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Contagion Effect of Natural Disaster and Financial Crisis Events on International Stock Markets

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Abstract: In the contemporary world bustling with global trade, a natural disaster or financial crisis in one country (or region) can cause substantial economic losses and turbulence in the local financial markets, which may then affect the economic activities and financial assets of other countries (or regions). This study focuses on the major natural disasters that occurred worldwide during the last decade, especially those in the Asia–Pacific region, and the economic effects of global financial crises. The heteroscedasticity bias correlation coefficient method and exponential general autoregressive conditional heteroscedasticity model are employed to compare the contagion effect in the stock markets of the initiating country on other countries, determining whether economically devastating factors have contagion or spillover effects on other countries. The empirical results indicate that among all the natural disasters considered, the 2008 Sichuan Earthquake in China caused the most substantial contagion effect in the stock markets of neighboring Asian countries. Regarding financial crises, the financial tsunami triggered by the secondary mortgage fallout in the United States generated the strongest contagion effect on the stock markets of developing and emerging economies. When building a diversified global investment portfolio, investors should be aware of the risks of major natural disasters and financial incidents.

Keywords: contagion effect; spillover effect; asymmetric volatility; natural disaster; financial crisis

1. Introduction

Various studies have described the considerable interlocking effect among stock markets worldwide. For example, Glick and Rose (1999) report that when a major impact on the international financial market occurs, international trade is the cause of market linking and transmission. Eun and Shim (1989) find through an empirical study that multilateral interactions between international stock markets exist and that the US stock market is the main source of international effect transmission. King and Wadhwani (1994) also confirm that if a price error occurs in a country's market, the error is transmitted to other markets, and that an increase in stock market volatility enhances the contagion effect. Aggarwal et al. (1999), Collins and Biekpe (2003), and Dungey et al. (2006) target financial events as their research subjects. Shen et al. (2015) examine the contagion effects of China's stock market after the European debt crisis. When an international financial crisis breaks, most of the countries vulnerable to the contagion effect are those with developing or emerging markets. Not only does the contagion effect occur when a financial crisis breaks, but the occurrence of disastrous events affects stock markets by contributing to market volatility. The contagion effect mentioned by Forbes and Rigobon (2002) has both positive and negative impacts; it not only triggers investors to amend their investment strategies during a financial crisis but also leads to the shifting of funds to other countries, resulting in multiple equilibria among markets.

The contagion effect refers to a country transmitting market changes to other countries after the impact of a major event and interdependency among countries. According to the World Bank, the contagion effect generally has three definitions: (1) The contagion effect is broadly defined as the process of market change transmission to other countries after a country experiences a major event that impacts its economy and stock market, which may lead to an impact from negative events and a spillover effect from positive events; (2) The limiting definition of the contagion effect is that the transmission of the impact from a major event exceeds expectations, leading to the comovement of financial assets between two countries; (3) In the highly limiting definition, the contagion effect means increased relatedness between markets after a major risk impact.

Studies have mostly discussed the contagion effect among markets during financial crises, namely the US stock market crash in 1987, the Mexican currency crash crisis in 1994, the Asian financial crisis that began in Thailand in 1997, the US subprime mortgage crisis in 2007, and the European debt crisis in 2010. Many researchers have studied the contagion effects of financial crises, such as Caporale et al. (2005) and Boyer et al. (2006). However, the contagion effect is not always related financial crisis; when a major natural disaster occurs, such as an earthquake, the international financial market can become volatile. Few researchers have discussed contagion effects caused by natural disasters. According to Lee and Wu (2009), the Osaka-Kobe, Japan earthquake in 1995 caused a substantial contagion effect on the stock markets of neighboring Asia–Pacific countries. Hence, the spillover and contagion effects caused by natural disasters are worthy of discussion and research.

Natural disasters occur around the world every year; however, with global warming increasing and there being notable occurrences of devastating earthquakes in recent years, several natural disasters have posed a great threat to life and property in recent years, such as the earthquake and tsunami in Southeast Asia at the end of 2004 and the 2011 earthquake in northeastern Japan. With global trade currently frequent, a major natural disaster may result in enormous economic loss and financial market volatility, which may even spread to the economic activity and financial asset volatility in other countries (or regions). On March 11, 2011, a devastating earthquake (seismic intensity of 9 on the Richter scale) occurred in northeastern Japan, which triggered a tsunami that nearly destroyed the area and led to a nuclear plant radiation leakage, causing serious casualties, economic and property damage, and a large blow to the chain-break effect arising from commodity supply and the money markets.

This paper's main contribution is in using financial events and major natural disaster events to study the resultant contagion effects that arise and, in doing so, more comprehensively than in other papers. This paper focuses on the major natural disasters that have occurred in the Asia–Pacific region over the last decade and the ensuing global financial crises. First, we employ the heterogeneity biases correlation coefficient model and the exponential generalized autoregressive conditional heteroscedastic (EGARCH) model proposed by Forbes and Rigobon (2002), in addition to examination of the possible contagion effect exerted by the affected country on the stock markets in other countries, to explore whether the factors causing harm to the economy lead to contagion or spillover effects in other countries. Then, we use the EGARCH model, as Lee and Wu (2009) did, to detect occurrences of crisis events and determine whether asymmetrical volatility in returns occurred among stock markets worldwide. We also analyze whether comovement and volatility spillover levels increased in the affected country and other sample countries after the impact of a crisis, or led to the contagion effect among stock markets.

