



Residual contagion in emerging markets: ‘herd’ and ‘alarm’ effects in informatization

Min Fang¹ · Shenggang Yang¹ · Yuliang Lei² 

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Abstract

The present study investigates residual contagion of the recent two international crises under the dual functions of “herd effect” and “alarm effects in informatization, focusing on emerging markets. Both the impulse response method and dynamic conditional correlation MGARCH model are used to capture residual contagion from developed markets to emerging markets during the period 2000–2016. The results show that the level of volatility in emerging stock markets was greater than that of developed markets, such as the US and the EU, although they are less integrated with the world. Emerging stock markets are significantly subjected to residual contagion during the US subprime mortgage crisis and Europe’s protracted debt crisis. Moreover, the residual contagion effects of these two crises are noticeably heterogeneous in emerging markets.

Keywords Emerging markets · Residual contagion · Informatization · DCC-MGARCH

1 Introduction

Since the end of the last century, the process of informatization and financial liberalization in emerging countries has been advancing rapidly, which increasingly integrates the economic and financial markets in emerging countries with those of developed markets. The integration degree between emerging and international markets is nowhere near developed markets, such as Europe and the United States, but the openness and immaturity of financial markets left emerging markets exposed to global risks in this age when information travels and been gathered rapidly [1].

✉ Yuliang Lei
lei_yuliang@hunau.edu.cn

¹ School of Finance and Statistics of Hunan University, Changsha 410011, People’s Republic of China

² College of Information Science and Technology of Hunan Agricultural University, Changsha 410128, People’s Republic of China

During the 2008 financial crisis, the US stock market plunged by 43% and emerging markets fell by 50%, as other markets also experienced different levels of volatility. In recent years, the financial developments in emerging markets have involved many risks and challenges in the situation of information asymmetry and overall downward economy. The volatility and adjustment of international financial markets could exert a risk spillover effect or even a residual contagion effect on emerging financial markets. Confronted with the complex and dynamic global economic environment and the potential systemic financial risks of a regional economy, the government and international investors are strongly concerned about the fragility of emerging financial markets.

However, the characteristics of the contagion channels that lead to a significant difference between the fluctuation range of emerging stock markets and its world integration degree remains scarcely examined. Some previous studies have mainly focused on illustrating the existence of contagion or co-movement in the international crisis [2–4]. In emerging market, an economy that possesses a great developing potential, has not been comprehensively analyzed relative to the characteristics of international residual contagion. On the basis of learning excellent studies, this article explores theories of contagion mechanism in emerging stock markets from different contagion channels. Then the contagion effects of the US subprime mortgage crisis, the European debt crisis, and its superposition of Brexit on emerging financial markets are diagnosed and compared in the research, utilizing impulse response analysis method and multivariate generalized autoregressive conditional heteroskedasticity (MGARCH) in a dynamic conditional correlation (DCC) framework. Thereafter, the fragility and heterogeneity of emerging financial markets show in international economic crisis were empirically discussed.

The major breakthrough lies in that, this paper will analyze the residual contagion channels of the international crisis to emerging markets in detail, so as to provide theoretical and empirical basis for excessive abnormal fluctuations of emerging capital markets during the international crisis. The research results of this paper will provide support for policy makers to better manage market information, transmit positive market signals, and improve the risk resistance of emerging financial markets.

2 Analysis of residual contagion channels

The World Bank offers three levels of explanations in defining contagion, and the most generalized contagion can be understood as the multinational dissemination of a shock or general transnational spillover effects. However, in this definition, the time when the contagion occurs is not limited to a crisis period. The narrow definition of contagion refers to the transmission or co-movement of shock exceeds economic fundamentals. Kenourgios and Dimitriou [5] considers financial contagion as a significant increase in stock returns between different markets or economies during a financial crisis. Thus, the causes of financial contagion may include multiple aspects, such as rational and irrational factors, international and regional factors, various complex factors between the financial system, and the real economy.

In globalization, the contagion channels of international crises include global, regional and residual contagion. Residual contagion refers to the manner in which other factors affect the return rate contagion in stock markets after eliminating regional and international objective factors. Different from global and regional contagion, residual contagion usually occurs between segmented markets with rare financial and trade links. For emerging markets, the channel of residual contagion is greatly significant for the spread of international financial market crisis, especially for the contagion mechanism under the "alarm effect" and "herd effect".

The most critical feature of residual contagion is that, contagion may still generate even in two mutually independent markets. In this process, international securities investors are the core elements, and the rapid spread of market information is the driving force for the evolution of investment behaviour. The "Alarm hypothesis" proposed by Goldstein [6] considered that a country's crisis reminds investors to re-evaluate other countries with similar economic fundamentals. A high-risk premium may still be generated even for a considerable level of risk due to the crisis. Moreover, some factors not previously associated with risk volatility may become a symbol of high risk when the risk perception of international investors is adjusted after the crisis. International investors become highly sensitive and risk averse. They usually quickly turn to hedge arbitrage mode in which investors prefer to resetting capital, fleeing to safe and highly stable markets, especially developed markets, thereby forming the "Herd Effect" [7, 8]. International investors become highly sensitive to emerging markets. Given the vulnerable macro basis, political risk, foreign reserve level, current account balance, government budget balance, and unemployment rate, volatility risk becomes higher in emerging markets during a crisis [9]. In addition, the risk aversion of international investors cause a serious shortage of funds in emerging markets, that their asset price became extremely sensitive. Figure 1 shows the channel mechanism of residual contagion.

In informatization, the advancement of information technology makes the international transmission of market information more efficient and directly, providing an important channel for residual contagion [10]. Research focusing on the hi-tech phenomenon verified the existence of abnormal stock return during the website-launching day and the two preceding days [11]. The volatility of the price-dividend ratio and the fluctuation of stock return are inclined to increase monotonically with international investor information in normal time. Nonetheless, the correlations between investor information and equity return volatility can be non-monotonic as the risk aversion surges in international crisis [12]. Thus it can be seen that the process of informatization can speed up the contagion, enlarge the contagion range as soon as the crisis breaks out.

Based on the aforementioned channel analysis of residual contagion, the hypotheses about the characteristics of residual contagion in emerging markets are proposed as follows.

