]. The Jaccard similarity J is defined as follows [31]:

$$J(P, Q) = \frac{|P \wedge Q|}{|P \vee Q|}, \quad (4)$$

where $\wedge(\vee)$ is the entry-wise maximum (minimum) of P and Q.

Table 2: Jaccard similarity of the JLG network over time.

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
2005	0.4430	0.3060	0.2280	0.1710	0.0900	0.0700	0.0500	0.0410	0.0350	0.0270
2006		0.4590	0.3000	0.2160	0.1140	0.0860	0.0650	0.0470	0.0390	0.0290
2007			0.4660	0.3150	0.1490	0.1090	0.0760	0.0550	0.0440	0.0340
2008				0.4560	0.2090	0.1470	0.0950	0.0650	0.0530	0.0390
2009					0.2730	0.1890	0.1150	0.0780	0.0600	0.0430
2010						0.4120	0.2580	0.1770	0.1410	0.1050
2011							0.3390	0.2230	0.1730	0.1260
2012								0.4640	0.3200	0.2260
2013									0.5030	0.3280
2014										0.4840

Table 3: Jaccard similarity of the GUG network over time.

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
2005	0.3580	0.2510	0.1620	0.1230	0.0470	0.0300	0.0090	0.0090	0.0000	0.0000
2006		0.4000	0.2470	0.1850	0.0460	0.0320	0.0330	0.0170	0.0050	0.0060
2007			0.3110	0.2450	0.0690	0.0410	0.0380	0.0190	0.0040	0.0050
2008				0.4820	0.1090	0.0640	0.0400	0.0260	0.0090	0.0110
2009					0.1490	0.0780	0.0410	0.0260	0.0090	0.0120
2010						0.3460	0.0350	0.0170	0.0100	0.0110
2011							0.0290	0.0130	0.0080	0.0090
2012								0.1260	0.0580	0.0950
2013									0.4630	0.1570
2014										0.2830

According to (2), we can obtain that the Jaccard similarity J between the JLG network and the GUG network is 0.0340, and that between the JLG network and the GEG network is 0.0460, and that between the GUG network and the GEG network is 0.0390. Therefore, the Jaccard similarity between different layers is relatively low, and thus a single-layer network is not quite representative of another single-layer network. This means that the structure varies greatly from one single-layer network to another, due to the difference of guarantee types.

Moreover, we can adopt the Jaccard similarity to analyze the similarity of individual layers over time, where the results are shown in Tables 2–4. From them, we can see that J values of the JLG market are roughly around 0.4500 for two consecutive years, and that of the GUG market and the GEG market have obvious fluctuation. This result shows that guarantee relationships in the JLG market are much more stable than those in the GUG market and the GEG market. Besides, the Jaccard similarity decreases with the increase of the lag phase in the three types of guarantee markets.

Similarity analysis is a relevant tool in assessing the stability of individual layers over time and the similarity between different layers. The above results show that the joint liability guarantee relationship is relatively stable in China's guarantee market and suggest significant complementarity between different segments of the guarantee market.

4.2. Centrality Analysis. Centrality is an important concept of network theory. In the paper we analyze mostly betweenness and eigenvector centrality. The betweenness centrality quantifies how frequently a node acts as a bridge along the shortest path between two other nodes and is computed as follows [23]:

$$C_B(v) = \frac{1}{(n-1)(n-2)} \sum_{i,j \neq v} \frac{N_{ij}(v)}{N_{ij}}, \tag{5}$$

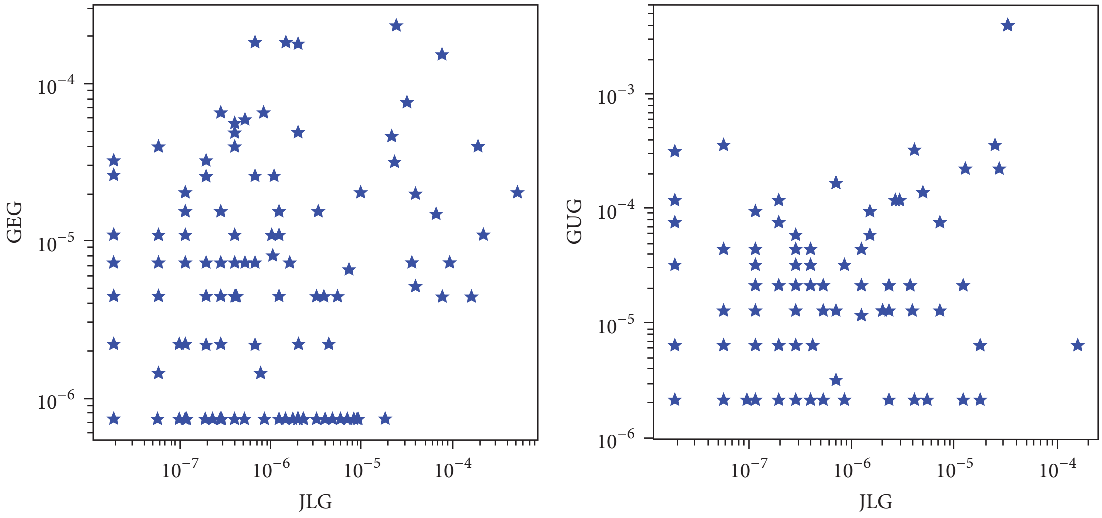
where $C_B(v)$ denotes the betweenness of node v, n is the number of nodes in the network, and N_{ij} represents the number of shortest paths between nodes i and j. $N_{ij}(v)$ is the number of shortest paths between nodes i and j that contain node v. Figure 2 reports the betweenness centrality in the JLG market either versus the betweenness in the GUG market (Figure 2(a)) or versus the betweenness in the GEG market (Figure 2(b)). From Figure 2, we can know that, in some cases, the betweenness centrality of a company can be markedly different in different layers. Therefore central companies in one layer are not necessarily central in another layer.