This remainder of this paper is organized as follows: Section 1 presents a discussion of the background and motivation for this study; Section 2 provides a review of studies associated with the contagion effect; Section 3 details the formal methodology employed; Section 4 presents a description of the sample data; Section 5 provides an analysis of the empirical results; and finally, Section 6 summarizes the findings and provides a conclusion.

2. Literature Review

The effects of volatility in equality markets are different or asymmetric; that is, good and bad news may have different effects called asymmetric volatility phenomenon. Empirical studies have provided numerous discussions of asymmetric volatility. Brooks (2007) uses the asymmetric power autoregressive conditional heteroscedastic (APARCH) model to analyze the asymmetric volatility of emerging markets and found that Middle Eastern and African markets have different characteristics than Latin American markets. Jayasuriya et al. (2009) investigate the asymmetric volatility of mature and emerging markets and discover that several mature and emerging markets exhibit large asymmetric volatility as a result of transaction costs, namely capital gains taxes and trading strategies. Talpsepp and Rieger (2010) measure asymmetric volatility based on the daily stock market returns of 49 countries. They suggest that gross domestic product capita, stock market participation, and analyst coverage are factors that increase asymmetric volatility. Dzieliński et al. (2018) analyze the asymmetric volatility of stock returns in US firms, and find that stocks that receive more attention from analysts and stocks with low institutional ownership show considerable asymmetric volatility. However, these studies only investigated asymmetric volatility; they did not discuss the contagion effect, which is an important factor in the transmission of market changes. Forbes and Rigobon (2002) define the contagion effect to be when an impacted country triggers market comovement within the region and substantially increases the relatedness between countries. This definition not only indicates that the contagion effect can be positive but also causes comovement and weakens negative effects.

With the globalization and liberalization of financial markets, cross-border investment and the presence of multinational companies have increased, thereby linking the funds that circulate in international markets. Thus, any financial crises and natural disaster events lead to contagion effects around the world. Eichengreen et al. (1996) believe that when a major event occurs in a country, international fund managers shift available funds to another country to avoid regional and system risks, which gives rise to relatedness of the two markets involved in the comovement. Madura (2003) suggests that when certain events occur that affect the overall global economy, international stock markets display the characteristic of comovement. Masson (1999) divides the contagion effect into the pure contagion effect and basic contagion effect. The contagion effect refers to investors' altered expectations or risk perceptions regarding the market when a major event takes place, leading to market pessimism.

Regarding methodology, most studies focus on the theory of correlation to analyze the transmission of a crisis from one country to another. Lee and Kim (1993) use weekly data as samples and the cross-section of stock returns correlation coefficient to detect the US stock market crash crisis that had a contagion effect on 12 countries. King and Wadhwani (1990) state that the cross-market correlation significantly increased among the United States, the United Kingdom, and Japan after the US stock market crash of 1987. On the basis of correlation coefficients after heteroscedasticity adjustment, Baig and Goldfajn (1999) find that during the Asian financial crisis period, a contagion effect existed among interest rates, currency rates, and stock returns in Thailand, Malaysia, Indonesia, South Korea, and the Philippines. Calvo and Reinhart (1996) and Baig and Goldfajn (1999) use a similar methodology to investigate the contagion effects that occurred after the 1994 Mexican Peso Crisis and 1997 Asian Crisis. Furthermore, Forbes and Rigobon (2002) use heteroscedasticity bias testing and employ as their sample the periods of the 1997 Asian financial crisis, the 1994 Mexican crisis, and the 1987 US stock market crisis. Nine countries in Southeast Asia, four countries in Central and South America, 12 countries of Organization for Economic Cooperation and Development (OECD), and four emerging countries—29 samples in total—displayed no contagion effect, as indicated by a significant change in the correlation coefficient, instead showing only an interdependence effect.

In many empirical studies, the contagion effect has been found in many stock markets based on a dynamic conditional correlation model. Some models in the autoregressive conditional heteroscedastic (ARCH) model has been emphasized in numerous studies for their ability to analyze the contagion effect. Hamao et al. (1990) adopt the GARCH model to estimate the conditional variance used to detect the relatedness of 12 countries with market volatility when the US stock market crash occurred in 1987. Among the stock markets in New York, London and Tokyo, a spillover effect appeared in the sequence of New York to London and then to Tokyo. Using the GARCH model, Aggarwal et al. (1999) find that the US stock market crisis in 1987 pushed the US stock market's volatility spillover to Latin America and emerging Asian countries. Sensoy et al. (2014) apply the DCC-GARCH model to estimate the dynamic conditional correlations of 13 European countries and Turkey. Ahmad et al. (2013) use a similar approach to analyze the contagion effects of the stock markets of Greece, Ireland, Portugal, Spain and Italy on the stock markets of Brazil, Russia, India, Indonesia, China, South Korea and South Africa after the Eurozone crisis. Lee and Wu (2009) employ the EGARCH model to estimate asymmetric volatility leading to the contagion effect among stock markets.

