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Study on higher-moment risk spillover effects between stock and exchange rate markets: An empirical analysis based on China's Mainland and Hong Kong markets

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Abstract

In the context of the deepening opening-up of China's financial markets to the outside world, this paper combines the GARCHSK higher-moment volatility model with the spillover index method to quantitatively analyze the higher-moment risk spillover effects among China's mainland stock market, Hong Kong stock market, onshore RMB market, and offshore RMB market. The empirical results show that: (1) Besides the volatility spillover effects, the skewness and kurtosis spillover effects among the four markets are also significant; (2) The offshore RMB market mainly acts as the risk spillover net transmitter under all moments; while the onshore RMB market acts as the skewness and kurtosis spillovers net transmitters, and the volatility spillover net receiver; the mainland stock market and Hong Kong stock market act as the volatility spillover net transmitter and the kurtosis spillover net receiver respectively; (3) The risk spillover effects between the markets of the same type, i.e., the mainland and Hong Kong stock markets, the offshore and onshore RMB markets, demonstrate the characteristic of risk spillover matching; (4) From a spatial perspective, the net pairwise volatility spillover network forms clusters of the markets with the same type, while the structure of net skewness and kurtosis spillover network is more stable. The research findings are of reference significance for the regulatory authorities to comprehensively and systematically understand the risk contagion characteristics among financial markets across regions.

Keywords: Higher-Moment, Risk Spillover Effects, Stock Market, Exchange Rate Market

Introduction

China's economy is becoming more integrated with the global economy as domestic financial markets are further opened to the outside world. The foreign exchange market, especially the offshore RMB market, has become an important bridge connecting domestic and foreign capital markets. Besides, the unique regional advantages and policies of Hong Kong have made Hong Kong the most significant offshore RMB center for China. To avoid the negative impact of external risks transferred to the mainland financial market through the markets in Hong Kong, it is necessary to understand the characteristics of risk contagion among China's mainland stock market, Hong Kong stock market, onshore and offshore RMB markets, and then design corresponding risk-averse measures to withstand the risk spillovers.

The researchers have paid attention to the connection between the stock market and the foreign exchange market for a long time. They have achieved remarkable results in analyzing the risk spillover effects between them. However, there are still deficiencies in the existing literature: Firstly, most research focuses on the first and second moments, namely the risk spillovers of return and volatility. The reason for this is that traditional econometric models rely on asset return normal conditional distribution assumptions, which assume that the skewness and kurtosis of the return distribution are constant. However, if spillover research focuses solely on return and volatility risks, it will overlook the impact of asymmetries related to downside (upside) risk, because the distribution of asset returns usually does not satisfy normality, and generally shows non-normal, asymmetric, and thick-tailed distributions in the real world. Considering that skewness and kurtosis can better model the above distribution characteristics, and that higher-moments also provide corresponding information about the asymmetric or tail risk, risk spillover studies that only consider return and volatility are limited (He et al., 2021). In addition, in such research areas as financial asset pricing (Xu et al., 2007), risk hedging (Zhang et al., 2009), and portfolio optimization (Peng et al., 2013), the impact of higher-order moment risks cannot be ignored. Secondly, from the perspective of research content, the current research mainly focuses on the relation between the stock and the foreign exchange markets in the same region, and few risk spillover research has paid on the four markets between mainland China and Hong

Kong simultaneously. Cui et al. studied the higher-moment risk spillover effects between Chinese stock markets (Cui et al., 2020) and international stock markets (Cui et al., 2021), and Xie He et al. (He et al., 2021) discussed the higher-moment risk spillover characteristics of eight stock markets in the world. There has been little research on higher-order moment risk spillovers between and among the stock and foreign exchange markets in mainland China and Hong Kong as a whole. Therefore, the goal of our research is to investigate the higher-moment spillover effects between the stock and foreign exchange markets in mainland China and Hong Kong. The paper not only helps to have a deeper understanding of the interconnection between financial markets across regions, but also provides advice for preventing and reducing financial and economic risks contagion and formulating financial market reform policies.