Hypothesis 1 The shock remains significant even for emerging stock markets which were less with integrated with the international stock market when big and

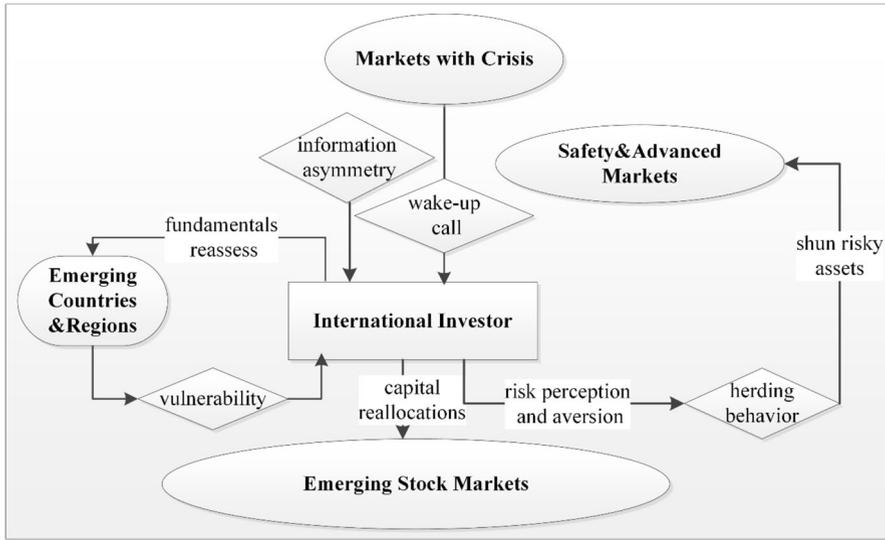


Fig. 1 Residual contagion channel

consequential international events occurred. That is assuming the existence of residual contagion.

Hypothesis 2 Given the complexity of political, economic, and financial differences among emerging markets, the volatility spillover and contagion effects of the emerging markets caused by major international crisis also differed.

3 Materials and methods

3.1 Data and specification of indicators

This study used the Morgan Stanley Capital International (MSCI) index to measure the stock market performance. The index contains the stock indices of emerging markets, the European Union, developed countries, and the world. The index also includes nine stock market indices, such as the United States, Chinese mainland's stock market, Taiwan, India, Indonesia, Chile, Mexico, Thailand, and South Africa. Except for the United States, a developed country, the other eight regions are emerging markets. The data were collected daily from January 3, 2000 to August 2, 2016 with a total of 4324 time series samples. The data are all from the WIND database.

According to the daily closing price of the MSCI index, proper treatment is applied to the collected data to reflect the average daily return in each stock market, as shown in Eq. (1).

$$r_{i,t} = \ln(p_{i,t}/p_{i,t-1}) \times 100\% \quad (1)$$

where $p_{i,t}$ is the index of stock market i at time t , and $r_{i,t}$ is the daily rate of return for the stock market i at time t .

3.2 Methodology

The DCC-MGARCH model proposed by Engle [13] involves two-step method to estimate the time-varying conditional covariance matrix Q_t . The first step is to estimate the conditional covariance of each asset using the univariate GARCH-in-mean model. The second step is to determine the conditional correlation coefficients according to the parameters estimated at first step.

Let $r_{i,t}$ be the average daily return vector of stock index i , that is $r_{i,t} = Cx_t + \varepsilon_{i,t}$, where x_t is average daily return vector of stock indices, $\varepsilon_{i,t}$ is defined as the residual of the average daily return on stock index i . $\varepsilon_{i,t}$ is multiplied by $H_t^{1/2}$ and v_t , which are the Cholesky factor of the time-varying conditional covariance matrix H_t and the independent normal distributing innovation, respectively. Thus, $\varepsilon_{i,t}$ is also time-varying.

According to the univariate GARCH model, the first step is to generate $\sigma_{i,t}^2$, the conditional volatility of asset i in the t period. α_j is defined as the ARCH parameter, and β_j is the GARCH parameter. The specific formula is as follows:

$$\sigma_{i,t}^2 = s_i + \sum_{j=1}^{p_i} \alpha_j \varepsilon_{i,t-j}^2 + \sum_{j=1}^{q_i} \beta_j \sigma_{i,t-j}^2 \quad (2)$$

Let $D_t = \text{diag}(\sigma_{1,t}^2 \dots \sigma_{m,t}^2)$, the time-varying variance matrix of the stock daily return rate H_t and its diagonal elements $h_{ii,t}$ and $h_{jj,t}$ follow the univariate GARCH process. The variance matrix of stocks i and j average daily return rate can be expressed as:

$$H_t = D_t^{1/2} R_t D_t^{1/2}. \quad (3)$$

The second step is to calculate R_t , that is, the time-varying conditional correlation matrix. Let Q_t be the positive definite covariance matrix. The matrix

$$R_t = \text{diag}(Q_t)^{-1/2} Q_t \text{diag}(Q_t)^{-1/2} \quad (4)$$

Finally, according to DCC-mean-reversion process, the time-varying conditional covariance matrix Q_t of average daily returns in stock market i and j can be obtained.

$$Q_t = (1 - \lambda_1 - \lambda_2)R + \lambda_1 \tilde{\varepsilon}_{t-1} \tilde{\varepsilon}'_{t-1} + \lambda_2 Q_{t-1} \quad (5)$$

where $\tilde{\varepsilon}_t$ is the standard residual vector, $\tilde{\varepsilon}_t = D_t^{-1/2} \varepsilon_t$, which equals the standardized stock yield vector. λ_1 and λ_2 are non-negative, and $\lambda_1 + \lambda_2 < 1$. λ_1 is the effect of the standardized stock yield on the current conditional covariance, and λ_2 is the effect of the post lag conditional covariance of two stock yields on the current conditional covariance.

4 Analysis based on descriptive statistics and impulse response function

4.1 Preliminary analysis

The statistics of stock yield in each market from January 3, 2000 to August 2, 2016 are described in Table 1. Compare the average value of stock yields in various markets during a full sample period, it can be seen that the average daily returns of emerging markets and the USA market are higher than that of the global markets, where is used as a benchmark. Whereas the average daily returns of the EU and the developed markets are lower than that baseline. The performance of each emerging market is much different in the past seventeen years. When Thailand experiences a boom with an average stock return of about 0.04%, the average daily return of the Chinese mainland's stock market is just similar to the general level of the whole emerging market with standard deviation of 1.7. While Indonesia's stock market is slightly more volatile than China's, its return is much higher. The performance of the Chile stock market is more attractive than that of China. That is due to the average daily return of Chile stock market reaches up to 0.037%, but the risk level measured by standard deviation is much lower than the average risk in emerging markets. Except for Chile, the average volatility of other emerging stock markets is higher than the overall volatility in the US, EU, and developed markets, as well as the rate of return. Almost all of the representative emerging markets possess high risk and return, side by side.

