The Stock Correlation Network Model and Its Influencing Factors in China's Green Finance Market

Qianting Ma (mqt2626@njau.edu.cn)
Nanjing Agricultural University
Jiaxin Zhao
Nanjing Agricultural University
Xiaoyang Ji
Nanjing Agricultural University
Junchi Shi
Nanjing Agricultural University
Xi Chen
Nanjing University of Finance and Economics

Research Article

Keywords: Green financial market, Stock correlation network, Systemically importance, Green financial policies

Posted Date: June 30th, 2022

DOI: https://doi.org/10.21203/rs.3.rs-1768515/v1

Abstract

Green finance is a significant step to achieving environmentally sustainable development in the context of carbon neutrality. Based on the perspective of the stock correlation network, we select 51 green and environmental protection enterprises and construct the stock correlation network model in China's green financial market according to the correlation of their stock price fluctuations. On this basis, it discusses its network topologies and its dynamic evolution characteristics. After that, it deeply studies its impact mechanism of systemically importance in China's green financial market and introduces the major green financial policies for comparative analysis. In the light of empirical research, we can obtain the following results. First, the stock size distribution in China's green financial market has a power-law tail. Second, a sharp drop in the market index will increase the aggregation of the stock correlation network in the green financial market. Third, the variables about corporate social responsibility, corporate R&D investment intensity, and corporate green innovation output play significant roles in promoting the individual companies' systemically importance ranking in the stock correlation networks of China's green financial market. Fourth, the implementation of major green financial policies has promoted the improvement of the systematic importance of state-owned enterprises. Finally, the research enriches the application research of complex network theory in the green financial market and provides practical guidance for regulators to strengthen the risk monitoring of the green financial market.

1. Introduction

Green development is inseparable from the support of a green financial system. The government work report in 2021 puts forward the goal of "double carbon". In the same year, the State Council issued the guiding opinions on accelerating the establishment and improvement of a green and low-carbon circular development economic system. The document proposed to achieve "carbon peak" and "carbon neutralization". We need to guide the financial system through market-oriented means and provide necessary investment and financing support. Therefore, it is the general trend to use green finance as a mean of environmental protection. It plays a significant role in guiding and motivating more capital to green enterprises.

For the research of green finance, scholars mainly focus on its three complex issues, namely green financial products, green financial market mechanisms, and green financial policies. Specifically, research on green financial products mainly includes green credits, green bonds, green stocks, green insurances, green development funds, weather derivatives, etc. (Peng et al., 2018; Zhang et al., 2020; Sun et al., 2021). Research on the green financial market mechanism mainly includes technology upgrades, green credit guarantees, green investments, and financial risk management (Sági, 2017; Zhu et al., 2017; Steffen, 2021). Research on green finance policy mainly includes the reform of existing fiscal revenue management and distribution policy (Wang and Zhi, 2016), the quality evaluation of green finance policy (Zhou et al., 2020), an exploration of the type of fiscal policy for green finance development (Chang et al., 2020), the enactment of strict environmental regulation by the government (Cui et al., 2020), the reform and innovation of existing financial tools based on Fintech (Muganyi et al., 2021).

As a significant driving force for the development of green finance, whether the stock market can provide positive feedback for the sustainable development of enterprises and carry out effective resource allocation is a significant basis for judging the effectiveness of the construction of the green financial system. It can be said that the stock market is an obviously manifestation of the value of green finance. At the same time, research on the stock network by domestic and foreign scholars has become more and more mature, and the stock market is also of great significance in reflecting the financial activities and the financial status of enterprises. However, few scholars have conducted relevant research on green financial market activities from the perspective of stock correlation network. Therefore, it has a strong practical guiding significance to analyze the green financial market by establishing stock correlation networks.

The stock market is a highly complex system. In a stock market network, a single stock serves as a node of a network, and the relationship among stocks serves as its edge. It is helpful to study the operation mechanism of the stock market by constructing the networks to study the correlation among stocks. In terms of the construction method of a stock network, Mantegna et al. (1999) used the minimum spanning tree method to construct the stock market network for the first time. By analyzing the correlation coefficient of 500 stock returns, they obtained the hierarchical network of the American stock market. Since then, a large number of scholars have used this method, such as Coletti (2016), Kazemilari et al. (2017), Han (2019), etc. In addition, some scholars have carried out a series of extensions, such as the threshold method (Xu et al., 2017; Xi and An, 2018; Guo et al., 2022) and hierarchical tree (Nobi et al., 2015; Patwary et al., 2017; Chen et al., 2022).

The correlation network of the above stocks is weightless. With the deepening of research, some scholars gradually consider the influence of an indicator among stocks, that is, construct a weighted network for correlation analysis. In this regard, Pan et al. (2021) and Liu et al. (2022) have constructed a weighted network for detailed research based on the correlation of stock market return volatility. At the same time, scholars have found that the network structure characteristics of different countries are also significantly differentiated by building stock market networks. Such as the scale-free characteristics of the US stock network (Kim et al., 2002), the small-world nature of the Chinese stock market network (Wang and Yang, 2015), the community structure of the Asia-Pacific stock network (Zhang et al., 2015), the dynamics of the Vietnamese stock network Evolutionary features (Nguyen et al., 2019).

The systemically importance is a significant topological index in complex network theory and plays a considerable role in network structure analysis. The higher the systemically importance of the node in the stock network, the more important its position in the stock network is, and it is also the key monitoring object to prevent the spread of risks in the stock market. For the identification of the systemically importance nodes from the perspective of complex networks, some scholars have carried out related research. For example, Jaramillo et al. (2014) systematically proposed strength centrality, degree centrality, betweenness centrality, closeness centrality, entropic eigenvector centrality, and PageRank centrality. Nicosia et al. (2012) proposed Feedback centrality based on PageRank centrality. Rincón and

Villalobos (2013) proposed authority centrality and hub centrality. However, few scholars have conducted in-depth discussions on the factors that affect the level of systemic importance in the stock network.

In addition, the impact of critical events may lead to changes in the network topology of the stock market. Such studies usually take the local or global financial crisis as the key event. For example, Onnela et al. (2003) showed that the minimum spanning tree length constructed based on the correlation coefficient of returns during the US stock market crisis shortened and led to dynamic changes in the network structure of the stock market. Nobi et al. (2014) studied the dynamic evolution characteristics of the Korean stock network structure before and after the crisis. Yang et al. (2014) found that the stock market crisis will change the correlation structure between the US stock markets, showing a trend from weak to strong. Liu et al. (2022) described the evolutionary characteristics of the network structure in the Chinese stock market bull market and bear market, respectively. Based on this, we can deserve further in-depth discussion for a specific green financial market with the impact of critical events, such as the implementation of major green financial policies.

Overall, existing scholars have conducted in-depth research on the stock network market in various countries. But the research on the stock network of a specific green financial market is limited. Therefore, the analysis of the stock network in China's green financial market has a particular meaning. Based on this, this paper will construct a dynamic network model of China's green financial market based on the correlation of stock price fluctuations in the green financial market, which will help us to understand the pattern and distribution of the green financial industry more intuitively. Compared with the existing research, the main contributions of this paper are as follows: First, it studies the topological structures and dynamic evolution characteristics of the stock correlation network in the green financial market. Second, it analyzes the influence of the systemically importance of the stock correlation network in the green financial market. Finally, it discusses the changes in the structural characteristics of the stock correlation network in the green financial market before and after the implementation of major green financial policies.