Because of financial markets increasingly becoming open, the advancement of information, and international capital markets gradually reaching maturity, when a financial crisis or major natural disaster occurs in a country, the country's economy and the economy of countries with close ties to it are affected. Therefore, most researches have focused on the contagion effect of financial crises; it has seldom discussed whether a contagion effect is produced among countries when a natural disaster event occurs. This paper investigates whether a contagion effect is produced between a country suffering from a financial crisis or a natural disaster and the other countries it trades with. Furthermore, we employ the heterogeneity biases correlation coefficient model and the EGARCH model to examine contagion effects.

3. Methodology

3.1. Heteroscedasticity Biases Correlation Coefficient Method

Two methods exist to investigate the contagion effect. First, we apply the heteroscedasticity bias testing of Forbes and Rigobon (2002). Second, because heteroscedasticity bias testing ignores the risk posed by the tail of the distribution, we employ the EGARCH model, as also used in Lee and Wu (2009), to test the existence of contagion effects.

The heteroscedasticity biases correlation coefficient method proposed by Forbes and Rigobon (2002) is adopted to test the comovement of stock market returns between two countries before and after a crisis occurs. Traditionally, the correlation coefficient is used without taking into account the varied stock price volatility between the two periods before and after a crisis. When a crisis occurs, the stock market is affected, causing higher stock price volatility compared with before the crisis. Therefore, traditional correlation coefficients must undergo heteroscedasticity stock price volatility rate adjustment for the periods before and after the crisis to reduce estimation errors.

Let x_t and y_t be two random variables that are two stock price returns of two stock markets and follow Equation (1) as

$$y_t = \alpha + \beta x_t + \varepsilon_t \tag{1}$$

where $E(\varepsilon_t) = 0$, $E(\varepsilon_t) = c < \infty$ (c is the constant), and $E(x_t\varepsilon_t) = 0$. For Equation (1), the correlation coefficient as

$$\rho = \frac{\sigma_{xy}}{\sigma_x\sigma_y} = \beta\frac{\sigma_x}{\sigma_y} \tag{2}$$

Then, we divide x_t into two kinds: high stock price volatility, h, and low stock price volatility, *l*. The variance of x_t for high stock price volatility (σ^h_{xx}) and low stock price volatility $\left(\sigma^l_{xx}\right)$, we define as follows:

$$1 + \delta = \frac{\sigma^h_{xx}}{\sigma^l_{xx}} \tag{3}$$

According to Forbes and Rigobon (2002), the correlation coefficient after adjusting is as follows:

$$\rho^* = \frac{\rho}{\sqrt{1 + \delta[1 - \rho^2]}} \tag{4}$$

This testing method is applied to compare the relatedness between two markets during regular days and a period of crisis. When a country is impacted by a crisis event, the correlation coefficient of the stock markets in two countries during the period of crisis is significantly increased compared to regular days. This indicates that the transmission mechanism of the two markets is strengthened after the impact, thus more apparent comovement after the impact. If the correlation coefficient during the period of crisis does not significantly increase compared to regular days, it means that the comovement before and after the crisis is apparent, thus showing interdependence.

For testing contagion effect, we transfer Equation (4) to Fisher Z values as Lee and Wu (2009). The test statistics are as follows

$$Z = \frac{Z_{rt} - Z_{rs}}{\sqrt{\frac{1}{n_t - 3} + \frac{1}{n_s - 3}}} \tag{5}$$

where

$$Z_{rt} = \frac{1}{2} \ln\left(\frac{1+\rho_t}{1-\rho_t}\right)$$

$$Z_{st} = \frac{1}{2} \ln\left(\frac{1+\rho_s}{1-\rho_s}\right)$$

Here, ρ_t and ρ_s are the correlation coefficients of stock returns before and after events. Z_{rt} and Z_{rs} are the Fisher Z values, which are transferred from ρ_t and ρ_s. n_t and n_s are days during crisis and regular period. Finally, the hull and alternative hypotheses are constructed as $H_0 : Z_{rt} \leq Z_{rs}$ (no contagion effect) vs. $H_1 : Z_{rt} > Z_{rs}$ (contagion effect).

3.2. Unit Root Test

Before performing empirical analysis of time series data, the time series data used must possess stationarity. If nonstationary data variables are present, the spurious regression mentioned by Granger and Newbold (1974) may be produced. The purpose of a single test is to determine whether a time series is in a stationary state and to decide whether the variables can be verified through an original standard or differential pattern. A time series is stationary if its mean and variance do not change over time.

This study adopts three methods for performing unit root tests, namely the Augmented Dickey and Fuller (ADF), Phillip–Perron (PP) and Kwiatkowski–Phillips–Schmidt–Shin (KPSS) tests. The ADF test was first proposed by Dickey and Fuller (1979) and then adjusted by Said and Dickey (1984). The PP test was proposed by Phillips and Perron (1988). Finally, the KPSS test was developed by Kwiatkowski et al. (1992).

3.3. EGARCH Model

The EGARCH model is used to explore the contagion effect among stock markets when a crisis event occurs and the asymmetric volatility among stock market returns in different countries before and after the crisis event. Through asymmetric volatility, the volatility spillover in the affected country's stock market and that of other countries can be determined.