During the US subprime mortgage crisis, the average rate of return in emerging markets is -0.128% , which is solely superior to the EU market. The rate of return in the Chinese mainland's stock market is not the worst, but its volatility is the largest

Table 1 Statistical description of stock average returns in different markets

	Market						
	Emerging	USA	EU	Developed	Global	China	Chile
Full sample period							
Mean (%)	0.021	0.012	0.005	0.009	0.010	0.021	0.037
Standard deviation	1.069	1.105	1.367	0.913	0.900	1.700	1.058
	IN	ID	Mexico	TH	TW	ZA	
Mean (%)	0.022	0.029	0.028	0.040	0.019	0.024	
Standard deviation	1.559	1.711	1.370	1.574	1.323	1.609	
During subprime mortgage crisis							
Mean (%)	-0.128	-0.088	-0.162	-0.116	-0.117	-0.111	-0.036
Standard deviation	1.969	1.996	2.050	1.554	1.549	2.907	1.505
	IN	ID	Mexico	TH	TW	ZA	
Mean (%)	-0.124	-0.121	-0.104	-0.095	-0.110	-0.012	
Standard deviation	2.403	2.61	1.946	1.945	1.789	1.994	

IN stands for India, ID stands for Indonesia, TH stands for Thailand, TW stands for Taiwan, ZA stands for South Africa

with standard deviation reaches up to 2.9. Compared with Chile and South Africa, the Chinese mainland's stock market is inferior in return and stability. Therefore, whether in the full sample period or the international crisis period, the return volatility in emerging markets is larger compared with that of developed markets. Moreover, emerging markets varies given the difference between economic foundation and financial policies in various Countries.

4.2 Pulse response analysis

Figure 2 shows the cumulative impulse response of the US stock yield toward that of emerging markets, the EU markets, developed markets and three representative emerging markets (Chinese mainland, Taiwan, and Chile) from July 31, 2007 to March 31, 2009. It helps visually explain and compare the impacts of the US subprime mortgage crisis on various markets. Stock yields in emerging markets, the EU market, and developed market had a positive response at early stage and backed down to adjust slightly when subjected to positive shocks from US stocks. Once emerging markets suffered from the shocks of the US stock market, the initial response was only slightly weaker than the EU markets, and the cumulative impact was basically flat with the EU market. The response in developed markets was relatively subdued in the latter stages, and the impact on the stock yield was much weaker than those of emerging markets and the EU market. Although the financial link between emerging markets and the US is weaker than the EU, but the

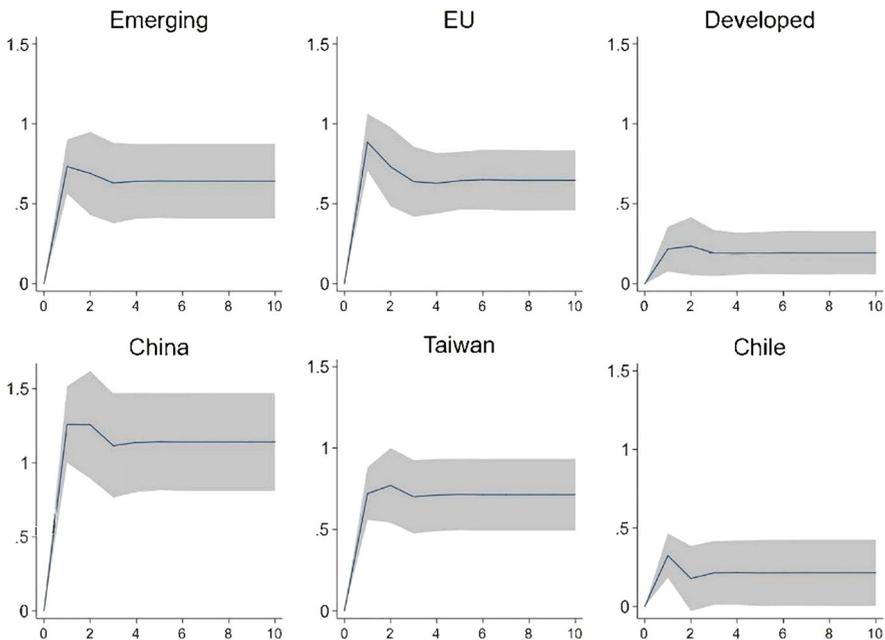


Fig. 2 The cumulative impulse response to US subprime crisis

cumulative impact of the US subprime mortgage crisis is almost the same as the EU markets, whose government are facing a huge deficit. That is due to the immaturity of monetary policy framework and financial system of emerging countries, which makes emerging markets less resistant to external market shocks. After the re-evaluation of the value of emerging stock markets, the divestment behaviour taken by international speculative institutions will lead international and domestic investors to follow suit, forming a herd effect. In addition, some speculative institutions may withdraw their investment in all emerging markets due to the fragile financial system of an emerging country.

Combined with the statistical description analysis of stock yields in each market, China, Taiwan, and Chile were chosen as representatives to analyze the impact of the US subprime mortgage crisis on different emerging countries. Figure 2 shows that the Chinese mainland's stock market responds more than one unit when it suffered a unit shock from the US subprime mortgage crisis. The phenomenon could be explained by the excessive panic and over stimulating economic policies in Chinese mainland's stock market during the crisis. China is already the second largest economy in the world, but it is insufficiently mature in financial market management and stock market operation. Taiwan's economic and financial linkages with US markets are not close, but absolutely cutting off the indirect shocks of the volatility in other emerging markets is difficult for such a small regional market during international crisis. As a result, the stock market in Taiwan has also been hit to a certain extent. Benefitting from Chile's stable institutional framework, effective macro policies, and well-developed infrastructure, the impact of the US subprime mortgage crisis on Chile was effectively buffered. The buffer period is relatively short and not as stable as developed markets, nevertheless, the cumulative response of Chile's stock market was comparable to that of developed markets. Thus, the political and economic foundation of a country is also a crucial part of the environment in which its stock market could develop steadily. Otherwise, the market will be fragile when an international crisis comes even if it is huge in size. The performance of the three representative markets reveals that each country in an emerging economy responds differently when subjected to the shock of international crisis, due to the heterogeneity of political institution, economic foundation, and financial systems. Therefore, we preliminary speculate that the volatility spillover and contagion effects of emerging markets caused by the major international crisis are also different, which has been proposed in Hypothesis 2, and will be further supported through the DCC-MGARCH model in a later section.