The remainder of this paper is organized as follows. Section 2 describes the theoretical models and research hypotheses of the green financial market. It mainly includes three aspects: the stock correlation network model, the stock correlation network systemically importance index, and the research hypotheses. In Section 3, we discuss the main research design scheme. It mainly includes three aspects: the sample selection and data sources, the network structure characteristics in China's green financial market, the research model and variable selection. In Section 4, we discuss the main empirical results. It mainly includes four aspects: descriptive statistics, empirical analysis of benchmark models, robustness testing and heterogeneity analysis. Section 5 provides the main conclusions.

2. Theoretical Model And Research Hypothesis

2.1 Stock correlation network model

A network node represents a single stock in the stock correlation network model. The network edges among nodes represent the correlation of price fluctuations among stocks. According to the research of Pan et al. (2021), we construct a stock correlation network model. We first assume that there are N stocks in the market, and the period is T days. For stocks *i* and *j*, we let a time series length of L and a network interval of s. $\mathrm{Y}_i(\mathrm{n})$ and $\mathrm{Y}_j(\mathrm{n})$ are their stock logarithmic return series, respectively. Then the calculation formulas of the price volatility coefficient correlation matrix $\rho(\mathrm{n}) = \left[\rho_{ij}(\mathrm{n})\right](i = 1,2,\cdots,\mathrm{N}; j = 1,2,\cdots,\mathrm{N})$, metric distance matrix $\mathrm{D}(n) = \left[d_{ij}(n)\right](i = 1,\cdots,\mathrm{N}; j = 1,2,\cdots,\mathrm{N})$ and the weight matrix $\mathrm{W}(k) = \left[w_{ij}(n)\right](i = 1,\cdots,\mathrm{N}; j = 1,2,\cdots,\mathrm{N})$ are presented as formulas (1), (2), and (3), respectively:

$$\rho_{ij}(n) = \frac{\langle Y_i(n)\,Y_j(n)\rangle - \langle Y_i(n)\rangle\langle Y_j(n)\rangle}{\sqrt{\left(\langle Y_i^2(n)\rangle - \langle Y_i(n)\rangle^2\right)\left(\langle Y_j^2(n)\rangle - \langle Y_j(n)\rangle^2\right)}}$$

1

$$d_{ij}(n) = \sqrt{2\left(1 - \rho_{ij}(n)\right)}$$

2

$$w_{ij}(n) = e^{-d_{ij}(n)}$$

3

where $\langle Y_i(n)\rangle$ represents the mathematical expectation of the sequence $\left\{Y_i^1(n), Y_i^2(n), \cdots, Y_i^L(n)\right\}$, $\rho_{ij}(n) \in [-1,1]$, $d_{ij}(n) \in [0,2]$, $w_{ij}(n) \in \left[\mathrm{e}^{-2}, \mathrm{e}^{-1}\right]$.

2.2 Stock correlation network systemically importance index

Degree centrality is one of the most significant topological indicators to describe the centrality of network nodes in the complex network. The greater the degree centrality of the node *i*, the more important the position of the node in the network. In the stock correlation network, network centrality is one of the indicators to measure the systemically importance of enterprises in the network. Degree centrality is one of the most important topological indicators used to describe network centrality in complex network structures. The degree of a node represents the number of edges connected to the node, and a node with more connected edges means more connections with other nodes and greater influence. Therefore, the greater the degree centrality of node i, the higher the degree of systemically importance of the node in the network.

Drawing the experience of research conducted by Opsahl et al. (2010) and Pan et al. (2021), the degree centrality (*DC*) of node *i* in the directed weighted network *G* is defined as equations (4), (5) and (6):

$$DC(i) = k_i^{1-\beta} \times s_i^{\beta}$$

4

$$k_i = \sum_{j}^{n} a_{ij}$$

5

$$s_i = \sum_{j}^{n} w_{ij}$$

6

where k_i denotes the degree of node *i* in the unweighted network corresponding to the directed weighted network *G*, s_i indicates the strength of node *i* in the directed weighted network *G*, βαrepresents the adjustment parameter between node degree and node strength, and *n* represents the number of nodes in the network (that is, the number of stocks).

2.3 Research hypotheses

A single node represents a single stock in the stock correlation network. Network centrality is one of the indicators to measure the systemically importance of enterprises in the network system. The higher the centrality in the network, the more systemically important the enterprise in the correlation network. It also means that it can contact more enterprises and share more information and resources. At the same time, the stronger the ability to control information and resources, the greater the competitiveness in the network.

According to the stakeholder theory proposed by Freeman et al. (2021), corporate social responsibility is not only the economic responsibility to shareholders, but also the corresponding responsibility to the government, customers, employees and the environment. On the one hand, it can improve the enterprise's social value and enhance its external competitiveness through the positive feedback of the enterprise's internal and external social resources. On the other hand, it can also enhance the enterprise's tangible and intangible resources to enhance the enterprise's internal and external competitiveness. Based on this, this paper puts forward hypothesis 1.

Hypothesis 1

The corporate social responsibility has a positive impact on improving the competitiveness of enterprises and making them systemically important in the stock correlation network of China's green financial market.

Innovation is the source of vitality for enterprises to enhance their competitiveness, and R&D is the driving force for ensuring enterprise innovation. R&D investment is not only reflected in the supply of funds, but also includes the training of R&D personnel and the efficiency of transforming R&D products into innovative outputs (Pan et al., 2021). Stable R&D investment can promote the innovation activities of enterprises and enhance the long-term competitiveness of enterprises. Based on this, this paper proposes Hypothesis 2.

Hypothesis 2

The corporate R&D investment intensity has a positive impact on improving the competitiveness of enterprises and making them systemically important in the stock correlation network of China's green financial market.

In the current situation of a deteriorating ecological environment, the future competitive advantage of enterprises must rely on the positive promotion of sustainable environmental development, and the output of green innovation is particularly important (Yang et al., 2021). Enterprises pay more attention to green innovation and accelerate the transformation of green innovation output, which can not only avoid the punishment of environmental regulation, but also produce green products with both functions and environmental benefits. It plays a meaningful role in meeting the green consumption needs of consumers, shaping the green brand image and improving the market competitiveness. Based on this, this paper puts forward hypothesis 3.

Hypothesis 3

The corporate green innovation output has a positive impact on improving the market competitiveness of enterprises and improving the ranking of systemically importance in the green finance stock correlation network.

The influence mechanism of the above theoretical analysis is shown in Fig. 1.

3. Research Design Scheme

3.1 Sample selection and data sources

Considering the core elements of environmental protection, sustainable development, and social responsibility in the definition of green enterprises, this paper collects a total of 51 stocks of green enterprises in China's listed companies from January 1, 2013 to December 31, 2020. The daily closing price data of all stocks is processed through forwarding re-weighting. After the initial data processing, the daily log-return data of 51 stocks for 1944 trading days can be obtained. The total number of stock correlation networks in the green finance market is 32. The data selected in this paper are all from the Wind database.