The traditional econometric and time series models make inferences and enable research under the assumption that the variance remains fixed. However, numerous time series data show that the variance is not fixed but changes with time. For example, the price fluctuations of financial assets in a financial market usually possess certain characteristics that are time-dependent. The empirical studies of Mandelbrot (1963) and Fama (1965) state that stock returns possess distributions with a high narrow peak and heavy tail, volatility clustering, and stock price fluctuations that do not conform to the hypothesized normal distribution or show self-relatedness. Engle (1982) proposed the autoregressive conditional heteroscedasticity (ARCH) mode, which allows conditional variance to be subject to effects of the per-term square error and the implied conditional variance to change with time, thus supporting the hypothesis of unreasonable homogenous variance in the traditional econometric model. However, Bollerslev (1986) believes that the ARCH model's linearly declining lag structure in the conditional variance is too arbitrary. To avoid generating a negative variance parameter and correcting the ARCH model's excessively lengthy linearly declining structure, Bollerslev (1986) proposed the GARCH (generalized ARCH) model. Because only the size of residual items in the GARCH model affects the variance, the impacts of good and bad news on stock price volatility cannot be distinguished. As for international stock market returns, if asymmetric volatility exists, the EGARCH model proposed by Nelson (1991) is a more suitable choice for targeting conditional variance asymmetry.

The study adopts the EGARCH (1,1) model, which is proposed by Nelson (1991), as follows:

$$\mu_t = \alpha_0 + \sum_{i=1}^{n} \alpha_i \mu_{t-i} + \varepsilon_t \quad (6)$$

$$\ln\left(h_t^2\right) = \beta_0 + \beta_1(|u_{t-1}| - E|u_{t-1}| + \gamma u_{t-1}) + \omega \ \ln\left(h_{t-1}^2\right) \quad (7)$$

where $u_t = \frac{\varepsilon_t}{h_t^2} \sim \text{iid } N(0,1)$. Equation (6) regards the autoregression of a stock return. Equation (7) is the variance equation, which is the key equation of the EGARCH model. In Equation (7), u_{t-1} is positive and negative for good and bad news, respectively. However, when γ is negative, the negative news causes a future volatility increase that is greater than the future volatility increase caused by a positive news. When the absolute values of the γ coefficients during the two periods increase, the asymmetric volatility level has increased. If the asymmetric volatility increases, contagion effect is said to have occurred.

4. Data

The aim of this paper was to explore major natural disaster and financial crisis events that have occurred over the past decade. The major natural disaster events considered are the 3.11 earthquake in Japan in 2011; the 2008 Sichuan earthquake; Hurricane Katrina, which caused serious flooding in New Orleans, the United States, in 2005; and the 2004 earthquake off the coast of Indonesia that triggered a tsunami in South Asia. The financial crisis events considered are the 2011 European debt crisis and the 2008 global financial crisis. Events are the sample periods. The natural disasters and financial crisis events are described in Tables 1 and 2.

Table 1. Major Natural Disasters.

Event	Affected Countries	Number of Casualties	Economic Losses
3.11 Earthquake	Japan	About 24,000 people	USD309 billion
■ On March 11, 2011, an earthquake reaching 9.0 on the Richter Scale occurred off the shore of Sendai, Miyagi Prefecture in Northeast Japan and led to a 37.9-m tsunami that caused a radiation leak at the Fukushima nuclear power plant. These three disasters created numerous deaths and injuries, and the shutdown of the Industrial Zone located in northeast Japan caused serious economic losses. This is the deadliest natural disaster to happen to Japan since World War II.			
China's Sichuan Earthquake	China	About 460,000 people	USD86 billion
■ An earthquake reaching 8.0 on the Richter Scale occurred in Wenchuan County, Sichuan Province, China. The main affected areas were Sichuan, Gansu and Shanxi. According to the Chinese government reports, there were 69,227 victims, 374,643 injured, and 17,824 missing in the Wenchuan earthquake. There were 17,923 affected industrial enterprises. The Sichuan disaster area included 44 industrial parks, 42 small business entrepreneurial bases, and Shanxi 5 county industrial park infrastructures, which received damage of different degrees.			
Hurricane Katrina	United States, Mexico	656 people died 27 million people affected	USD300 billion
■ Hurricane Katrina was a Category 5 hurricane that occurred in August 2005 and ravaged 5 southeastern states in the United States. It caused serious damage to New Orleans, 80% of which became flooded. The statistics show that 656 people died and 27 million people were affected. More than a third of the oil fields in the Gulf of Mexico were forced to close. Seven refineries and a major US crude oil export facility were also temporarily shut down.			

Table 1. *Cont.*

Event	Affected Countries	Number of Casualties	Economic Losses
South Asian tsunami	Indonesia, Thailand, Sri Lanka, India, Maldives	About 400,000 people	USD10 billion
■ An earthquake reaching 9.3 on the Richter Scale occurred in Indonesia at the northern tip of Sumatra off the northwest coast of Aceh Province and triggered a tsunami up to 30 meters high. It caused about 292,000 deaths in Indonesia, and more than 610,000 people became refugees. Some tourist areas in Thailand also received severe damage. Most of the stricken regions were in the countryside, so major industrial sectors and infrastructure in the countries were not significantly impacted.			