5 Further analysis based on the DCC-MGARCH model

5.1 Clustering characteristics of the stock indexes

Figure 3 shows the volatility of stock yields in the US and other main economies from January 3, 2000 to August 2, 2016. The figure shows strong co-movements among all the above stock markets where the returns fluctuated sharply during the international crises, especially at the time of US subprime mortgage crises. There is

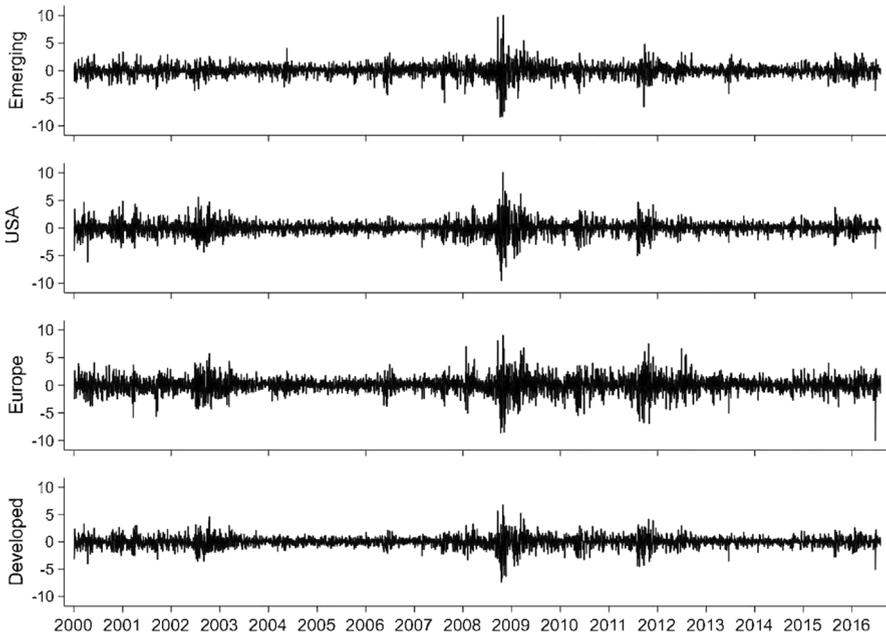


Fig. 3 Volatility cluster gram of stock yields in the U.S. and other economies

a similar tendency of volatility among emerging market, the USA, the Europe, and even the developed, as well as the global markets. In normal time, stock yields in above markets fluctuate modestly. As we can see from the Fig. 3 that, the stock yield of emerging market has been fluctuated more gently since 2000–2006, while no sign of weaker volatility in emerging markets in time of crisis than other markets. Not only that, stock returns show significant volatility clustering during the US subprime mortgage crises, and after the escalation of the European debt crisis in the latter half of 2011. However, the volatilities of stock returns in each major market were mild during the non-crisis period, revealing the variance of the stock yield in each market is not constant, and there is heteroscedasticity. The stock yields of various markets have the characteristics of clustering volatility, which means that heteroscedasticity may exist. Therefore, considering the volatility of variance, the GARCH family model was chosen in this study, which can investigate the risk contagion of the financial market effectively.

5.2 ARCH test

This study used two types of methods to test if the variable has heteroscedasticity. The result of autoregressive conditional heteroscedasticity test (ARCH-LM test) in Table 2 indicates that the residual sequence square of the average daily stock yields in various stock markets has autoregressive conditional heteroscedasticity.

Table 2 ARCH-LM test of stock yields in different markets

ARCH-LM test (Lag 1)							
	Emerging	USA	EU	Developed	Global	China	Chile
Chi2	185.31***	183.51***	50.76***	170.05***	164.77***	41.80***	116.66***
	IN	ID	Mexico	TH	TW	ZA	
Chi2	38.03***	77.61***	7.82***	269.2***	50.27***	45.84***	

Table 3 shows that the q statistics of the Ljung-Box test result rejects the null hypothesis that the residual square sequence does not have autocorrelation. Therefore, the residual square sequence of the average daily stock yields are dependent random distributions. Thus, the disturbance term has conditional heteroscedasticity.

5.3 Estimates of DCC-MGARCH model in emerging markets and other markets

The research from Chiang et al. [14] found out that, during the whole crisis period, the dynamic conditional correlation of stock yields among various markets in each stage may have significant differences. For example, the correlation between Asian markets during the Asian crisis performed a steady downward trend in the early stage. However, this correlation increased and maintained a high correlation level in the latter stage for a long time, which is the characteristic of the financial crisis contagion in Asian and other emerging markets. This study combined Kenourgios's definition of financial contagion with Chiang's research conclusions on the financial contagion during the Asian crisis to estimate the financial contagion of emerging markets.

Table 4 shows the parameters estimated by utilizing the DCC-MGARCH model between emerging markets and the US, EU, global markets, developed markets, respectively. As shown in Table 4, $\lambda_1 + \lambda_2 < 1$ but close to 1, which means the estimation process is convergent. Therefore, the conditional covariance of stock yield in emerging markets and other markets remains a long-term sustainability. The estimation result of λ_1 shows that emerging markets are sensitive to the innovation of the EU and US markets, as well as developed and global markets. The estimation result of λ_2 shows that the post-lag conditional covariance between emerging markets and various main markets substantially impact the current conditional covariance and the mutual volatility spillover effect lasts for a long period.