1 Methodology

This paper firstly uses the higher-moment volatility GARCHSK model constructed by Leon et al.(León et al., 2005) to capture time-varying conditional higher moments for the return series of the mainland China and Hong Kong stock and foreign exchange markets. We then use the spillover index approach proposed in (Diebold et al., 2012) to estimate the higher-moment risk spillovers among the above four financial markets, which can measure spillover effects based on assessing the Forecast Error Variance Decomposition (FEVD) within the generalized VAR framework.

1.1 GARCHSK model

This paper uses the GARCHSK model to obtain the conditional volatility, skewness and kurtosis of the four market return series.

$$\begin{cases} \mathrm{r_t} = \mu_t + \varepsilon_t = \mu_t + \sqrt{h_t} z_t \\ \mathrm{h}_t = \beta_0 + \sum_{i=1}^{q_1} \beta_{1,i} \varepsilon_{t-i}^2 + \sum_{j=1}^{p_1} \beta_{2,j} h_{t-j} \\ \mathrm{s}_t = \gamma_0 + \sum_{i=1}^{q_2} \gamma_{1,i} z_{t-i}^3 + \sum_{j=1}^{p_2} \gamma_{2,j} s_{t-j} \\ \mathrm{k}_t = \delta_0 + \sum_{i=1}^{q_3} \delta_{1,i} z_{t-i}^4 + \sum_{j=1}^{p_3} \delta_{2,j} k_{t-j} \end{cases}$$

where $\varepsilon_t \mid I_{t-1} \sim D(0, h_t, s_t, k_t)$, I_{t-1} is the information set at time *t-1*, $D(0,h_t,s_t,k_t)$ represents the Gram-Charlier distribution including mean, volatility, skewness and kurtosis; h_t, s_t k_t are the conditional variance, skewness, and kurtosis, respectively.

1.2 The spillover index method

In order to estimate the size and direction of the risk spillover effects more effectively, this paper adopts the spillover index method proposed by Diebold and Yilmaz (Diebold & Yilmaz, 2012). The calculation process is as follows:

We first construct a 4-dimensional p-order VAR process: $X_t = \sum_{i=1}^{p} \Phi_i X_{t-i} + \varepsilon_t$, where $X_t = (x_{1t},\ x_{2t},\ x_{3t},\ x_{4t})$ are the mainland China stock index, Hong Kong stock index, the onshore RMB and offshore RMB in period *t*, Φ_i is a 4×4 coefficient matrix, error vector $\varepsilon_t \sim iid(0,\ \sum)$, where $\sum$ is variance covariance matrix. When VAR(p) satisfies the stability condition, it can be rewritten as an infinite-order vector moving average VMA(∞) process: $X_t = \sum_{i=0}^{\infty} \Psi_i \varepsilon_{t-i}$.

In generalized variance decomposition, if variable x_j is impacted by external factors, the proportion of the H-step forecast error variance that can be explained by variable x_k is $(\theta_H)_{j,k} = \frac{\sigma_{kk}^{-1} \sum_{h=0}^{H-1} \left((\Psi_h \Sigma)_{j,k} \right)^2}{\sum_{h=1}^{H-1} (\Psi_h \Sigma \Psi_h')_{j,j}}$, which reflects how much the change in variable x_j is influenced by other variables in the system, where $\sigma_{kk} = (\sum)_{k,k}$. The proportion of forecast error variance $(\theta_H)_{j,k}$ is the basis for constructing the variance decomposition spillover index.