Table 1 lists the closing prices of 51 stocks on the last trading day in 2020. It can be seen from Table 1 that in China's green financial market, there are 5 stocks with a closing price of more than 10 yuan, 29 stocks with a closing price of 5–10 yuan and 17 stocks with a closing price of less than 5 yuan. ‘600323’, ‘002034’, ‘000803’, ‘300103’ and ‘600283’ are the top five stocks in China's green financial market and the leading stocks in China's green financial market. Among them, ‘600323’ has the highest market value, and its closing price on the last trading day reached 24.55 yuan. It is the only stock with a share price of more than 20 yuan among green environmental protection enterprises.

Table 1
The closing price of 51 stocks on the last trading day

Stock Code	Daily closing price	Stock Code	Daily closing price
‘600323’	24.55	‘300055’	6.04
‘002034’	15.49	‘300056’	6.00
‘000803’	13.39	‘000605’	5.81
‘300103’	10.56	‘600217’	5.74
‘600283’	10.16	‘300072’	5.68
‘002645’	9.03	‘002573’	5.28
‘002672’	8.70	‘600769’	5.24
‘600388’	8.69	‘601158’	5.12
‘000551’	8.07	‘000598’	4.71
‘000685’	8.01	‘600526’	4.53
‘000967’	8.00	‘002266’	4.50
‘002549’	7.87	‘300172’	4.47
‘300070’	7.60	‘002310’	4.14
‘300190’	7.46	‘601199’	3.90
‘002205’	7.42	‘300262’	3.86
‘000920’	7.25	‘300355’	3.58
‘300140’	7.18	‘300266’	3.35
‘600292’	7.12	‘000068’	3.25
‘300187’	6.78	‘300197’	3.17
‘600168’	6.77	‘300152’	2.79
‘000826’	6.76	‘600008’	2.76
‘000544’	6.75	‘000711’	2.64
‘600874’	6.64	‘000005’	2.53
‘300137’	6.51	‘600187’	2.50
‘600461’	6.37	‘002210’	2.15
‘002658’	6.07		

To further explore the stock size distribution of China's green financial market at different times, we use the stock size distribution for further analyzing it. Figure 2 shows the double logarithm distribution of the stock price scale and its cumulative probability of 51 Chinese green financial markets from 2013 to 2020 in the double logarithm coordinate system. It can be seen from Fig. 2 that when the stock price scale exceeds a certain threshold, the distribution of stock scale in China's green financial market during 2013–2020 corresponds to the power-law distribution with indexes of 2.8329, 5.7770, 7.5790, 5.5006, 4.9458, 4.9458, 4.1076 and 4.5814 respectively, showing apparent power-law tail characteristics. In fact, the empirical study of Fujiwara et al. (2010) also found that the asset size distribution has the characteristic of power-law tail, and the stock size distribution of green financial market constructed in this paper reproduces this characteristic again. This also shows that only a minority group holds large-scale assets in the whole green financial market, while the majority group has only a small amount of wealth.

(1) T = 2013 with power-law index 2.8329 (2) T = 2014 with power-law index 5.7770

(3) T = 2015 with power-law index 7.5790 (4) T = 2016 with power-law index 5.5006

(5) T = 2017 with power-law index 4.9458 (6) T = 2018 with power-law index 4.9458

(7) T = 2019 with power-law index 4.1076 (8) T = 2020 with power-law index 4.5814

Figure 2. Stock price distribution of China's green finance market during 2013–2020

3.2 Network structure characteristics

To analyze the correlation between stocks in China's green financial market, we build stock correlation networks. Figure 3 shows the stock correlation network on the last trading day of 2020, in which the nodes of the network represent green enterprise stocks, and their edges represent the correlation between stocks. The larger the nodes, the stronger the network centrality of stocks, and the more significant the position in the network.

Figure 3. Stock correlation network of China's green financial market

It can be seen from Fig. 3 that stocks ‘000605’, ‘002205’, ‘300055’ and ‘300137’ are at the core of the network, have stronger relevance with other stocks, and have a greater impact on the green finance stock network. At the same time, only a few stocks are in the core position in the green financial market, while the rest are mostly distributed on the edge. The greater the degree centrality of the corresponding stock node in the stock market network, the stronger the risk contagion ability in the stock market network. It can be seen from Table 1 that the order of stocks ranked according to market value in China's green financial market is different from that ranked according to degree centrality, which shows that we should pay attention to stocks with high market value and pay enough attention to stocks that are systemically important in the stock correlation network of China's green financial market to avoid the risk infection in the network.

In order to study the dynamic evolution characteristics of stock association network in China's green financial market, referring to the research of Pan et al. (2021), we selected the average path length and clustering coefficient for in-depth research. Figure 4 depicts the average path length and clustering coefficient evolution of 32 quarterly stock association networks constructed by 51 stocks in China's green financial market from 2013 to 2020. As can be seen from Fig. 4, the average path length of the stock association network of China's green financial market fluctuated up and down in the range of 2.4–3.5 during the whole evolution process, and the clustering coefficient fluctuated steadily between 0.3–0.5. In addition, it can be found that the average path length became short and the clustering coefficient increased in January 2016 during the evolution of the stock network. It is mainly due to the sharp decline of the A-share market in the whole month, which results in the strong consistency of the market's volatility.

3.3 Research model and variable selection

To deeply explore the internal mechanism of the evolution of the green financial stock market structure, this paper will further explore what factors affect the systemically importance of the stock correlation network in China's green financial market during the dynamic evolution of the network. Based on previous research ideas and regarding the latest research results of Freeman et al. (2021), Pan et al. (2021), and Yang et al. (2021), this paper constructs the following model:

$$DC = \alpha_0 + \alpha_1 CSR + \alpha_2 R\&D + \alpha_3 Innov + \alpha_4 Dman + \alpha_5 Pman + \alpha_6 lnCap + \alpha_7 Growth + \alpha_8 lnTobinQ + \alpha_9 Type + \epsilon$$

7

This paper selects the network centrality of the stock correlation network in China's green financial market as the explained variable to represent the systemically importance, which is specifically measured by degree centrality (*DC*) with its adjustment parameter β = 0.5. Where α_0 is a constant term and ϵ is a random disturbance term. At the same time, this paper selects the following explanatory variables: *CSR* represents corporate social responsibility, which is derived from Hexun's corporate social responsibility score; *R&D* refers to the corporate R&D investment intensity, which is measured by the ratio of total R&D expenditure to total operating income; *Innov* indicates the corporate green innovation output, which is expressed as the logarithm after adding one to the number of green patents. In addition, this paper selects the following control variables: *Dman* and *Pman* indicate whether the management holds shares and the proportion of management shares; lnCap indicates the corporate capital structure, which is the logarithm of total liabilities divided by total assets; *Growth* refers to the growth of the enterprise, which is specifically expressed as the growth rate of the enterprise's operating revenue; lnTobinQ represents the logarithm of the Tobin Q value of the enterprise; Type represents the type of enterprise, and the state-owned enterprise is 1, otherwise 0. The above data are all from Guotai'an database and Hexun.com.

4. Empirical Results

4.1 Descriptive statistics

To control the influence of extreme values, the tail reduction treatment of the research variables at the 1% level is carried out in this paper. The descriptive statistics of the main variables are shown in Table 2. All samples are in a reasonable range of values, which provides a good basis for subsequent research.

