Research on Risk Contagion Mechanism between Chinese Green Securities and Traditional Financial Markets

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Abstract. With the continuous expansion of China's green securities market, the increasing variety of financial derivatives, and the complexity of its funding sources, the controllability of risks in the green securities market is gradually decreasing. During the integration process with traditional financial markets, it is likely to accumulate risks and trigger risk contagion. This paper reconstructs the research framework of the financial system and explores the risk contagion mechanism among green bonds, green stocks, and the complete financial market divided by industry. By constructing R-Vine Copula models, the risk contagion paths between China's green securities market and traditional financial markets at the systemic level are explored, further improving the theoretical framework of risk transmission mechanisms under specific market conditions in China. The research findings not only help regulators maintain the stability and healthy development of the green securities market, but also improve the risk control system of green securities, and promote green securities investors to avoid investment risks and optimize asset allocation.

Keywords: Green securities; risk contagion; R-vine copula.

1 Introduction

Green finance is a policy tool that promotes sustainable development by guiding the pricing and circulation of assets to mobilize social and economic resources. Currently, China is in a critical period of economic structural adjust-ment and transformation of development patterns, and there is an urgent need to reform the traditional economic development model that comes at the cost of environmental damage. Green finance not only enhances capital returns through optimizing resource allocation but also effectively supports the development of domestic green and environmental industries, making it an important means for improving the quality of China's economic development. Additionally, the ad-vantages of convenient trading, high liquidity, and relatively low risks of green securities have attracted numerous investors to pursue diversified asset alloca-tion, further driving the expansion of green securities market.

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However, as the scale of China's green securities market continues to expand and open policies are further implemented, the enhanced liquidity of capital in different markets also intensifies the transmission of financial market risks. Ad-ditionally, the recent impact of the COVID-19 pandemic has significantly slowed down global economic development, leading to increased investor panic. In the long run, these factors may cause risks to transform into a "butterfly effect" be-tween multiple markets, causing a large-scale transmission of financial risks and negatively impacting consumption and investment through wealth effects, there-by impacting the real economy. Therefore, this paper conducts research on the risk transmission mechanisms between China's green bond market, green stock market, and traditional financial market, which not only helps identify the infor-mation transmission laws and risk contagion effects between them but also has significant implications for the allocation of resources between China's emerging green finance market and the traditional financial market, as well as the risk pre-vention of the overall domestic financial market.

2 Literature Review

As two financial instruments that promote sustainable development, green bonds refer to bonds used to finance environmental projects, such as renewable energy, bioenergy, and low-carbon transportation, while green stocks refer to stocks issued by companies that are committed to sustainable development, in-corporating environmental benefits and protection into their operations and hav-ing high environmental performance [1]. Compared to traditional financial mar-kets, the green securities market has emerged relatively late, so most research has focused on the risk characteristics and investment value of these products. Among them, Croce et al.[2] first proposed the lack of identification, tracking, and recording of risk characteristics related to green projects in the market.. In recent years, more scholars have started to pay attention to the financial risks inherent in the green securities market. Based on the liquidity risk and yield of green bonds, Febi et al.[3] pointed out that the liquidity risk of green bonds is currently very low, and the main reason for the liquidity risk of the green bond market is insufficient supply and excessive demand.