Since $\sum_{k=1}^{N} (\theta_H)_{j,k} \neq 1$ in generalized variance decomposition, the following standardization processing is required $\left(\tilde{\theta}_H\right)_{j,k} = \frac{(\theta_H)_{j,k}}{\sum_{k=1}^{N} (\theta_H)_{j,k}}$. The resulting $(\tilde{\theta}_H)_{j,k}$ can then be used to calculate the risk spillover level of the variable x_k to the variable x_j under the forecast period H. On this basis, the total spillover index C^H, the directional spillover index $C_{j\cdot}^H$ and $C_{\cdot j}^H$ can be defined as follows:

$$C^H = \frac{\sum_{k,j=1;k\neq j}^{N} \left(\tilde{\theta}_H\right)_{j,k}}{N} \times 100$$

$$C_{j\cdot}^H = \sum_{k=1,k\neq j}^{N} \left(\tilde{\theta}_H\right)_{j,k} \times 100,\quad C_{\cdot j}^H = \sum_{k=1,k\neq j}^{N} \left(\tilde{\theta}_H\right)_{k,j} \times 100$$

2 Data and statistical descriptions

For the stock market, the daily closing prices of the Shanghai Securities Composite Index (SHZ) and the Hong Kong Hang Seng Index (HSI) were selected to represent the mainland and Hong Kong stock markets, respectively. For the foreign exchange markets, the daily central parity rate (CNY) of the RMB against the US dollar is selected to represent the onshore RMB market, and the daily closing price of the RMB spot exchange rate (CNH) in the offshore market is chosen to represent the offshore market. The data perion is from May 1, 2012 to March 31, 2021. The daily return of each market is calculated by taking the first-order logarithmic difference of the index closing/middle price: $r_t = 100 * \ln(p_t/p_{t-1})$, where r_t is the logarithmic return on day t, p_t is the closing/middle price on day t. All data are taken from the Wind database.

Table 1 provides the summary statistics of the return series for the four markets. As can be seen from Table 1, the volatility of the two stock markets is significantly greater than that of the foreign exchange markets. The mainland stock market has higher volatility than the Hong Kong stock market. Furthermore, the offshore RMB market is more volatile than the onshore RMB market. In addition, it can be seen that the skewness of each return series is not equal to 0, the kurtosis is greater than 3, and the JB test is significant at the 1% level, which indicates that each return series presents the characteristics of the thick-tailed distribution. According to the results of an ARCH-LM test, there is a significant ARCH effect in all market returns; thus, ARCH-type models can be used to obtain the conditional volatility, skewness, and kurtosis of these return series. Also, the ADF test shows that all returns are stationary.

	SHZ	HSI	CNY	CNH
Mean	0.0166	0.0140	0.0022	0.0020
SD	1.4043	1.1572	0.1922	0.2656
Skewness	-0.9975	-0.2969	0.6422	0.4242
Kurtosis	10.3186	6.0442	12.6357	14.7761
J-B	5030.1210***	840.9595***	8260.5650***	12185.5100***
Q(10)	43.9180***	6.3389	37.0340***	6.8260
ARCH(10)	34.4097***	14.9367***	47.1258***	4.7918***
ADF	-44.2340***	-45.9074***	-41.0788***	-47.2070***

Table 1 Descriptive statistics of the four return series

Note: J-B is the normality test of Jarque and Bera (1980). Q(10) is the autocorrelation test of Ljung and Box (1978) for first order. ADF is the unit root test. ARCH test is used to test ARCH effects. ***Denote significance at 1% level.

3 Empirical Analysis

In this section, we will empirically investigate the static and dynamic higher-moment risk spillover characteristics of the stock and foreign exchange markets in Mainland China and Hong Kong based on the risk spillover index approach. We use the AIC information criterion to choose the optimal lag length of the VAR model. Referring to the settings of He et al. (2021), we set the ahead forecasting horizon as 100 and the rolling time window length as 400.

3.1 Static spillover effects

Table 2-4 shows the static spillover indexes of volatility, skewness, and kurtosis among the four markets, and conclusions are as follows:

	SHZ	HSI	CNY	CNH	FROM
SHZ	90.57	4.91	1.46	3.07	2.36
HSI	24.59	64.84	1.31	9.27	8.79
CNY	1.94	0.71	53.88	43.47	11.53
CNH	2.94	0.78	25.21	71.07	7.23
TO	7.37	1.6	6.99	13.95	TCI
NET	5.01	-7.19	-4.54	6.72	29.91

Table 2 Volatility spillovers between and among 4 markets

Note：FROM represents the spillover effects that a single market receives from all other markets, TO represents the spillover effect that a single market transmits to other markets, NET is 'TO' minus 'FROM', and TCI represents the total spillover effect. The same below.