Table 2
Definition and descriptive statistics of variables

VARIABLES	Mean Value	Standard Deviation	Minimum Value	Maximum Value
DC	60.669	4.383	50.293	72.557
CSR	21.902	14.138	-16.687	96.103
R&D	2.669	2.270	-1.289	13.753
Innov	0.771	1.136	-1.635	3.752
Dman	0.733	0.446	-0.156	1.156
Pman	0.104	0.176	-0.086	0.801
lnCap	-0.801	0.458	-2.108	0.000
Growth	0.288	0.841	-0.905	5.590
lnTobinQ	0.842	0.290	-0.027	1.208
Type	0.419	0.497	-0.156	1.156

4.2 Empirical analysis of benchmark models

This paper uses Stata15 software to analyze the influencing factors of the systemically importance of stock correlation networks in China's green financial market. To judge whether the characteristics of individual effects are related to explanatory variables, we first need to use the Hausmann model to judge whether to establish a fixed effect model or a random effect model. According to the results of the Hausmann test, the *P*-value of the Hausmann test is 0.000. Therefore, we reject the original hypothesis and select the fixed effect model for regression.

The regression results are shown in Table 3. Columns (1) and (2) are OLS estimates, and columns (3) and (4) are fixed-effect models. Columns (2) and (4) control the impact of the years. The VIF test is adopted to avoid multicollinearity among variables. The results show that the VIF values of each variable are less than 10, indicating that there is no multicollinearity in the model.

Table 3
The regression results of the factors affecting the systemically importance

VARIABLES	OLS	OLS	FE	FE
	(1)	(2)	(3)	(4)
CSR	0.0580***	0.0466***	0.0293***	0.00415
	(-5.94)	(-4.43)	(-3.09)	(-0.55)
R&D	0.108	0.045	0.179**	0.0721
	(-1.34)	(-0.53)	(-2.14)	(-1.1)
Innov	0.720***	0.601***	0.586***	0.258**
	(-4.5)	(-3.81)	(-4.3)	(-2.38)
Dman	-0.353	-0.457	0.896**	0.803**
	(-0.87)	(-1.05)	(-2.04)	(-2.36)
Pman	-0.407	-0.259	-3.631**	-3.613***
	(-0.27)	(-0.17)	(-2.38)	(-3.07)
lnCap	-1.171**	-1.078**	0.756*	1.018***
	(-2.46)	(-2.21)	(-1.88)	(-3.25)
Growth	-0.505**	-0.508**	-0.181	-0.154
	(-2.09)	(-2.33)	(-1.41)	(-1.54)
lnTobinQ	0.39	-0.354	-1.435*	-2.674***
	(-0.66)	(-0.53)	(-1.87)	(-3.03)
Type	1.312***	1.290***	0.301	-0.165
	(-3.33)	(-3.16)	(-0.67)	(-0.45)
Year	/	YES	/	YES
_cons	57.19***	59.31***	60.56***	64.00***
	(-66.69)	(-60.6)	(-62.23)	(-66.92)
N	1632	1632	1632	1632
Note: *, **, and *** indicate 10%, 5%, and 1% significant, respectively; T-statistics are reported in the parentheses.				

According to the individual fixed effect model, the explanatory variables about corporate social responsibility, R&D investment intensity, management's shareholding status, management's shareholding ratio, corporate green innovation output, corporate capital structure and Tobin Q value will all play significant roles in promoting the systemically importance ranking of individual companies in the stock correlation networks of China's green financial market.

(1) Corporate social responsibility

The corporate social responsibility plays a positive role in promoting the systemically importance ranking of individual companies in the stock correlation networks of China's green financial market. It displays that the higher the sense of corporate social responsibility, the more central the position in the green financial stock market network. Therefore, hypothesis 1 is verified. Enterprises will gradually form an environmental protection mechanism due to actively fulfilling their social responsibilities, which will increase their technical and economic investment in both production and waste treatment. Therefore, the more significant their position in the green financial network, the stronger their influence.

(2) Corporate R&D investment intensity

The corporate R&D investment intensity plays a positive role in promoting the systemically importance ranking of individual companies in the stock correlation networks of China's green financial market. It demonstrates that the larger the proportion of total R & D expenditure in operating revenue, the more the enterprise pays attention to environmental protection activities and is more important in the green financial stock market network. Therefore, hypothesis 2 is verified. Many green enterprises have introduced advanced high-tech in R&D, which have become the main production activities.

(3) Corporate green innovation output: The corporate green innovation output plays a positive role in promoting the systemically importance ranking of individual companies in the stock correlation networks of China's green financial market. It exhibits that the more green innovation output of enterprises, the more green patents for inventions. In addition, the more attention they pay to their environmental protection behavior in the process of their own development, the more significant they are in the green financial stock market network. Therefore, hypothesis 3 has been verified. Enterprises carry out green output to reduce the later environmental cost and improve the competitiveness in the case of environmental regulation. Therefore, the more the green innovation output, the stronger the competitive edge, and the more influential they are in the stock network of the green financial market.

4.3 Robustness testing

To investigate the reliability of the above model estimation results, a robustness test is carried out in this paper. The method of adjusting the degree centrality parameters is adopted, and the adjusting parameters of degree centrality are {\beta }=1 and {\beta }=1.5, respectively. Table 4 displays the regression results of the degree centrality adjustment parameter {\beta }= 1, and Table 5 exhibits the regression results of the degree centered adjustment parameter {\beta } = 1.5. The regression results show that the variables about corporate social responsibility, R&D investment intensity, management's shareholding status, management's shareholding ratio, and corporate green innovation output play significant roles in promoting the systemically importance ranking of individual companies in the stock correlation networks of China’s green financial market. The significance level and sign direction of each variable are consistent with the previous text, and the coefficient is slightly adjusted, indicating that the result of this model is robust.

Table 4
The regression results of the degree centrality adjustment parameter {\beta }= 1

VARIABLES	OLS	OLS	FE	FE
	(1)	(2)	(3)	(4)
CSR	0.0693***	0.0547***	0.0375***	0.00585
	(-5.83)	(-4.26)	(-3.29)	(-0.66)
R&D	0.13	0.0504	0.220**	0.0829
	(-1.38)	(-0.5)	(-2.18)	(-1.08)
Innov	0.859***	0.712***	0.706***	0.301**
	(-4.49)	(-3.79)	(-4.3)	(-2.37)
Dman	-0.49	-0.3	-4.242**	-4.218***
	(-0.28)	(-0.16)	(-2.31)	(-3.05)
Pman	-0.394	-0.529	1.059**	0.938**
	(-0.82)	(-1.03)	(-2.00)	(-2.35)
lnCap	0.562	-0.387	-1.464	-3.110***
	(-0.8)	(-0.49)	(-1.59)	(-3.00)
Growth	-1.400**	-1.275**	0.828*	1.178***
	(-2.48)	(-2.21)	(-1.71)	(-3.19)
lnTobinQ	-0.592**	-0.603**	-0.214	-0.19
	(-2.11)	(-2.42)	(-1.38)	(-1.61)
Type	1.534***	1.514***	0.369	-0.162
	(-3.32)	(-3.17)	(-0.68)	(-0.38)
Year	/	YES	/	YES
_cons	32.03***	34.63***	35.80***	40.09***
	(-31.36)	(-29.82)	(-30.6)	(-35.65)
N	1632	1632	1632	1632

Note: *, **, and *** indicate 10%, 5%, and 1% significant, respectively; T-statistics are reported in the parentheses.