With the frequent occurrence of financial events and rapid transmission of in-formation, some scholars have begun to quantitatively analyze the magnitude of risks in the green securities market and the distribution of risks among different markets to supplement the existing research on the risk tolerance and transmis-sion capacity of the green securities market.[4] Kanamurat[5] proposed a new model to study the correlation between green bonds and energy commodities, and examined the performance of green bonds relative to traditional bonds. The study found that the investment performance of green bonds is superior to that of tradi-tional bonds, but this advantage weakens over time. Nguyen et al.[6] found that there is a low and negative correlation between green bonds and stocks. The syn-chronicity between the green bond market and the stock market is weak. The impact of large price fluctuations in the stock market on green bond prices can be disregarded, and the correlation weakens with increasing lag.. Reboredo et al.[7-8] further studied the causal relationship between oil prices and stock prices of clean energy companies and found that the former is the Granger cause of the latter. Arif M[9] found that the spillover between the green bond market and the traditional financial market mainly occurs over a shorter time period, and the COVID-19 pandemic has intensified the temporal-frequency spillover between green bonds and the traditional financial market. For the green bonds market, Reboredo[10] further refined the research framework and found a weak interac-tion between the green bond market and the corporate bond market, government bond market, stock market, and energy commodity market. Reboredo and Ugo-lini[11] expanded the research scope to the complete traditional financial market and found that there is a close price contagion effect between the green bond market, fixed income market, and foreign exchange market.

In conclusion, green securities have the desirable characteristics of low risk levels, stable returns, and strong liquidity. They play an important role in promot-ing the development of green environmental projects and facilitating high-quality economic growth. However, there is a shortage of research on the risk contagion effects between the green securities market and traditional financial markets, especially in the context of China's domestic green bond and green stock mar-kets. Therefore, it is necessary to supplement the theoretical framework in this field through related research and further expand the scope of research to com-prehensively and systematically study the risk contagion mechanisms between the green securities market and traditional financial markets, including bonds, stocks, foreign exchange, currency, and commodity markets.

3 Model Construction

This section mainly introduces the R-vine Copula model setting and construction method adopted when exploring the risk contagion mechanism between green securities and the financial market.

Due to the existence of nonlinear dependence between financial variables, according to Sklar's theorem, Copula function is a type of function that connects the joint distribution function with its respective marginal distribution functions, and the joint distribution of multidimensional variables can be decomposed into a product of marginal distribution functions. First, the standardized residual vector $\left(e_{1,t}, e_{2,t}, \dots, e_{k,t}\right)$ can be obtained from the DCC-GARCH model. Let the joint distribution function of$\left(e_{1,t}, e_{2,t}, \dots, e_{k,t}\right)$be F,he joint density function be$f$,the marginal distribution functions be F_1,F_2 ,…,F_k ,and the marginal density functions be f_1,f_2 ,…,f_k , According to Sklar's theorem, there exists a K-dimensional Copula function C such that:

$$F\left(e_{1,t}, e_{2,t}, \dots, e_{k,t}\right) = C\left(F_1\left(e_{1,t}\right), F_2\left(e_{2,t}\right), \dots, F_k\left(e_{k,t}\right)\right) \tag{1}$$

Let $u_{i,t} = F_i\left(e_{i,t}\right)$,then:

$$F\left(e_{1,t}, e_{2,t}, \dots, e_{k,t}\right) = C\left(u_{1,t}, u_{2,t} \dots, u_{k.t}\right) \tag{2}$$

Taking the derivative of (2) on both sides yields.

$$f\left(e_{1,t}, e_{2,t}, \dots, e_{k.t}\right) = c\left(u_{1,t}, u_{2,t}, \dots, u_{k,t}\right) \times \prod_{i=1}^{k} f_i\left(e_{i,t}\right) \tag{3}$$

Build the Copula function based on equations (1) to (3), and estimate the Copula parameters using the maximum likelihood estimation method.

$$L(\xi; x) = \sum_{i=1}^{n} log\left(f_i(\varphi_i; x)\right) + log\left(c(\theta; x)\right) + log\left(c\left(\theta; F_1(x_1), \dots, F_n(x_n)\right)\right) \tag{4}$$

In the equation$\xi = (\varphi_1, \varphi_2, \dots, \varphi_3; \theta)$includes the parameters$\varphi$ for the marginal distributions and the parameter and θ for the Copula.