	SHZ	HSI	CNY	CNH	FROM
SHZ	85.02	14.78	0.02	0.18	3.75
HSI	14.12	85.36	0.23	0.29	3.66
CNY	0	0	51.66	48.34	12.08
CNH	0.12	0.06	48.28	51.54	12.11
TO	3.56	3.71	12.13	12.2	TCI
NET	-0.19	0.05	0.05	0.09	31.6

Table 3 Skewness spillovers between and among 4 markets

	SHZ	HSI	CNY	CNH	FROM
SHZ	89.37	10.61	0.01	0.01	2.66
HSI	11.26	87.8	0.43	0.51	3.05
CNY	0	0.01	50.28	49.71	12.43
CNH	0.01	0	49.72	50.26	12.43
TO	2.82	2.65	12.54	12.56	TCI
NET	0.16	-0.4	0.11	0.13	30.57

Table 4 Kurtosis spillovers between and among 4 markets

Firstly, besides volatility spillover, there also exist significant skewness and kurtosis spillover effects between the four markets in mainland China and Hong Kong, in which the total spillover indexes of volatility, skewness, and kurtosis reaches 29.91%, 31.6%, and 30.57%, respectively. The results show that risks are highly connected in terms of not only volatility, but also skewness and kurtosis risks. Four markets in mainland China and Hong Kong are highly interconnected.

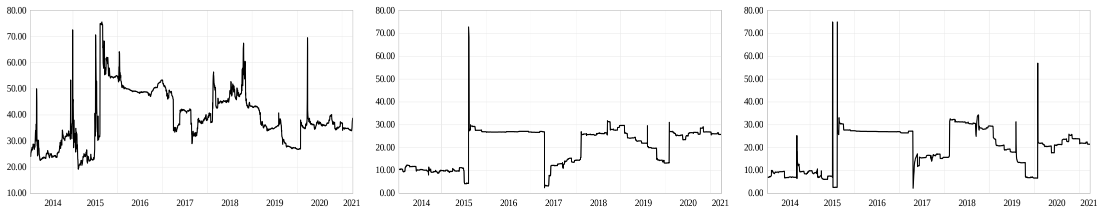
Secondly, from the perspective of foreign exchange markets, the offshore RMB market mainly acts as a risk spillover net transmitter under all moments. The onshore RMB market serves as the volatility spillover net receiver and as the skewness and kurtosis spillover net transmitters. From the perspective of the stock markets, the mainland stock market mainly acts as the volatility and kurtosis spillover net transmitters, and as the skewness spillover net receiver. In contrast, the Hong Kong stock market plays the role of the volatility and kurtosis spillover net receivers, and of the skewness spillover net transmitter.

Thirdly, among the four markets, the mainland stock market has the most significant risk spillover index to itself. This is because in Mainland China, relevant restrictive policies on stock trading processes designed by policymakers have a significant impact on the stock market. For example, trading systems such as price limit and the "T+1" trading system reduce the effects of external shocks on the Mainland stock market.

Finally, from the perspective of market type, the total spillover index of volatility, skewness, and kurtosis risks between the same type of markets, i.e., the mainland and Hong Kong stock markets, the onshore and offshore RMB markets, are greater than those between different types of markets, indicating that risks are more likely contagious between the same type of markets.