Table 2. Financial Crisis Events.

Events	Country	Start Date
Global Financial Tsunami	United States	2008/9/15
■ The financial crisis of 2007–2008, also known as the Global Financial Crisis, is the worst financial crisis since the Great Depression of the 1930s. The crisis was caused by bursting of the United States housing bubble. It threatened the collapse of large financial institutions, stock markets worldwide, and housing market in many areas. The crisis resulted in a downturn in economic activity leading to the 2008–2012 global recession.		
European Debt Crisis	Greece, Portugal, Ireland, Spain, Cyprus,	2009/11/23
■ The European debt crisis, known as the Eurozone crisis or the European sovereign debt crisis, has been taking place in the European Union since the end of 2009. Several Eurozone member states, Greece, Portugal, Ireland, Spain and Cyprus, were unable to repay or refinance their government debt. Greece was the first developed country to default the debt. The states that were adversely affected by the crisis faced a strong rise in interest rate spreads for government bonds and overly high government structural deficits.		

The stock markets before and after the aforementioned events are sampled for discussion of the stock market index day returns of the United States and 10 Asian countries (Thailand, Malaysia, Indonesia, Philippines, Singapore, Taiwan, South Korea, China, Hong Kong, and Japan), and comparison of the differences before and after the major disaster events. The sample countries and stock market indexes are listed in Table 3. Furthermore, we select 6 months before and after each major disaster event as the sample period (Table 4).

Table 3. Sample country and stock market index.

Country	Stock Market Index
United States	Dow Jones Industrials Index (US)
Taiwan	Weighted Share Price Index (TS)
Hong Kong	Hange-Seng Bank Index (HK)
China	Shang-Hai B Share Index (SB)
Japan	Nikkei Average Share Price Index (JP)
South Korea	Korea Seoul Composite Stock Exchange (KR)
Indonesia	Share Price Index Jakarta (ID)
Thailand	Bangkok SET Index (TH)
Malaysia	KLSE Composite Stock Exchange Index (MY)
Philippines	Manila Composite Share Index (PH)
Singapore	Straits Times Industrials Share Index (SG)

When a country is affected by an event, the correlation coefficient between the stock markets of the two countries during the crisis period substantially increases, and the asymmetric volatility between the periods immediately before and after a crisis also significantly increases. This indicates that the transmission mechanisms of the two markets after the impact are strengthened, causing more apparent comovement and volatility spillover between the two markets, leading to the contagion effect.

Table 4. Sample period.

Events		Period	Start Date	End Date
Natural Disasters	3.11 Earthquake	Before Events After Events	2010/09/10 2011/03/14	2011/03/11 2011/09/09
	Sichuan Earthquake	Before Events After Events	2007/11/12 2008/05/13	2008/05/02 2008/11/12
	Hurricane Katrina	Before Events After Events	2005/02/24 2005/08/26	2005/08/24 2006/02/26
	South Asian Tsunami	Before Events After Events	2004/06/28 2004/12/27	2004/12/24 2005/06/24
Financial Crisis	Global Financial Tsunami	Before Events After Events	2008/03/10 2008/09/16	2008/09/12 2009/03/16
	European Debt Crisis	Before Events After Events	2009/05/22 2009/11/24	2009/11/20 2010/05/24

5. Empirical Results and Analysis

5.1. Correlation Coefficient Tests

5.1.1. Japan's 3.11 Earthquake Disaster Event

First, we analyze the 6 months before and after Japan's 3.11 earthquake disaster event. Table 5 shows the contagion effect on the international stock market and the correlation coefficients of stock price index returns before and after the earthquake. The correlation coefficients are adjusted using the heteroscedasticity bias adjustment method proposed by Forbes and Rigobon (2002) and Lee and Wu (2009). In the 6-month period after the earthquake, although the correlation coefficients of the United States, Taiwan, Hong Kong, South Korea, and Singapore increased, it can be seen from the verified Z values that only the coefficient of South Korea showed a significant increase alongside that of Japan. This indicates that the comovement phenomenon in South Korea became more obvious after Japan's 3.11 earthquake impacted the stock markets. Thus, Japan's 3.11 earthquake increased the two countries' stock market comovements.

After heteroscedasticity bias adjustment to the correlation coefficients regarding Japan's 3.11 earthquake, the results showed that Japan's stock market changes influenced the future trade on stock markets in other countries. In the 6 months after the earthquake, South Korea's stock market comovement with Japan's stock market significantly increased, producing a contagion effect. This occurred because South Korea is situated close to Japan and the radiation leak at the Fukushima nuclear power plant caused South Korean citizens to have doubts and anxiety about their food, air and water. The key components of many South Korean electronic products are imported from Japan, so the production chains of electronics companies, such as Samsung and LG, were affected, further affecting South Korea's stock market and producing a ripple effect.