When the dimension of variables increases, the Copula model becomes difficult to analyze high-dimensional variables. According to PCC theory, the multidimensional Copula functions can be decomposed into a series of two-dimensional Copula functions multiplied together, in order to describe the dependence structure between random variables. The graph theory concept of Vine structure is introduced for PCC construction, where multiple ordered trees represent the relationships between multidimensional variables, and each edge of each tree corresponds to a Pair-Copula function. The R-Vine model is constructed based on the algorithm of maximum spanning tree (MST-PRIM algorithm), as shown in equation, which maximizes the sum of absolute Kendall's τ between any two nodes in the tree, denoted by δ.

$$max \sum \left|\delta_{i,j}\right| \tag{5}$$

In this paper, a sample data dimension of 14 is selected. According to the principle of constructing multidimensional Copula functions based on Pair Copula functions, there will be 91 function types to be determined. The multidimensional Copula function can be decomposed into a product of multiple Pair Copula functions. The density function of the mixed R-Vine Copula is to be determined.

$$f(x) = \prod_{k=1}^{n} f_k\,(x_k) \prod_{k=n-1}^{1} \prod_{i=n}^{k+1} c_{m_{k,k} m_{i,k}} \big| \, m_{i+1,k}, \dots, m_{n,k} \left(F_{m_{k,k}|m_{i+1,k},\dots,m_{m,k}}, F_{m_{i,k}|m_{i+1,k},\dots,m_{n,k}}\right) \tag{6}$$

4 Empirical Analysis

To comprehensively explore the risk contagion characteristics between China's green securities market and traditional financial markets, this study supplements the existing literature by examining the complete financial system divided by industry segmentation. However, due to the lack of significant correlation between certain secondary financial sub-markets, such as the information industry and healthcare industry, these few financial sub-markets were not included in the research framework. After adjustments, the research objects in this study are divided into two major categories, namely the green securities market and traditional financial markets, consisting of a total of 15 financial sub-markets. Specifically, the green securities market includes two sub-markets, green bonds and green stocks, while the traditional financial markets include 12 secondary sub-markets divided by industry segmentation, namely the stock market, bond market, foreign exchange market, commodity trading market, and currency market from the primary sub-markets. To better measure the performance of each financial sub-market, this study selects representative financial indices as proxy variables, and the market numbers and specific proxy indices are listed in Table 1. All financial data in this article is sourced from the Wind financial database, with a focus on daily closing price data. The sample period ranges from June 2, 2015, to June 10, 2024.

Table 1. Research framework of China's green securities market and traditional financial markets

Financial market	Primary sub-market	Secondary sub-market	Variable	Proxy index
Green Security Market		Green bond market	Green-B	CBA04903.CS
		Green stock market	Green-S	930956.CSI
Traditional Financial Market	Stock Market		Energ-S	000908.CSI
			Mater-S	000909.CSI
			Indus-S	000910.CSI
	Bond Market		Corpo-B	H11006.CSI
			Treas-B	H11008.CSI
			Finan-B	000923.CSI
			Enter-B	H11007.CSI
	Futures Market		Indus-C	NH0500.NHF
			Agric-C	NH0200.NHF
			Energ-C	NH0300.NHF
	Money market		Repo-M	Repo rate
	Exchange market		Forex	CNYX.CNI

Table 2. The descriptive statistics of return series for each financial market

	Mean	Std dev	Skewness	Kurtosis	Jarque-Bera	ADF	ARCH-LM
Green-B	0.0000	0.0008	0.3305	14.6909	1970.058***	-10.715***	183.362***
Green-S	-0.0001	0.0175	0.6824	3.2551	1134.725***	-12.150***	321.976***
Indus-S	0.0002	0.0166	0.6199	5.4412	2837.049***	-12.686***	527.143***
Energ-S	0.0000	0.0168	0.5220	4.1341	1655.751***	-12.976***	308.124***
Mater-S	0.0000	0.0175	0.6659	3.7318	1429.969***	-12.407***	411.052***
Corpo-B	-0.0002	0.0002	-0.4347	4.5665	1967.936***	-12.261***	2047.802***
Treas-B	-0.0002	0.0011	-0.3363	10.2903	9690.047***	-16.443***	1262.362***
Finan-B	-0.0002	0.0008	0.5852	11.4006	1196.897***	-14.413***	185.753***
Enter-B	-0.0002	0.0005	0.3518	16.5702	2506.887***	-15.730***	811.807***
Indus-C	-0.0005	0.0118	0.1981	1.9385	355.972***	-12.333***	146.429***
Agricl-C	-0.0001	0.0072	-0.0031	2.7800	703.220***	-18.334***	781.274***
Energ-C	-0.0003	0.0127	0.1422	1.7181	275.657***	-17.989***	781.272***
Repo-M	0.0004	0.1571	0.0554	8.7917	7043.369***	-19.903***	300.161***
Forex	0.0000	0.0028	0.9202	111.6336	1136.388***	-16.201***	122.413***