Table 3 Q test of stock yields in different markets

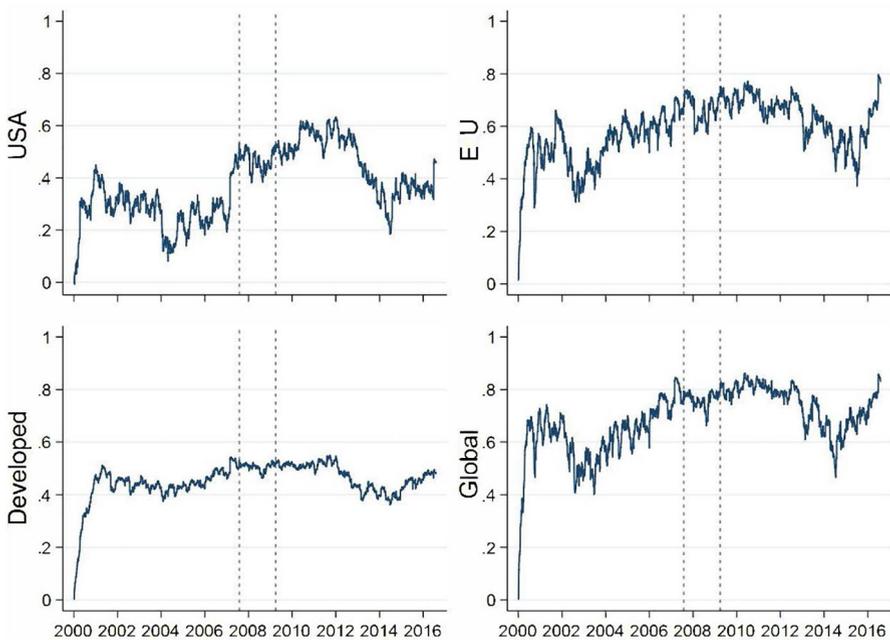
Ljung-BoxQTest							
	Emerging	USA	EU	Developed	Global	China	Chile
Q-statistics	300.86***	109.22***	102.28***	149.47***	180.57***	77.48***	159.04***
	IN	ID	Mexico	TH	TW	ZA	
Q-statistics	84.99***	71.78**	104.64***	61.88**	71.05**	70.01**	

Table 4 DCC-MGARCH model estimation of emerging markets and other economies

Parameter	Markets			
	USA	EU	Developed	Global
Cross-correlation coefficient	0.453*** (7.32)	0.647*** (20.66)	0.454*** (17.07)	0.748*** (28.54)
λ_1	0.008*** (4.17)	0.013*** (6.28)	0.004* (2.38)	0.0141*** (6.44)
λ_2	0.99*** (485.07)	0.982*** (345.94)	0.991*** (369.40)	0.981*** (343.36)
$\lambda_1 + \lambda_2$	0.997	0.995	0.995	0.995

Except for the global stock market, which contains the stock information of emerging markets, the cross-correlation degree between emerging markets and the EU stock markets is the highest throughout the sample period. The cross-correlation between the US stock market and emerging markets is much weaker with the correlation coefficient of 0.453. The results imply the volatility of the stock markets mentioned above shock the emerging stock markets, the international stock markets have significant volatility spillover effects on emerging markets.

The dynamic correlation coefficients of the emerging and other stock markets in Fig. 4 show that the dynamic correlation between emerging stock market and other

**Fig. 4** Dynamic correlation coefficients of emerging and other stock markets

stock markets has a periodic change during the US subprime mortgage crisis. From the beginning of the subprime mortgage crisis in August 2007 to the outbreak of the financial crisis in September 2008, the dynamic correlation between the emerging stock market and other stock markets in global declined in oscillation. After September 2008, the subprime mortgage crisis, which originated in the US, broke out and evolved into a global financial crisis. The dynamic correlation between the emerging stock market and the US stock market increased significantly.

Figure 5 shows that the conditional covariance between the US markets and emerging markets reached the highest level in history during the US subprime mortgage crisis, and the volatility spillover effect is evident. The other main stock markets also suffered the impact of the US subprime mortgage crisis. Thus, the indirect impact of the EU markets also exists apart from the direct volatility spillover effect of the US stock market. Therefore, in the background of financial globalization, emerging stock markets are infected by the international financial crisis, and the contagion sources are diversified. When the international financial crisis occurs, as the Figs. 3 and 5 together indicate, the shock to emerging stock markets is not slighter than other markets although the financial and trade links with the US is weaker than the developed markets, such as the EU. Information about the fragility of emerging market economy and financial system become quickly mastered by global investors in infrmatization. When the market is depressed, international investors immediately adjust their judgment and preference for financial risks in emerging markets and switch on a risk-averse arbitrage mode. Under the herd effect and alarm effect, the capital resetting operation of major investment institutions sent risk signals to

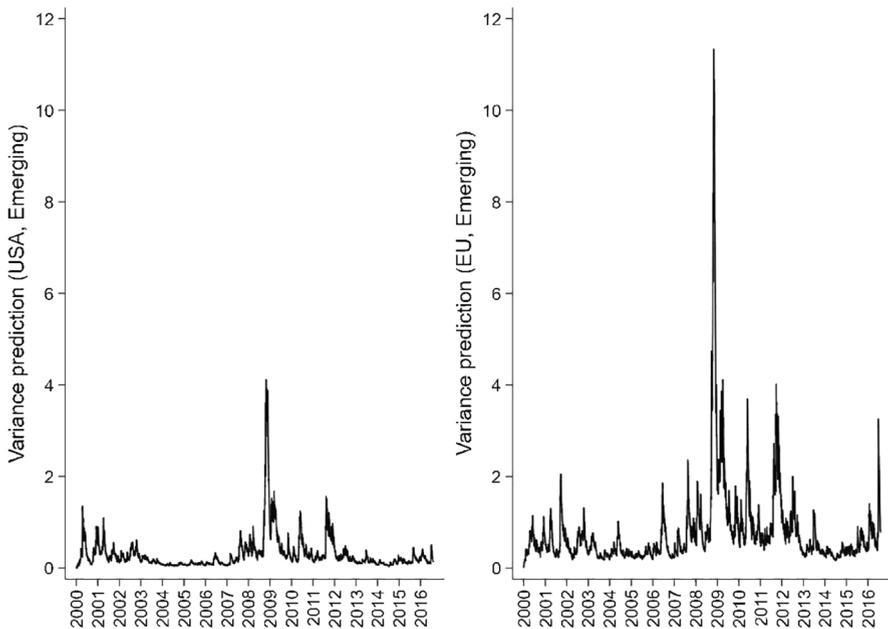


Fig. 5 Volatility spillover effects of the US and the EU on emerging stock markets

other investors. Domestic and international investors flee from less resilient emerging markets to relatively mature and stable capital markets such as the US and Japan. This, in turn, exacerbate the shock to emerging markets, creating residual contagion effects.