5.1.2. Sichuan Earthquake

The second event explored in this paper is the 2008 Sichuan earthquake, and the results are shown in Table 6. Before the adjustment, in the 6 months before the earthquake, only Taiwan, Indonesia, Thailand and Singapore had positive correlation, but in the 6 months after the earthquake, the correlation coefficients of all the sample countries' stock index returns were positive and higher than the correlation coefficients before; the correlation coefficients of Taiwan, Japan, South Korea, Indonesia, Philippines and Singapore increased significantly. Therefore, the Sichuan earthquake resulted in an increase in the degree of comovement of these countries' stock markets with Shanghai's stock market.

Table 5. The Correlation Coefficients after heteroscedasticity biases adjustment: Japan's 3.11 earthquake.

	Before Adjustment						After Adjustment					
	Before Events		After Events				Before Events		After Events			
Country	**σ**	**ρ_s**	**σ**	**ρ_t**	**Z Value**	**Contagion**	**σ**	**ρ_s^***	**σ**	**ρ_t^***	**Z Value**	**Contagion**
US	0.684	0.063	1.332	0.136	0.563	N	0.684	0.121	1.332	0.261	1.096	N
TS	0.810	0.229	1.249	0.259	0.238	N	0.810	0.344	1.249	0.385	0.361	N
HK	1.076	0.132	1.346	0.253	0.949	N	1.076	0.165	1.346	0.311	1.179	N
SB	1.395	0.401	1.053	0.134	−2.199	N	1.395	0.315	1.053	0.101	−1.700	N
JP	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
KR	0.885	0.059	1.530	0.157	0.753	N	0.885	0.102	1.530	0.267	1.299 *	Y
ID	1.181	0.187	1.110	0.100	−0.670	N	1.181	0.176	1.110	0.094	−0.631	N
TH	1.058	0.147	1.189	0.037	−0.840	N	1.058	0.165	1.189	0.041	−0.944	N
MY	0.567	0.186	0.534	0.107	−0.612	N	0.567	0.176	0.534	0.101	−0.578	N
PH	1.076	0.000	0.996	0.066	0.496	N	1.076	0.000	0.996	0.061	0.459	N
SG	0.761	0.172	1.056	0.258	0.684	N	0.761	0.236	1.056	0.349	0.938	N

Note-1. * is denoted significant at 10% level; 2. ρ_t and ρ_s are the correlation coefficients of stock returns before and after events before heteroscedasticity biases adjustment. On the other hand, ρ_s^* and ρ_t^* are the correlation coefficients of stock returns before and after events after heteroscedasticity biases adjustment; 3."N" denotes no contagion effect between two countries. "Y" denotes there are contagion effects between two countries; 4. "n.a." means the event occurred in the country. In this table, the 3.11 earthquake occurred in Japan; 5. "US" is United States, "TS" is Taiwan, "HK" is Hong Kong, "SB" is China, "JP" is Japan, "KR" is South Korea, "ID" is Indonesia, "TH" is Thailand, "MY" is Malaysia, "PH" is Philippines, and "SG" is Singapore.

Table 6. The Correlation Coefficients after heteroscedasticity biases adjustment: China's Sichuan earthquake.

	Before Adjustment						After Adjustment					
	Before Events		After Events				Before Events		After Events			
Country	σ	ρ_s	σ	ρ_t	**Z Value**	**Contagion**	σ	ρ_s^*	σ	ρ_t^*	**Z Value**	**Contagion**
US	1.284	−0.073	2.616	0.054	1.274	N	1.284	−0.149	2.616	0.109	2.595 ***	Y
TS	1.766	0.028	2.241	0.173	1.471 *	Y	1.766	0.036	2.241	0.218	1.863 **	Y
HK	2.719	−0.088	3.544	0.351	4.554 ***	Y	2.719	−0.115	3.544	0.441	5.892 ***	Y
SB	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
JP	1.989	−0.038	3.298	0.108	1.458 *	Y	1.990	−0.062	3.298	0.177	2.416 ***	Y
KR	1.605	−0.068	2.770	0.066	1.342 *	Y	1.605	−0.117	2.770	0.113	2.316 ***	Y
ID	2.035	0.025	2.587	0.233	2.124 **	Y	2.035	0.032	2.587	0.292	2.689 ***	Y
TH	1.366	0.067	2.544	0.075	0.072	N	1.366	0.125	2.544	0.138	0.134	N
MY	1.472	−0.011	1.279	0.031	0.422	N	1.472	−0.009	1.279	0.027	0.367	N
PH	1.538	−0.042	2.450	0.109	1.508 *	Y	1.538	−0.065	2.410	0.169	2.362 ***	Y
SG	1.753	0.019	2.352	0.190	1.736 **	Y	1.753	0.025	2.352	0.252	2.323 ***	Y

Note-1. *, ** and *** are denoted significant at the 10%, 5% and 1% level, respectively; 2. ρ_t and ρ_s are the correlation coefficients of stock returns before and after events before heteroscedasticity biases adjustment. On the other hand, ρ_s^* and ρ_t^* are the correlation coefficients of stock returns before and after events after heteroscedasticity biases adjustment; 3."N" denotes no contagion effect between two countries. "Y" denotes that there are contagion effects between two countries; 4. "n.a." means the event occurred in the country. In this table, the Sichuan earthquake occurred in China; 5. "US" is United States, "TS" is Taiwan, "HK" is Hong Kong, "SB" is China, "JP" is Japan, "KR" is South Korea, "ID" is Indonesia, "TH" is Thailand, "MY" is Malaysia, "PH" is Philippines, and "SG" is Singapore.