Table 5
The regression results of the degree centrality adjustment parameter {\beta }= 1.5

VARIABLES	OLS	OLS	FE	FE
	(1)	(2)	(3)	(4)
CSR	0.0626***	0.0484***	0.0361***	0.00612
	(-5.71)	(-4.09)	(-3.48)	(-0.78)
R&D	0.119	0.0432	0.204**	0.0723
	(-1.43)	(-0.49)	(-2.23)	(-1.06)
Innov	0.773***	0.637***	0.644***	0.269**
	(-4.46)	(-3.78)	(-4.32)	(-2.38)
Dman	-0.446	-0.261	-3.743**	-3.715***
	(-0.28)	(-0.16)	(-2.25)	(-3.01)
Pman	-0.33	-0.46	0.941*	0.824**
	(-0.77)	(-1.00)	(-1.96)	(-2.32)
lnCap	0.596	-0.312	-1.089	-2.721***
	(-0.96)	(-0.45)	(-1.30)	(-2.94)
Growth	-1.263**	-1.139**	0.679	1.028***
	(-2.50)	(-2.20)	(-1.54)	(-3.13)
lnTobinQ	-0.522**	-0.540**	-0.189	-0.178*
	(-2.12)	(-2.50)	(-1.35)	(-1.69)
Type	1.351***	1.341***	0.34	-0.109
	(-3.3)	(-3.17)	(-0.69)	(-0.29)
Year	/	YES	/	YES
_cons	17.90***	20.29***	21.06***	25.09***
	(-19.51)	(-19.53)	(-19.79)	(-25.06)
N	1632	1632	1632	1632

Note: *, **, and *** indicate 10%, 5%, and 1% significant, respectively; T-statistics are reported in the parentheses.

4.4 Heterogeneity Analysis

We introduce major green financial policies for comparison and verification. In order to achieve the "double carbon" goal of green transformation, China has continuously issued new green financial policies in recent years. The research on green financial policy is not only an important content to accelerate the realization of the "double carbon" goal, but also a significant measure to promote China's economic transformation and promote economic development. In August 2016, the people's Bank of China issued “the guidance on building a green financial system” (hereinafter referred as “the Guidance”). It made an overall plan for the green financial system at the national level, marking the rise of China's green finance from economic policy to national strategy, which is of far-reaching significance to the development of China's green finance. Meanwhile, according to the statistics on the green credit balance of Chinese commercial banks from 2013 to 2019, it can be found that the growth rate of green credit balance in June 2017 was the largest, more than 10%. It can be considered that the significant increase in the balance of green credit is the role of the guiding opinions due to the lag effect in the release and implementation of the policy. It once again shows the great significance of the green finance policy based on the guiding opinions to the development of green finance in China. Therefore, this paper selects “the Guidance” issued in August 2016 as the major green financial policy in the development of green finance. We intend to explore whether the influencing factors of the systemically important level of stock correlation networks in China's green financial market have changed before and after the implementation of the major green financial policy. Taking the major green financial policies in August 2016 as the dividing line, Table 6 displays the impact of different factors on the centrality of stock related networks in China's green financial market before and after the implementation of the major green financial policies.

Table 6
Heterogeneity Analysis of regression model

VARIABLES	Before the implementation of green finance policy		After the implementation of green finance policy	
	OLS	FE	OLS	FE
CSR	0.0497***	0.0484***	0.028	-0.00912
	(-3.81)	(-3.21)	(-1.58)	(-0.58)
R&D	0.141	0.172	0.0893	0.0578
	(-1.31)	(-1.14)	(-0.9)	(-0.42)
Innov	1.134***	1.359***	0.563***	0.595***
	(-4.45)	(-5.6)	(-2.91)	(-3.48)
Dman	0.952	3.957***	-0.737	0.515
	(-1.52)	(-3.84)	(-1.49)	(-0.88)
Pman	-1.285	-5.947*	1.166	-0.456
	(-0.68)	(-1.83)	(-0.72)	(-0.21)
lnCap	-0.94	0.886	-1.463**	0.552
	(-1.30)	(-1.31)	(-2.27)	(-0.86)
Growth	-0.193	0.0688	-0.762***	-0.096
	(-0.68)	(-0.32)	(-2.82)	(-0.57)
lnTobinQ	-0.806	2.828**	2.518**	15.62***
	(-1.06)	(-2.09)	(-2.18)	(-6.72)
Type	2.001***	1.488	1.165***	1.589***
	(-3.21)	(-1.08)	(-2.99)	(-3.13)
_cons	56.26***	54.86***	55.65***	44.47***
	(-48.84)	(-32.34)	(-35.49)	(-17.46)
N	714	714	918	918

Note: *, **, and *** indicate 10%, 5%, and 1% significant, respectively; T-statistics are reported in the parentheses.

Clear conclusions can be drawn according to the fixed effect model. Before the people's Bank of China issued major green finance policies, the variables about corporate social responsibility, management's shareholding status, management's shareholding ratio, corporate green innovation output and corporate Tobin Q value play significant roles in promoting the systemically importance ranking of individual companies in the stock correlation networks of China's green financial market. After the release of major green finance policies, the variables about corporate green innovation output, corporate Tobin Q and corporate type play significant roles in promoting the systemically importance ranking of individual companies in the stock correlation networks of China's green financial market.

It can be seen that before and after the people's Bank of China issued the green finance policy, the variables about corporate social responsibility, management's shareholding status and management's shareholding ratio changed from significant to insignificant. It demonstrates that the implementation of the green finance policy weakens the role of these explanatory variables in promoting the ranking of individual enterprises in the stock correlation network of China's green financial market.

At the same time, it is worth noting that before and after the people's Bank of China issued major green financial policies, the variable of corporate type changed from insignificant to significant at the level of 1%. It exhibits that the green financial policy has promoted the improvement of the ranking of state-owned enterprises in the stock correlation network of China's green financial market to a certain extent. Green bond is an important part of green financial products, but there are still some problems, such as insufficient development and unbalanced resources. According to the report released by the International Research Institute of green finance of the Central University of Finance and economics, the main issuers of green corporate bonds are state-owned enterprises. In 2020, state-owned enterprises issued a total of 70.84 billion yuan of green corporate bonds, with 64 issuing enterprises. Private enterprises issued 2.37 billion yuan of green corporate bonds, with only four issuing enterprises. To some extent, this reflects the state's policy preference for state-owned enterprises in issuing green bonds. At the same time, small and micro enterprises also have higher standards and requirements in the face of green bond issuance, so it is difficult to participate in green bond financing.