3.2 Dynamic spillover effect

The dynamic total spillover index of each moment, shown in Fig. 1, suggests that the information spillover of higher-moments changes over time. From Figure 1, the following conclusions can be drawn:



Volatility Skewness Kurtosis

Figure 1 Dynamic total spillovers

Firstly, the risk spillover effects of each moment among the four markets in mainland China and Hong Kong show significant time-varying characteristics, and the risk spillover effects of skewness and kurtosis show similar trends. Secondly, risk spillover effects of each moment increase sharply to the emergence of significant economic events and major policy adjustments. For example, the outbreak of the "stock market crash" in 2015, the "8.11" exchange rate reform, the Sino-US trade dispute, and the outbreak of the Covid-19 pandemic all caused a sharp rise in the total spillover index of each moment, indicating that major risk events and policy adjustments are more likely to enhance the links among the four markets in China. The reason is that negative information and emotions spread rapidly between markets, leading to irrational trading behaviors in the stock and exchange markets when significant crisis events occur, thus intensifying the risk contagion effects across markets. Finally, the total volatility spillover changes more frequently than the skewness and kurtosis spillovers, indicating that the volatility spillovers are more vulnerable to risk events.

In general, major crisis events and related policy reforms can significantly increase the interaction degree between the stock and foreign exchange markets in mainland China and Hong Kong. The results also shows that the risk spillover effect of each moment computed in our paper can well capture the changes of risk contagion across the markets, especially when significant risks occur.

Fig. 2-4 shows the net risk spillover of volatility, skewness, and kurtosis for the four markets, respectively. The following conclusions can be drawn from the figures:

Firstly, the net spillover of each moment for the four markets in China shows significant time-varying characteristics. Besides, the net spillovers of skewness and kurtosis for the markets with the same type, i.e., the mainland and Hong Kong stock markets, the onshore and offshore RMB markets, have similar patterns and trends.

Secondly, from the perspective of the stock markets, the net spillover effects show different time-varying trends under different moments. The net volatility spillover in the mainland stock market is relatively small except for the occurrence of significant risk events, indicating that the mainland stock market is more vulnerable to policy intervention, reducing the impact of external shocks on the mainland stock market; the net volatility spillover in the Hong Kong market is higher than that in the mainland stock market, which suggests that the Hong Kong market, as a net risk receiver, has accepted more volatility spillover from other markets, and is more market-oriented. In terms of the net spillover effects of skewness and kurtosis, the levels of net spillovers in both the mainland and Hong Kong stock markets are small. Still, the net spillover effects increase sharply only when major crisis events occur. In addition, the net volatility spillover fluctuates more frequently than the skewness and kurtosis spillovers, which also shows that the net volatility spillover is more vulnerable to risk events.

Thirdly, from the perspective of the foreign exchange markets, the net spillover effects present similar time-varying trends under different moments. Before the "8.11" exchange rate reform in 2015, the onshore RMB was acted as a risk net transmitter under each moment, while the offshore RMB was served as a risk net receiver under each moment. After the exchange rate reform, the onshore RMB is manifested as a significant risk net receiver under each moment. In contrast, the offshore RMB is acted as a risk net transmitter under all moments, thus becoming a risk contagion source across different financial markets. Due to a series of foreign exchange reform measures such as the "8.11" exchange rate reform and counter-cyclical factors started in 2015, the marketization of the RMB exchange rate has been improved, and other markets have had a significant impact on the onshore RMB exchange rate, especially the offshore RMB market. Onshore RMB has then become a risk net receiver, while offshore RMB has become a risk net transmitter.

Fourthly, the onshore RMB and the offshore RMB markets have shown a risk spillover matching phenomenon, which means that when onshore RMB is a risk net receiver (transmitter), CNH becomes a risk net transmitter (receiver). This also reflects the strong linkage between the onshore and offshore RMB markets.