The verification method in this paper is used to conduct the heteroscedasticity bias adjustment of the correlation coefficients. Table 6 shows that the correlation coefficients of China and 10 other countries during the regular and crisis periods were greater after adjustment than before. In the 6 months after the earthquake, the countries that showed a significant increase in correlation coefficients after adjustment were the United States, Taiwan, Hong Kong, Japan, South Korea, Indonesia, the Philippines and Singapore. The verified Z values indicate that the correlations of the United States, Taiwan, Hong Kong, Japan, South Korea, Indonesia, the Philippines and Singapore with China had significantly increased, showing that when the Sichuan earthquake occurred, comovement in the impacted stock markets in these eight countries had become more obvious and produced a contagion effect.

According to a study conducted by the World Bank, China currently has a trade surplus over advanced American and European economies and a trade deficit with East Asian countries. In 2004, for example, China only accounted for 26% of total exports compared with regional export, but accounted for 51% of total imports compared with imports of other countries in the region. From 1990 to 2004, the total ratio of exports from China to all East Asian countries in comparison to exports to China increased significantly. According to the World Bank's data and research on Chinese exports, China's total exports in 2007 exceeded those of the United States, and China became the second largest world exporter after Germany.

5.1.3. Hurricane Katrina

The third event explored in this paper is Hurricane Katrina, which caused severe damage to New Orleans in the United States. The correlation coefficients of the rates of return on stock price indexes of the United States and 10 other countries are shown in Table 7. Before the adjustment, in the 6 months after the hurricane, the degree of correlation was not high, and only the degree of correlation between the Shanghai stock market and US stock market increased. Therefore, the stock market of Shanghai produced a degree of comovement during the aftermath of Hurricane Katrina. The correlation coefficients of the United States and 10 other countries in the regular and crisis periods were not significantly increased after adjustment. The verified Z values indicate that the correlation between the Chinese and United States markets increased significantly after Hurricane Katrina.

After heteroscedasticity adjustment of the correlation coefficients, the results show that the changes in the US stock market 6 months after the earthquake had significantly increased only the degree of comovement with the Hong Kong market. The US and Hong Kong stock markets experienced a contagion effect caused by this catastrophic event. According to the Census and Statistics Department of the Hong Kong government, the external trade statistics show that in December 2012, the value of exports to Asian countries increased by 14.8%, and the total value of exports to European countries and the United States also increased substantially, in particular, to the United Kingdom (16.7%), the United States (12.8%) and Germany (6.3%), showing that the transmission of international trade and the crisis had a considerable degree of correlation.

5.1.4. South Asian Tsunami

The fourth event explored in this paper is the South Asian tsunami in Indonesia, and the corresponding results are presented in Table 8. Before the adjustment, in the 6 months before the South Asian tsunami, only Thailand, Malaysia, the Philippines and Singapore had positive correlations. In the 6 months after the South Asian tsunami, the degree of correlation did not significantly increase. Only the degree of correlation between the stock markets in the United States and Japan increased. This paper proposes that the stock markets of the United States and Japan had a degree of comovement with the stock market of Indonesia due to the South Asian tsunami. After adjustment, only the correlation coefficients of the United States were significantly increased, and the verified Z values show that after the South Asian tsunami, the US and Indonesian stock markets produced a degree of comovement, causing a contagion effect.

The United States is Indonesia's second largest trading partner, and the two countries have close economic ties. According to the statistics of the Indonesian Ministry of Industry and Trade, the trade volume between Indonesia and the United States in 2001 was USD11.68 billion. The United States provides loan assistance to Indonesia through bilateral and multilateral channels, and in 2002, the FBI and Indonesian authorities exchanged views on security and defense issues, including the fight against terrorism and transnational crime. Therefore, international trade was affected by the impact of the crisis on the two national stock markets.

5.1.5. Global Financial Tsunami

The fifth event explored in this paper is the global financial tsunami triggered by the secondary mortgage fallout in the United States, and the results are presented in Table 9. Before the adjustment, in the 6 months before the global financial tsunami, only Taiwan, Shanghai, China, Japan, South Korea, Indonesia and Singapore had positive correlations. In the 6 months after the global financial tsunami, the degree of correlation increased significantly in comparison with the 6 months before. In the 6 months after the crisis, the degree of correlation was not high, and only the correlation coefficients of the stock markets of Thailand and the Philippines increased. Therefore, the stock markets of the countries produced a degree of comovement during the global financial tsunami.

The correlation coefficients after adjustment are larger than those before adjustment. In the 6 months after the crisis, the correlation coefficients of Hong Kong, South Korea, Thailand and the Philippines were significantly increased, and the verified Z values indicate that the stock markets in Hong Kong, South Korea, Thailand and the Philippines produced a degree of comovement with the US stock market and caused a contagion effect.