The US subprime mortgage crisis led to a continually expanding Greek debt after 2009, embroiled the other markets in Europe also into debt crisis gradually after 2010. The European debt crisis eased with the introduction of favourable policies in subsequent period. The dynamic correlation coefficient diagram between emerging markets and the EU market at the top right of Fig. 4 shows that the dynamic correlation between emerging stock market and the European stock market was maintained at a high level in the early stages of the European debt crisis. While the dynamic correlation coefficient between emerging stock markets and the US and the global stock markets continued to rise at the same period. International investors who just stepped out from the US subprime mortgage crisis neither thought that the European sovereign debt problem would evolve into an international crisis nor considered that the highly government leveraged debts were risky. They assumed that the EU would definitely be safer than emerging markets. Thus, the European debt crisis did not create obvious residual contagion in emerging markets at the early stage. However, in early 2012, a more serious sovereign debt crisis occurred in Greece without Omen of Clarity, the European debt problem entered its most severe stage.

Figures 4 and 5 show that, at the beginning of 2012, the dynamic correlation between emerging markets and the EU market declined rapidly and then rebounded to a high level. In this period, the conditional covariance of the EU market and emerging markets reached a new peak. The volatility spillover effect of the EU market on emerging markets is noticeable, and emerging stock markets were subjected to the contagion of the European debt crisis. From then, the EU has introduced a series of arrangements and policies to get over from the European debt crisis, which allowed international investors to see the hope of resurgence. At the beginning of 2015, the European debt crisis escalated again, led the dynamic correlation coefficient of the two markets to an abnormal situation where the coefficient fell first and then rose rapidly to a high level again. The contagion effect was fairly pronounced. On June 23, 2016, the winning of the Brexit vote sparked worldwide concerns about the future of Britain and the EU, which would inevitably impact international investment. The superposition effect of the European debt crisis and the Brexit can also be observed in Figs. 4 and 5. The dynamic correlation coefficient, as well as the conditional covariance of emerging stock market and the other main stock markets in international increased sharply at the end of the sample period. This increase demonstrated once again that the European financial market shocks have apparent volatility spillover effects and residual contagion effects on emerging stock markets.

The whole European debt crisis inevitably influenced international investment. Time and time again sudden fermentation of the whole European debt crisis provides international investors with an "Alarm" that the issue of government debt is highly risky. Therefore, emerging markets can also be estimated as a market unfit for investment due to their potential risk of government debts make them lose the attraction to international investors. In addition to the international contagion through economic and financial opening channels, emerging markets also suffered

from the impact of residual contagion as explained above, which verified Hypothesis 1 in this study. During this debt crisis, emerging markets which is far less harmful than the US subprime mortgage crisis, still suffered from residual contagion, as the result of financial fragility in emerging markets. Thus, they can never be the refuges for international investors when the international financial crisis occurs.

5.4 Estimates of DCC-MGARCH models in representative emerging markets and the US market

The financial development degree and economic institution arrangements are considerably different among various emerging markets. Moreover, their correlation degree and correlation method with developed markets and all the other main stock markets also varies. Therefore, the fluctuation rang of stock yields in the emerging markets are different when facing international events.

Table 5 shows DCC estimated results of eight representative emerging markets and US stock markets. The estimation process is convergent from $\lambda_1 + \lambda_2 < 1$ and close to 1. The estimated results of parameters λ_1 are statistically significant, which states that each emerging market is sensitive to innovation information from the US stock market. The estimated results of λ_2 show that the conditional covariance of every two markets is stable in the long run, and the volatility spillover effect should last for a long time. From the estimated results of cross-correlation coefficients, interactivities between the eight emerging markets and the US stock markets are significant. But the degree of cross-correlation between China and the US stock markets is not high, the estimated coefficient is just 0.082. Mexico, as the car industry

Table 5 Estimates of DCC-MGARCH models for emerging and US markets

Markets	Parameter			
	Cross-correlation coefficient	λ_1	λ_2	$\lambda_1 + \lambda_2$
China	0.082* (1.99)	0.008*** (4.14)	0.986*** (446.44)	0.994
Chile	0.444*** (16.01)	0.0126*** (5.11)	0.977*** (268.17)	0.980
India	0.256** (2.94)	0.006** (2.73)	0.992*** (327.61)	0.990
Indonesia	0.29*** (8.61)	0.0185 (4.61)	0.968*** (144.66)	0.987
Mexico	0.628*** (53.26)	0.006* (2.26)	0.966*** (86.01)	0.970
Thailand	0.200* (2.01)	0.006* (2.55)	0.992*** (281.29)	0.990
Taiwan	0.031 (1.79)	0.010 (1.47)	0.879*** (18.69)	0.880
South Africa	0.381*** (5.23)	0.004** (3.75)	0.9949172 (700.33)	0.999

base and backyard of the US, has close relationship for economic and financial exchange, and the population mobility with America. These linkages help generate residual contagion through the channel of communication of information. Mexican stock market has the highest degree of cross-correlation with the US stock market, and the cross-correlation coefficient is 0.628. Taiwan, Indonesia, and Thailand are weakly correlated with the US compared with other emerging markets. The spillover effects of the US stocks fluctuation on these three markets are also relatively minimal.

Combining Table 5 with Fig. 6, contagion effects induced by US subprime mortgage crisis on emerging markets can be found clearly. The part between the vertical dashed lines in Fig. 6 represents the period of the US subprime mortgage crisis. In this period, all the dynamic correlation coefficients of the US and some emerging markets, including China, Chile, India, Indonesia, Thailand, and South Africa, decrease at first followed a sharp increase after, indicating that all the above countries are contaminated by the US subprime mortgage crisis. The reactions of China and Thailand are obviously unusual among these contaminated markets. Their dynamic correlation coefficients with the US stock market turn negative and then increase sharply to a high position with a vast span, which can be explained by the implement of excessive expansionary policies. For example, China introduced a "four-trillion economic stimulus plan" after the outbreak of US subprime mortgage crisis, which drove the stock index and real estate market investment in China to soar. However, such stimulus policies could just temporarily compensate for the