5. Conclusions

This paper constructs the stock correlation network of China's green financial market based on 51 green environmental protection enterprises in China. After that we empirically study the factors affecting the systemically importance of the stock correlation network, and introduce the major green financial policies issued by the people's Bank of China in 2016 for comparative research. Through empirical research and analysis, our main conclusions include the following. First, through the cumulative probability double logarithm distribution of China's stock price, it can be seen that the stock distribution in China's green financial market has the characteristics of the power-law tail. Second, the stock correlation network of China's green financial market shows stable changes in clustering coefficient and average path length in the whole evolution process, and the serious decline of the market will aggravate the aggregation of stock correlation network in the green financial market. Third, the top five stocks in market value in China's green financial market are inconsistent with the top five stocks in systemically importance. It shows that in the process of financial supervision, we should not only focus on monitoring stocks with large stock scale, but also focus on supervising stocks at important nodes in the stock market to avoid their risk infection in the stock market network. Fourth, the variables about corporate social responsibility, R&D investment intensity, and corporate green innovation output play significant roles in promoting the systemically importance ranking of individual companies in the stock correlation networks of China’s green financial market. Fifth, the implementation of the green finance policy weakens the role of explanatory variables about corporate social responsibility, management's shareholding status and management's shareholding ratio in promoting the ranking of individual enterprises in the stock correlation network of China's green financial market. Sixth, the green financial policy has promoted the improvement of the ranking of state-owned enterprises in the stock correlation network of China's green financial market to a certain extent.

Based on the above conclusions, this paper puts forward the following policy suggestions. First, the stocks with the high systemically importance ranking are the key monitoring objects to prevent the risk infection in the green financial market. Strengthening the monitoring of "too related to fail" stocks is an important measure to prevent systematic risks. Secondly, we should strengthen the incentive of green innovation and increase the R&D investment of enterprises in green innovation to establish a perfect market mechanism and speed up the transformation of green innovation achievements. Finally, we should further improve the current situation of green financing of private enterprises to make more and more minor enterprises become the new driving force of China's green financial market. Effective measures include formulating more comprehensive green financing policies and developing more green financing products. To sum up, an in-depth study of the stock correlation network of China's green financial market is conducive to understanding the pattern and distribution of the green financial industry and helps the regulators to identify the core stocks that are "too correlated to fail" in the green financial market. It has theoretical reference value and practical guiding significance for strengthening the risk monitoring measures of the green financial market and maintaining the smooth operation of the green financial market.

Declarations

Acknowledgements

We wish to express our gratitude to the referees for their invaluable comments and suggestions. This research is supported by Fundamental Research Fund for Humanities and Social Sciences in Central Universities (Grant number SKYC2021021) and 2021 General Project of Philosophy and Social Science Research in Colleges and Universities of Jiangsu Provincial Department of Education (Grant number 2021SJA0059).

Ethics approval and consent to participate

Not applicable

Consent for publication

Not applicable

Availability of data and materials

The datasets generated and/or analysed during the current study are not publicly available due privacy or ethical restrictions but are available from the corresponding author on reasonable request.

Authors' Contribution

Qianting Ma: Conceptualization, Formal analysis, Revision and finalization, Funding acquisition. **Jiaxin Zhao**: Data curation, Methodology, Writing Original draft preparation. **Xiaoyang**: Data curation, Investigation, Methodology. **Junchi Shi**: Software, Formal analysis. **Xi Chen**: Formal analysis, Writing - review & editing.

Conflicts of interest

The authors declare that there are no conflicts of interest.

References

1. Chang K, Wan Q, Lou Q et al (2020) Green fiscal policy and firms' investment efficiency: new insights into firm-level panel data from the renewable energy industry in China. Renewable Energy 151:589–597
2. Chen H, Zheng X, Zeng DD (2020) Analyzing the co-movement and its spatial–temporal patterns in Chinese stock market. Physica A 555:124655
3. Coletti P (2016) Comparing minimum spanning trees of the Italian stock market using returns and volumes. Physica A 463:246–261
4. Cui H, Wang R, Wang H (2020) An evolutionary analysis of green finance sustainability based on multi-agent game. J Clean Prod 269:121799
5. Freeman RE, Dmytriyev SD, Phillips RA (2021) Stakeholder theory and the resource-based view of the firm. J Manag 47(7):1757–1770
6. Fujiwara Y, Aoyama H (2010) Large-scale structure of a nation-wide production network. Eur Phys J B 77(4):565–580
7. Guo X, Li W, Zhang H et al (2022) Multi-likelihood methods for developing relationship networks using stock market data. Physica A 585:126421
8. Han D (2019) Network analysis of the Chinese stock market during the turbulence of 2015–2016 using log-returns, volumes and mutual information. Physica A 523:1091–1109
9. Kazemilari M, Mardani A, Streimikiene D et al (2017) An overview of renewable energy companies in stock exchange: Evidence from minimal spanning tree approach. Renewable Energy 102:107–117
10. Kim HJ, Kim IM, Lee Y, Kahng B (2002) Scale-free network in stock markets. Journal-Korean Phys Soc 40:1105–1108

11. Liu W, Ma Q, Liu X (2022) Research on the dynamic evolution and its influencing factors of stock correlation network in the Chinese new energy market. Finance Res Lett 45:102138
12. Mantegna RN (1999) Information and hierarchical structure in financial markets. Comput Phys Commun 121:153–156
13. Martinez-Jaramillo S, Alexandrova-Kabadjova B, Bravo-Benitez B et al (2014) An empirical study of the Mexican banking system's network and its implications for systemic risk. J Economic Dynamics Control 40:242–265
14. Muganyi T, Yan L, Sun H (2021) Green finance, fintech and environmental protection: Evidence from China. Environ Sci Ecotechnology 7:100107
15. Nguyen Q, Nguyen NKK, Nguyen LHN (2019) Dynamic topology and allometric scaling behavior on the Vietnamese stock market. Physica A 514:235–243
16. Nicosia V, Criado R, Romance M et al (2012) Controlling centrality in complex networks. Sci Rep 2:218–218
17. Nobi A, Maeng SE, Ha GG et al (2014) Effects of global financial crisis on network structure in a local stock market. Physica A 407:135–143
18. Nobi A, Maeng SE, Ha GG et al (2015) Structural changes in the minimal spanning tree and the hierarchical network in the Korean stock market around the global financial crisis. J Korean Phys Soc 66(8):1153–1159
19. Onnela JP, Chakraborti A, Kaski K et al (2003) Dynamic asset trees and Black Monday. Physica A 324(1–2):247–252
20. Opsahl T, Agneessens F, Skvoretz J (2010) Node centrality in weighted networks: Generalizing degree and shortest paths. Social networks 32(3):245–251
21. Pan Z, Ma Q, Ding J et al (2021) Research on the stock correlation networks and network entropies in the Chinese green financial market. Eur Phys J B 94(2):1–11
22. Patwary EU, Lee JY, Nobi A et al (2017) Changes of hierarchical network in local and world stock market. J Korean Phys Soc 71(7):444–451
23. Peng H, Luo X, Zhou C (2018) Introduction to China's green finance system. J Service Sci Manage 11(01):94
24. Rincón CEL, Villalobos JP (2013) Authority Centrality and Hub Centrality as metrics of systemic importance of financial market infrastructures. Banco de la Republica de Colombia
25. Sági J (2017) Credit guarantees in sme lending, role, interpretation and valuation in financial and accounting terms. Econ Manage Innov 9(3):62–70
26. Steffen B (2021) A comparative analysis of green financial policy output in OECD countries. Environ Res Lett 16(7):074031
27. Sun Y, Sun Y, Li X (2021) Constructing a green financial innovation system with the PPP environmental protection industry fund. Int J Technol Manage 85(2–4):319–332