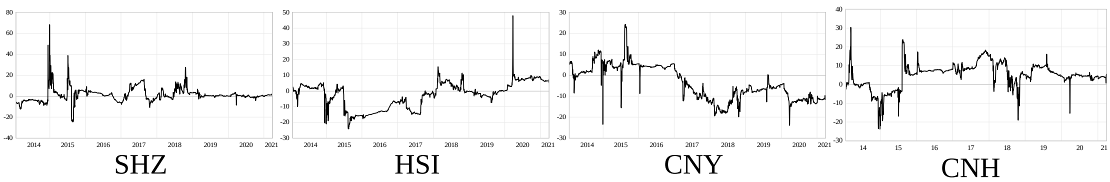


Figure 2 Dynamic net volatility spillovers

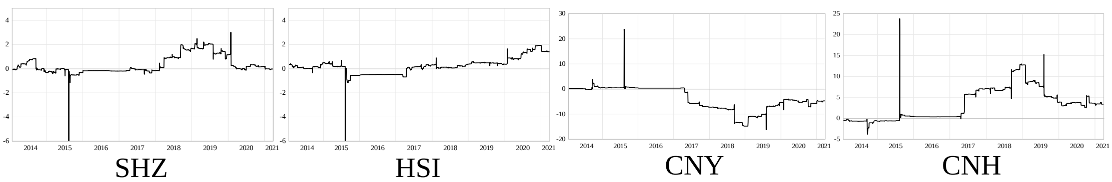


Figure 3 Dynamic net skewness spillovers

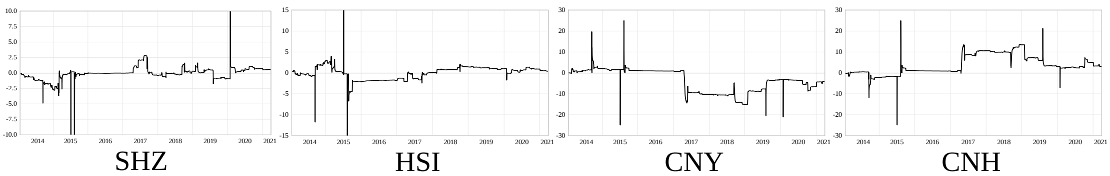
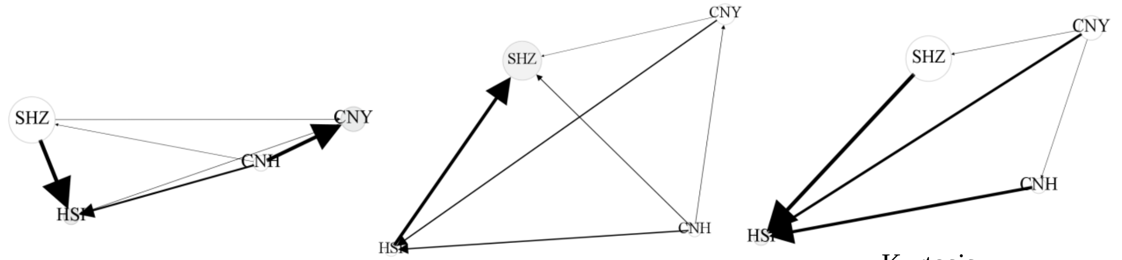


Figure 4 Dynamic net kurtosis spillovers

3.3 Net Pairwise Risk Spillover Network

Following Demirer et al. (Mert et al., 2018) to express the spillover effects from a spatial perspective, Figure 5 shows the net pairwise directional volatility, skewness, and kurtosis spillovers through networks. The structure of the net pairwise spillover network is obtained using the ForceAtlas2 algorithm (Mathieu et al., 2014), and we focus on the relative node position in the equilibrium state after the algorithm runs. The gray and white circles in the figure represent risk net receiver and transmitter respectively; the area of the circle depicts the level of the net pairwise spillover effects, that is, the larger the node area, the higher the level of the net risk spillover; the color and thickness of the arrows reflect the net risk spillover level between two markets, that is, the thicker the arrow and the darker the color, the higher the net spillover effects between the two markets.



Volatility Skewness Kurtosis

Figure 5 Net pairwise directional risk spillover network

From Figure 5, the following conclusions can be drawn:

Firstly, according to the distribution of nodes in the network, the four financial markets can be divided into two clusters consisting of the markets with the same in the net pairwise volatility spillover network. In the net pairwise skewness and kurtosis networks, four markets are located at the vertices of the networks, and no market is at the center of the networks. Overall, different from the net volatility spillover network, the net risk spillover structure among the four financial markets is relatively stable under skewness and kurtosis moments, which suggests that when there exists a shock on a financial market, the skewness and kurtosis risks have limited ability to spread across markets. They are not easy to generate systemic risk accumulation.