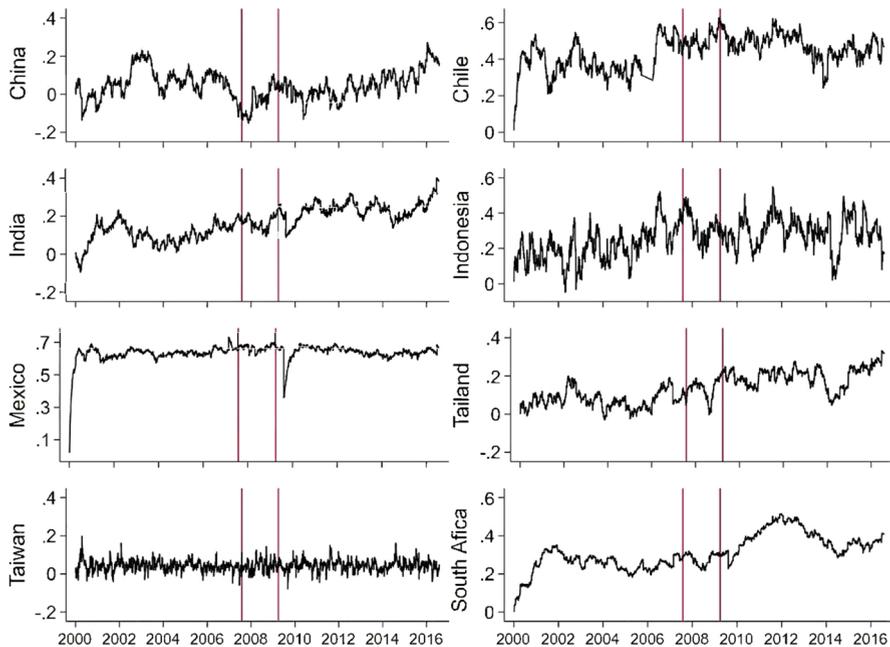


Fig. 6 Dynamic correlation coefficients between the emerging and US stock markets

negative effect of the US subprime mortgage crisis. The correlation coefficient between China and the US stock market still increased significantly at a later stage.

The correlation coefficients between other emerging stock markets and the US stock market show various degrees of fluctuations, which implying there exist residual contagion differences among those emerging markets. The dynamic correlation coefficient of Chile and the US has a high general level and does not show an excessive abnormal correlation coefficient, which is moderately affected by the US subprime mortgage crisis. The dynamic correlation coefficient and λ_2 estimated in DCC model between Taiwan and the US show that the volatility spillover effect of the US on Taiwan is unstable and unsustainable, and the correlation coefficient of the two markets also frequently fluctuate. The dynamic correlation coefficient of Taiwan and the US shows a downtrend then an uptrend during a recurrent fluctuation, which is slightly affected by finance.

The stock yields of Mexico and the US maintained a generally high correlation but failed to show outstanding change with only a small decline followed by a small rise. The contagion effect of finance is weak. The correlation of China, Thailand, and the US is relatively weak unlike that of Mexico. However, the dynamic correlation coefficients of China, Thailand, and the US fluctuated greatly. The residual contagion effect of the US market on Thailand market is especially outstanding. Therefore, the cross-correlation of the two markets is mainly reflected by the general level of their economic and financial ties. The high cross-correlation of two markets does not mean that the contagion effect was strong during the financial crisis. The high cross-correlation is due to the macroeconomic fundamentals, national policy, and financial system of the infected market. The degree of infection of the emerging markets during the international crisis varied owing to the differences of these factors. Therefore, Hypothesis 2 is confirmed. The US subprime mortgage crisis still has a strong residual contagion effect on markets with minimal correlation, such as China and Thailand, which means that the channel mainly has residual infectivity. Hypothesis 1 is also confirmed.

5.5 Estimates of DCC-MGARCH model in representative emerging markets and the EU markets

Table 6 shows that parameters λ_1 are all statistically significant in DCC-MGARCH model among emerging and EU markets. Every emerging market is differently sensitive to the innovation of EU markets. The estimated result of conditional covariance coefficient λ_2 illustrates that the interaction volatility of every two markets remains stable in the long term. Eight emerging stock markets and the EU market show a significant positive cross-correlation. The correlation between Indonesia and the EU market is the most weak, whereas the correlation between the Mexico/South Africa and the EU markets is relatively high, of which the cross-correlation coefficients are 0.524 and 0.497, respectively. The fluctuation of EU stocks has a weak or strong spillover effect on the eight emerging stocks.

Figure 7 shows the changes of dynamic conditional correlation coefficients between each representative emerging market and the EU market. Almost every

Table 6 Estimates of DCC-MGARCH models for emerging and EU markets

Markets	Parameter			
	Cross-correlation coefficient	λ_1	λ_2	$\lambda_1 + \lambda_2$
China	0.283*** (11.42)	0.0115*** (3.51)	0.971*** (112.08)	0.983
Chile	0.460*** (14.36)	0.00931*** (3.63)	0.984*** (208.33)	0.993
India	0.279*** (11.11)	0.0252*** (4.47)	0.944*** (72.40)	0.969
Indonesia	0.168*** (6.24)	0.0149** (2.36)	0.962*** (42.39)	0.977
Mexico	0.524*** (20.95)	0.0249*** (6.31)	0.956*** (140.46)	0.981
Thailand	0.240*** (8.99)	0.0269*** (3.85)	0.944*** (47.54)	0.971
Taiwan	0.211 (9.26)	0.007* (2.01)	0.973*** (77.47)	0.980
South Africa	0.497*** (14.66)	0.0156** (2.23)	0.976 (76.66)	0.992