28. Wang Y, Zhi Q (2016) The role of green finance in environmental protection: Two aspects of market mechanism and policies. Energy Procedia 104:311–316
29. Wang Y, Yang Z (2015) Correlation analysis of topology of stock volume of Chinese Shanghai and Shenzhen 300 index. In 2015 3rd International Conference on Mechatronics and Industrial Informatics (ICMII 2015). Atlantis Press
30. Xi X, An H (2018) Research on energy stock market associated network structure based on financial indicators. Physica A 490:1309–1323
31. Xu R, Wong WK, Chen G et al (2017) Topological characteristics of the hong kong stock market: A test-based p-threshold approach to understanding network complexity. Sci Rep 7(1):1–16
32. Yang C, Zhu X, Li Q et al (2014) Research on the evolution of stock correlation based on maximal spanning trees. Physica A 415:1–18
33. Yang W, Ma Q, He J et al (2021) Can green innovation subsidies reduce the systemic risk of green innovative enterprises? A simulation study.Technology Analysis & Strategic Management1–17
34. Zhang H, Wu S, Tian Y (2020) Does Green Credit Matter in the Effect of Payments for Ecosystem Services on Economic Growth? Evidence from Xin'anjiang River Basin. J Coastal Res 106(SI):435–439
35. Zhang W, Zhu Y, Zhao Y et al (2015) Research on Evolution of Asia-Pacific Stock Markets Network Structure Based on Complex Network Theory. J Comput Theor Nanosci 12(12):5859–5869
36. Zhou X, Tang X, Zhang R (2020) Impact of green finance on economic development and environmental quality: a study based on provincial panel data from China. Environ Sci Pollut Res 27(16):19915–19932
37. Zhu W, Zhu Z, Fang S et al (2017) Chinese students' awareness of relationship between green finance, environmental protection education and real situation. Eurasia J Math Sci Technol Educ 13(7):3753–3769