Secondly, in general, the net pairwise spillover effects of each moment between the markets with the same type are relatively more significant than that between different markets in the same region and different markets in different regions. Among them, the highest two net pairwise spillover effects are the net volatility spillover from the mainland to the Hong Kong stock markets and the offshore to the onshore RMB markets. In the net pairwise skewness and kurtosis spillover networks, the net risk spillover effects between the mainland and Hong Kong stock markets are the strongest. The findings also reflect the characteristics of risk spillover matching between the markets of the same type.

Finally, from the perspective of specific markets, for the foreign exchange markets, the offshore RMB market is the net risk spillover under each moment; the onshore RMB market is net skewness and kurtosis spillover transmitters and a net volatility receiver, which indicates that the foreign exchange market is the main source of risk contagion. For the stock markets, the mainland stock market is net volatility and kurtosis spillover transmitters and a net skewness spillover receivers. In contrast, the Hong Kong stock market is net volatility and kurtosis receivers and a net skewness transmitter.

In general, with the implementation of Shanghai-Hong Kong Stock Connection and Shenzhen-Hong Kong Stock Connection and the gradual liberalization of restrictions on QFII and RQFII, the linkage between China's mainland and Hong Kong stock markets has been strengthened. Investors from these two regions can allocate assets in another market through the tools mentioned above, making the connection between the two stock markets closer; in addition, various exchange reform policies have been implemented in China's foreign exchange market in recent years, including the use of counter-cyclical factors and foreign exchange risk reserves, which reduced the intervention of state administrative and enhanced the marketization of the RMB exchange rate, thus considerably enlarging the extent to which onshore RMB exchange rate is influenced by other markets, especially by the offshore RMB market. These reforms have led to the characteristics of risk spillover matching between markets of the same type. At the same time, they also cause the phenomenon of the risk contagion from the offshore RMB market to the onshore RMB market.

4 Conclusions

In the context of China's financial markets becoming more open to the outside world, this paper quantitatively analyzes the characteristics of higher-moment risk spillovers between and among the stock and foreign exchange markets in mainland China and Hong Kong using the GARCHSK model and risk spillover index approach. By measuring and analyzing the risk spillover effects of higher-moment among the four markets, the key findings are as follows: Firstly, the total volatility, kurtosis, and skewness spillovers between and among the four markets vary over time. Secondly, the total spillovers of volatility, skewness and kurtosis between the four markets are generally at a relatively high level, indicating that the markets between the mainland and Hong Kong are deeply linked. The risk of one market in the system can spread to other financial markets through the risk of different moments. Thirdly, from the perspective of specific markets, for the foreign exchange markets, the offshore RMB market is the main spillover net transmitter. In contrast, the onshore RMB market is the skewness and kurtosis spillover net transmitter and the volatility spillover net receiver. For the stock markets, the mainland and Hong Kong stock markets are volatility spillovers net transmitter and the kurtosis spillover net receivers, respectively. Fourthly, the level of risk spillover between the markets of the same type (mainland and Hong Kong stock markets, onshore and offshore RMB markets) is more significant than that between the markets of the different types. Fifthly, there is a risk spillover matching feature between the onshore and the offshore RMB markets, indicating that the correlation between onshore and offshore RMB markets is close. Finally, from a spatial perspective, the net pairwise volatility spillover network forms clusters of the markets with the same type. In contrast, the net pairwise skewness and kurtosis spillover networks are more stable in structure. For policymakers, it is essential to recognize that market risk is transmitted not only through volatility, but also through higher-order moments (skewness and kurtosis) across markets. Therefore, regulators need to establish corresponding monitoring measures according to the different characteristics of volatility, skewness, and kurtosis risk contagion.

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