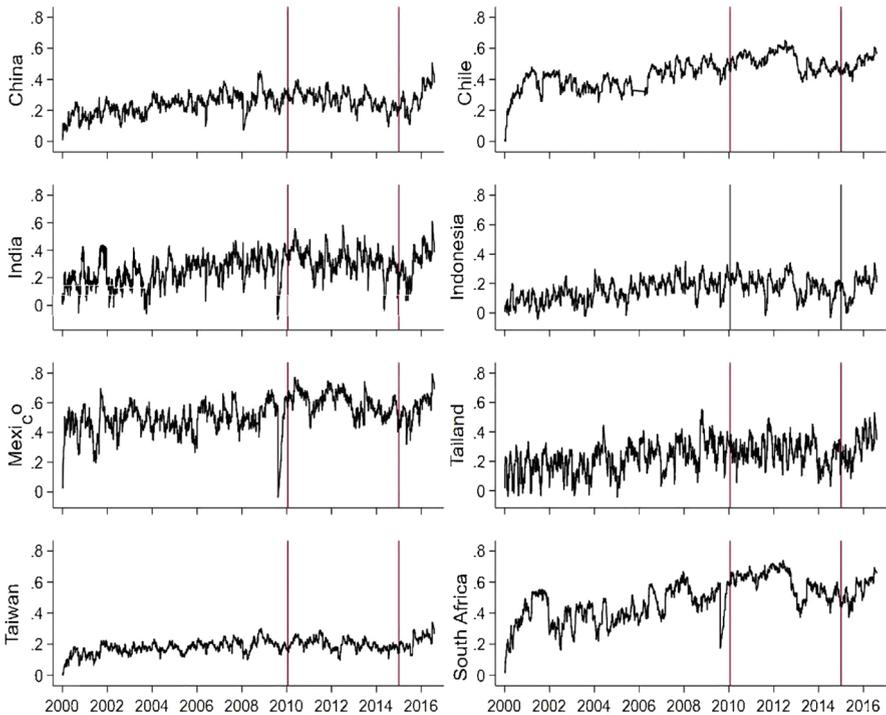


Fig. 7 Dynamic correlation coefficient between the emerging and EU stock markets

hard-hit country has adopted a relatively closed stimulating policy to enlarge investment for developing national economy after the US mortgage crisis, even so, the EU economy recovered slowly. Figure 7 indicates that the dynamic correlation coefficients of India, South Africa, and EU stocks show a free-fall demotion. Given the gradual recovery of the EU economy, the economic and financial relationships of every country with the EU gradually recovered, and the dynamic correlation coefficients also quickly rebounded to a high-order position. Under the impact of sluggish domestic economy and swine flu H1N1, the trade between Mexico and other countries decreased rapidly, resulted in the weakness of correlation with EU stock market. Soon after that, the co-movement strengthened gradually with the economic recovery of the two markets. However, the correlations of Chile, India, Indonesia, Mexico, Taiwan, and South Africa with the EU stock market rose quickly to a higher level after a shortfall when the European countries got in debt crisis at the beginning of 2010. The dynamic correlation coefficients of China, Chile, Thailand, and the EU frequently fluctuated during the crisis, indicating that the relationship of markets was unstable, which was not beneficial to the healthy development of the financial market. In short, the European debt crisis has a certain extent of residual contagion on these markets in this period.

The EU member states implemented a series of financial policies and agreed to create the European Financial Stabilization Mechanism (EFSM) thereafter, but things had never been going well when recovering from international crisis. The dynamic correlation coefficients of every emerging stock market with the EU stock market repetitively fluctuate and show apparent vulnerabilities. China, India, Indonesia, Mexico, and Thailand could not be well in their way due to the unstable economic environment and the financial market. The European debt crisis escalated in 2012, which had significant contagion effect on the stock markets of Chile, Mexico, Taiwan, and South Africa. International investors suffered a setback on investment in European markets when the European debt crisis escalated again in 2015. The dynamic correlation coefficient of each emerging market with the EU market continued to increase to a high-order position after a brief drop, followed a highly apparent upward trend after the Brexit referendum. Almost all the representative emerging markets suffered different degrees of crisis contagion in this round of European debt crisis.

In conclusion, dynamic correlation coefficient of most representative emerging markets with the US or the EU stock markets fluctuated frequently, which reflected the instability and vulnerability of emerging financial markets. (a) From the analysis of the estimated results of DCC-MGARCH and the impulse response to the US subprime mortgage crisis, emerging markets with a vulnerable macroeconomic foundation and weak correlation, did not suffer a smaller residual contagion compared with markets with high correlations. (b) On the contrary, they might experience strong residual contagion, which confirms Hypothesis 1. In that, residual contagion channels to emerging countries are diversified that they may suffer direct contagion from the crisis originated country, as well as indirect contagion from other contaminated countries. (c) Finally, from the estimated results of the DCC-MGARCH model, neither the cross-correlation degrees of every emerging stock market with the US, nor

with the EU stock market are evenness. Moreover, heterogeneity also exists in the contagion effect of every emerging market, which confirms Hypothesis 2.

6 Conclusion and suggestions

In the context of informatization and combined with major events in the international capital market since 2000, this paper examined the residual contagion effect of the international financial crisis on emerging markets to furtherly demonstrate the fragility of emerging markets and the heterogeneity of residual contagion. The statistical description and the impulse response analysis method were adopted to analyze the volatility level of emerging markets compared with the European, the US, and developed markets, as well as the extent of shock these markets suffered from international crisis. Moreover, we also applied the DCC-MGARCH model to explore the existence and heterogeneity of residual contagion when international financial crisis strike emerging markets. The main results are shown below.

First, the volatility level of stock yield in emerging markets is higher compared with the US, the EU, and the developed markets, and the impacts of international financial shocks on emerging stock markets are obvious.

Second, through the "alarm effect" and "herd effect", emerging markets were infected by the residual contagion of the international financial crisis due to their weak macro foundation and immature financial system, whether during the sub-prime mortgage crisis in the United States or the debt crisis in Europe.

Third, the heterogeneity of the US subprime mortgage and European debt crises is observed on the stock markets of each emerging market. Except for Mexico, all the other emerging stock markets were subjected to varying degrees of residual contagion during the US subprime mortgage crisis. The impact of contagion on Thailand was the largest, followed by South Africa. Almost all the emerging markets were subjected to varying degrees of residual contagion during the European debt crisis. Especially, the contagion effect became highly evident under the superposition impact of the Brexit vote.

Since the 1990s, emerging countries have witnessed rapid economic and financial development. With the advancement of information technology, emerging countries are increasingly integrated with other economies in the world. However, emerging countries' financial market development lags behind that of developed countries such as Europe and the United States. In view of the findings of this paper, it is suggested to improve the capacity of emerging countries to resist residual infections from the following aspects: First, the central Banks of emerging countries should accelerate the improvement of the macro-prudential assessment system, build a more flexible and modern financial market system, and improve the unified financial risk monitoring system. Secondly, a market information exchange and management mechanism should be formed to raise their profile in the global financial market, publicize the positive policies of the financial market through various channels to stabilize the confidence of international investors, and adopt various superior information technology to improve financial performance of domestic firms [15]. Finally, it is necessary to form an early warning mechanism of financial risks and improve

the capability to analyse the dynamic information of the global market in informatization, so as to gain insight into the signals of financial market crisis and resist international financial shocks.

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Compliance with ethical standards

Conflict of interest The authors declare no conflict of interest.

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