According to Table 2, during the sample period, except for traditional stock and forex markets which had negative average returns, the returns of other markets were mostly greater than or close to 0. It is observed that the average return of green stocks is lower than that of traditional stocks, revealing the drawback of lower return levels, while the higher return level of the green bond market compared to the traditional bond market highlights the stable returns of green stocks. In terms of the standard errors of each return series, stock and futures markets exhibit relatively high values, while other financial markets show lower values, confirming the preliminary conclusions drawn earlier. Analyzing the distribution features of each series, it is noted that the JB statistics for all financial markets are significant and have kurtosis greater than 3, with the majority of series displaying skewness greater than 0. This indicates a slight right skew in all financial markets, demonstrating the characteristic peakedness and fat-tailed distribution of financial time series. As a result, when fitting GARCH models to calculate volatility of each return series, the residuals are modeled using a skewed t-distribution. Furthermore, all financial markets have passed unit root tests, indicating they are stationary series suitable for time series analysis. The significant ARCH-LM statistics for most series suggest that all financial series exhibit heteroscedasticity, making them appropriate for fitting using GARCH models to extract volatility data.

Table 3. Parameter estimation table of the first level R-Vine-Copula model

edge	copula	par	par2	tau	Utd	Ltd
Indus-S,Green-S	t-copula	0.85	6.03	0.64	0.47	0.47
Energ-C,Indus-C	Frank copula	2.84	-	0.69	-	-
Indus-C,Agric-C	t-copula	0.86	5.10	0.65	0.52	0.52
Energ-S,Indus-C	Gaussian copula	0.43	-	0.28	-	-
Mater-S,Energ-S	Rotated Gumbel copula	1.79	-	0.54	-	0.53
Indus-S,Mater-S	t-copula	0.76	6.16	0.55	0.36	0.36
Green-B,Forex	Rotated Joe copula	30.00	-	0.94	-	0.98
Finan-B,Enter-B	Frank copula	0.33	-	0.04	-	-
Treas-B,Finan-B	t-copula	0.83	10.00	0.54	0.42	0.42
Treas-B,Green-B	t-copula	0.51	8.28	0.64	0.52	0.55
Corpo-B,Treas-B	t-copula	0.67	5.65	0.46	0.29	0.29
Repo-M,Indus-S	Rotated Gumbel copula	1.08	-	0.07	-	0.10
Repo-M,Corpo-B	Gaussian copula	-0.09	-	-0.06	-	-