Eigenvector centrality is defined as the principal eigenvector of the adjacency matrix defining the network [35, 36]. If the adjacency matrix of a network is denoted by A, then the equation of an eigenvector is as follows:

$$\lambda v = Av, \tag{6}$$

Table 4: Jaccard similarity of the GEG network over time.

	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
2005	0.2700	0.1240	0.1000	0.0920	0.0550	0.0250	0.0170	0.0090	0.0120	0.0060
2006		0.2030	0.1560	0.1040	0.0540	0.0310	0.0270	0.0120	0.0160	0.0070
2007			0.2920	0.1860	0.0800	0.0340	0.0270	0.0150	0.0180	0.0110
2008				0.3740	0.1240	0.0430	0.0230	0.0150	0.0170	0.0120
2009					0.2040	0.1080	0.0460	0.0260	0.0240	0.0200
2010						0.1320	0.0680	0.0360	0.0340	0.0230
2011							0.1030	0.0420	0.0370	0.0240
2012								0.3550	0.2270	0.1680
2013									0.3820	0.2780
2014										0.4490



(a) (b)

Figure 2: Betweenness centrality of the multiplex network.

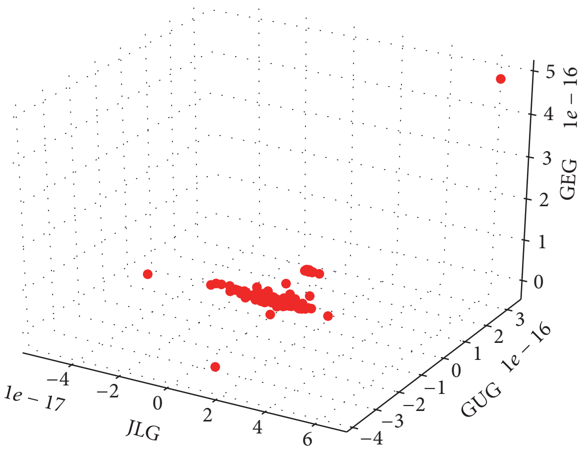


Figure 3: Eigenvector centrality of the multiplex network.

where λ is a constant and ν is the eigenvector. Figure 3 shows the three-dimensional plot of the eigenvector centrality of the multiplex network. From it, we can see that the top central node in one layer is also the top central node in another layer. For nodes except the top central node, we can also obtain that the eigenvector centrality of a company can be markedly different in different layers. This result is the same as that of the betweenness centrality.

According to the above analysis, we can see that the centrality measures are important tools, because they can give insight on the degree of specialization of some listed companies as guarantors for some type of guarantee. Therefore, in order to maintain the stability of the guarantee market in China, the centrality measure provides an important tool.

5. Conclusion

Financial markets are complex systems, which can be understood better based on network theory. Usually, there are more than one type of relationships between financial institutions. Therefore it is very important to understand financial markets from the perspective of multiplex networks rather than single-layer networks. In this paper, we examine how listed companies relate to each other in different types of guarantee relationships. We investigate a multiplex network with three layers corresponding, respectively, to joint liability guarantee, guaranteed guarantee, and general guarantee in China.

First, we find that three single-layer networks all have the scale-free property and are of disassortative nature; that is, companies of high degrees tend to be connected to companies with low degrees. Second, according to similarity analysis, we can know that the Jaccard similarity between different layers is relatively low, and thus a single-layer network is not quite representative of another single-layer network. For individual-layer networks, we find that guarantee relationships in the joint liability guarantee market are much more stable than those in the guaranteed guarantee market and the general guarantee market. And the Jaccard similarity decreases with the increase of the lag phase in the three types of guarantee markets.

Finally, we also investigate the betweenness and eigenvector centrality of a company in the network. The result of the betweenness centrality shows that central companies in one layer are not necessarily central in another layer. And the eigenvector centrality has the same result of the betweenness centrality except the top central company.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this article.

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