Figures

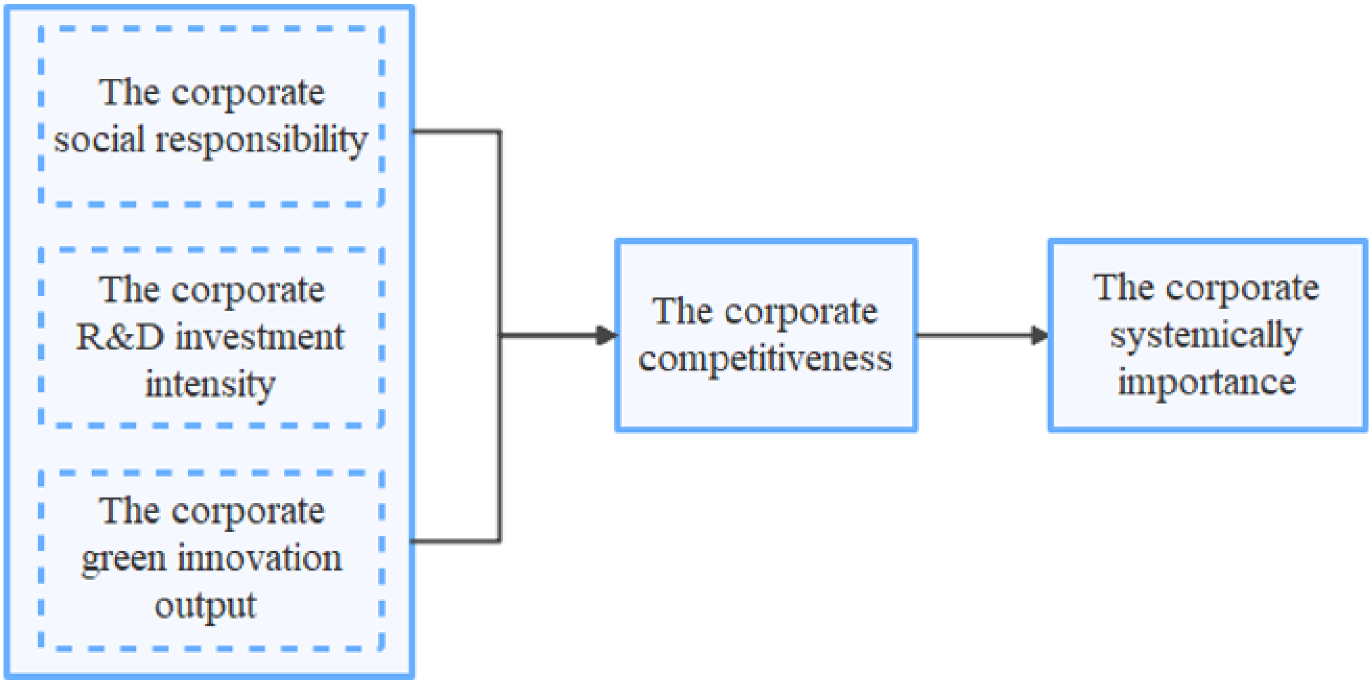

Figure 1

Influence mechanism diagram

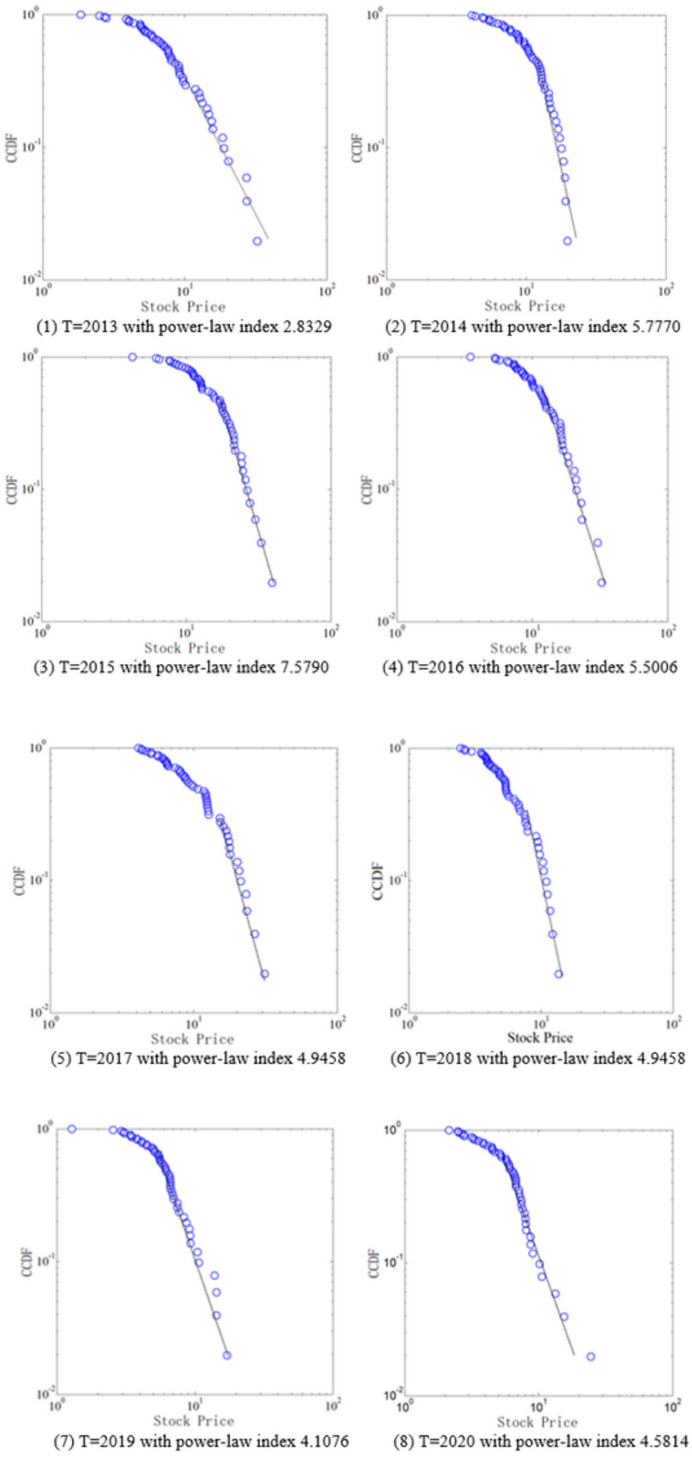

Figure 2

Stock price distribution of China's green finance market during 2013-2020

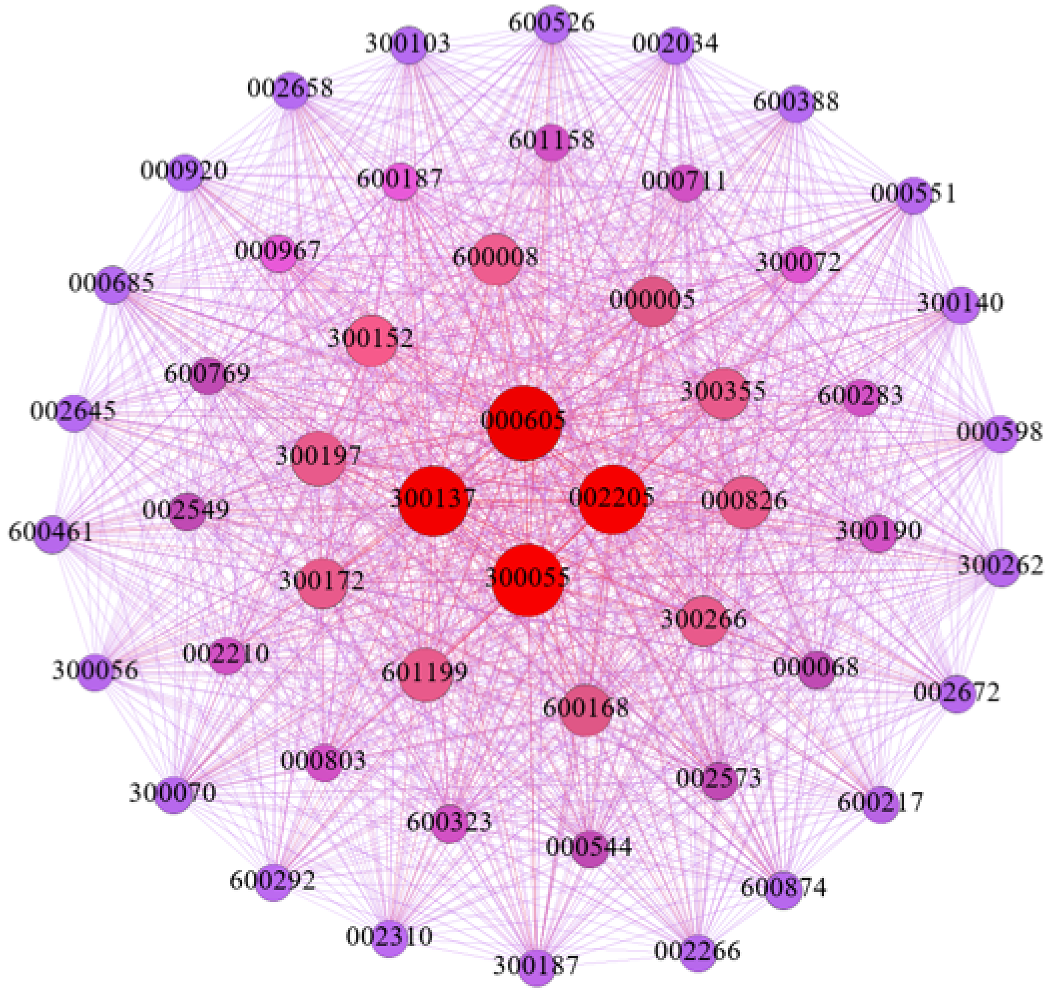

Figure 3

Stock correlation network of China's green financial market

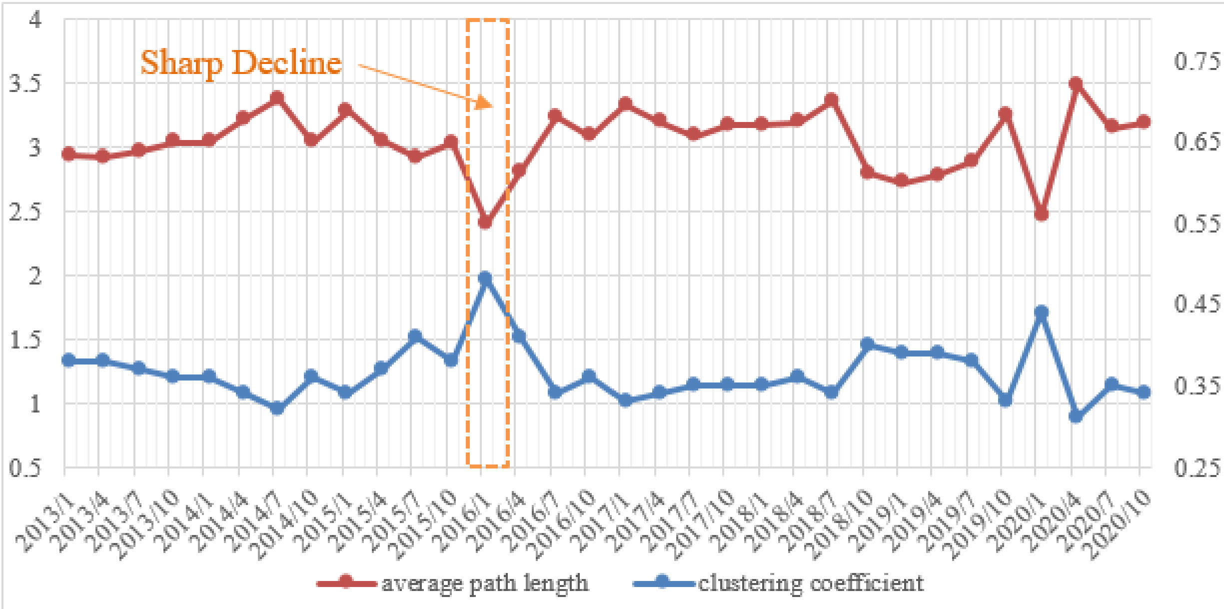

Figure 4

Evolution of average path length and clustering coefficient