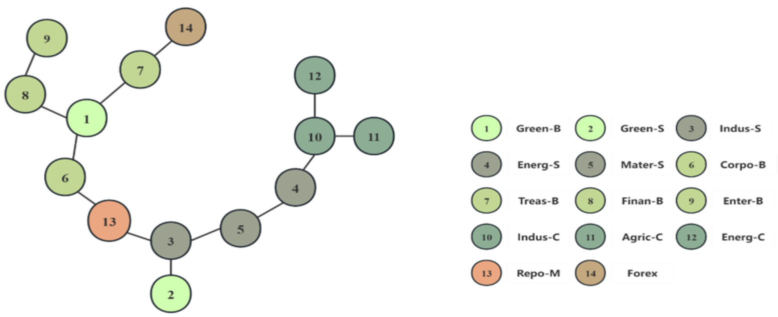

Fig. 1. Risk linkage network diagram of green securities and financial markets

Based on the results of the first tree of the R-Vine Copula model in Table 3 combined with the conventional linkage network in Figure 1, it can be observed that markets of the same type exhibit a stronger level of correlation, with the entire financial market being primarily connected through stock, bond, and futures markets. In terms of the linkage level between markets, the internal risk correlations within financial markets of the same type but different industries are all above 0.5, indicating that risks are more easily transmitted within markets. Furthermore, most markets exhibit asymmetrical upper tail correlation coefficients, meaning that when the volatility level of one market sharply increases, it is more likely to transmit risk and lead to a sharp increase in risk in other markets through risk contagion.

Specifically, within the financial system during sample periods, the green bond market is mainly connected to the corporate bond market, the financial bond market, and the energy futures market, serving as an intermediary market bridging the bond market and the futures market. In particular, the green bond market is connected to the government bond market through a t-copula distribution, with a correlation coefficient of 0.64, indicating a high level of linkage between the two. The green bond market is connected to the financial bond market through a t-copula, with a correlation coefficient of 0.83 and an upper and lower tail correlation coefficient of 0.42, suggesting a strong level of risk linkage between the two markets and a strong degree of symmetry. Moreover, extreme financial events have a relatively small impact on the intensity of risk contagion.

The green stock market is on the periphery of the stock market during normal periods and is connected to the industrial stock market. The green stock market is connected to the industrial stock market through a t-copula distribution, with a correlation coefficient of 0.85 and an upper and lower tail correlation coefficient of 0.47, indicating a strong level of risk linkage between the two markets and a strong degree of symmetry. Additionally, the industrial stock market and the industrial futures market are important risk transmission hubs in the entire financial system, connecting the stock market, money market, bond market, futures market, and bond market, indicating that the industrial sector remains a risk core in China's financial system and needs attention from market regulators.

By combining the correlation coefficient parameters in Table 3 during normal periods and the vine-like dependence structure in Figure 1, it can be further seen that the risk transmission structure of China's financial market is relatively stable during normal periods, with stronger risk correlation levels within the same market. When a market experiences unexpected financial volatility, financial risk tends to spread internally to markets of the same type, making it difficult for cross-market risk contagion to occur. Only when the risk is transmitted to hub markets such as the industrial stock market and industrial futures market does it have limited transmission to the external market, and the risk level may further weaken in the process. Therefore, the relatively stable market structure during normal periods leads to financial risks being concentrated within markets of the same type, making it difficult to form cross-market systemic contagion.

5 Conclusion

In conclusion, from the perspective of systemic risk linkage, in normal condi-tions, China's financial system is connected through the stock market, bond mar-ket, and futures market as the main components to form a linear risk linkage structure with other financial markets. There is strong intra-market risk linkage within the same type of market, and most markets have an asymmetric tail corre-lation structure, making them susceptible to the influence of extreme risks and facilitating risk transmission. During normal periods, China's financial system is connected to other financial markets mainly through the stock market, bond mar-ket, and futures market, forming a linear risk linkage structure. Compared to normal periods, the level of risk linkage and the linkage structure of various mar-kets in China's financial system undergo significant changes during financial events, and the linkage status between the green stock market and other financial markets also undergoes significant changes.

Based on the above research conclusions, this paper proposes the following suggestions: Firstly, for market regulators in the green securities market, the risk management indicator system can be optimized and the risk control level of the green securities market can be enhanced from the perspectives of optimizing risk management indicators and dynamically monitoring the international financial environment. Secondly, investors can also construct multiple investment portfo-lios by selecting green securities and markets with lower risk linkage based on the results of the research on the level of risk contagion between the green secu-rities market and traditional financial markets, in order to reduce potential in-vestment losses through diversifying funds and lowering internal risk contagion.

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