5.1.6. European Debt Crisis

The sixth event explored in this paper is the European debt crisis triggered by Greece's debt problems; the corresponding results are presented in Table 10. Before the adjustment, the correlation coefficients of the daily returns on the stock prices indexes of the United States and 10 other sample countries were positive; only South Korea exhibited a negative correlation. In the 6 months after the European debt crisis, however, only the correlation coefficients of Shanghai, China and Singapore were higher than during the 6 months before; no correlation coefficients were significantly increased. No country produced an increase in the degree of comovement with the United States as a result of the European debt crisis.

According to the correlation coefficients after heteroscedasticity bias adjustment, the correlation coefficients of the United States and 10 other countries in the regular and crisis periods were not higher after adjustment than before adjustment. The correlation coefficients of the United States and 10 other countries did not increase significantly. Regarding the verified Z values, the results were consistent with the unadjusted results. The main countries affected were the European countries. Thus, this paper takes the United States as the main country for comparisons, although the stock markets in other countries did not produce a contagion effect with the US stock market because of this event.

5.2. Unit Root Test

Before analyzing the asymmetric volatility, we must confirm the integrated order for stock price returns of every stock market to avoid spurious regression. Therefore, this paper tests the unit roots of the sample data using three popular methods, namely the ADF, PP and KPSS tests. Table 11 presents the results of the ADF, PP and KPSS unit root tests. The null hypothesis of the unit root is rejected in the ADF and PP test at a 5% significance level. However, the KPSS test cannot reject the null hypothesis of stationary data. Table 11 shows that all the time series are stationary in this study.

Table 7. The Correlation Coefficients after heteroscedasticity biases adjustment: Hurricane Katrina of the United States.

	Before Adjustment						After Adjustment					
	Before Events		After Events				Before Events		After Events			
Country	σ	ρ_s	σ	ρ_t	Z Value	Contagion	σ	ρ_s^*	σ	ρ_t^*	Z Value	Contagion
US	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
TS	0.789	0.078	0.955	−0.020	−0.743	N	0.789	0.095	0.955	−0.024	−0.899	N
HK	0.675	−0.156	0.781	−0.009	1.127	N	0.675	−0.180	0.781	−0.011	1.302 *	Y
SB	1.571	−0.148	1.031	0.037	1.412 *	Y	1.571	−0.098	1.031	0.024	0.929	N
JP	0.768	−0.001	1.290	−0.047	−0.353	N	0.768	−0.001	1.290	−0.079	−0.593	N
KR	0.996	−0.046	1.241	0.073	0.905	N	0.996	−0.058	1.241	0.090	1.127	N
ID	1.051	0.086	1.288	0.127	0.318	N	1.051	0.105	1.288	0.155	0.389	N
TH	0.995	−0.072	0.860	−0.111	−0.303	N	0.995	−0.062	0.860	−0.096	−0.262	N
MY	0.565	0.062	0.383	0.076	0.110	N	0.565	0.042	0.383	0.052	0.075	N
PH	1.239	0.023	0.848	−0.085	−0.821	N	1.239	0.016	0.848	−0.058	−0.562	N
SG	0.581	−0.170	0.659	−0.246	−0.611	N	0.581	−0.191	0.659	−0.277	−0.689	N

Note-1. * is denoted significant at 10% level; 2. ρ_t and ρ_s are the correlation coefficients of stock returns before and after events before heteroscedasticity biases adjustment. On the other hand, ρ_s^* and ρ_t^* are the correlation coefficients of stock returns before and after events after heteroscedasticity biases adjustment; 3."N" denotes no contagion effect between two countries. "Y" denotes that there are contagion effects between two countries; 4. "n.a." means the event took place in the country. In this table, Hurricane Katrina took place in the United States; 5. "US" is United States, "TS" is Taiwan, "HK" is Hong Kong, "SB" is China, "JP" is Japan, "KR" is South Korea, "ID" is Indonesia, "TH" is Thailand, "MY" is Malaysia, "PH" is Philippines, and "SG" is Singapore.

Table 8. The Correlation Coefficients after heteroscedasticity biases adjustment: South Asian tsunami.

	Before Adjustment						After Adjustment					
	Before Events		After Events				Before Events		After Events			
Country	σ	ρ_s	σ	ρ_t	Z-Test	Contagion	σ	ρ_s^*	σ	ρ_t^*	Z-Test	Contagion
US	0.659	−0.044	0.687	0.173	1.667 *	Y	0.659	−0.046	0.687	0.181	1.738 *	Y
TS	1.031	−0.024	0.782	0.067	0.691	N	1.031	−0.018	0.782	0.051	0.524	N
HK	0.812	−0.101	0.667	−0.013	0.674	N	0.812	−0.083	0.667	−0.011	0.554	N
SB	1.366	−0.063	1.535	−0.046	0.127	N	1.366	−0.070	1.535	−0.052	0.142	N
JP	0.986	0.075	0.758	0.257	1.434 *	Y	0.986	0.057	0.758	0.201	1.113	N
KR	1.235	−0.014	1.001	−0.006	0.060	N	1.235	−0.011	1.001	−0.005	0.048	N
ID	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
TH	1.145	0.010	0.949	0.031	0.157	N	1.145	0.008	0.949	0.025	0.130	N

Table 8. *Cont.*

	Before Adjustment						After Adjustment					
	Before Events		After Events				Before Events		After Events			
Country	σ	ρ_s	σ	ρ_t	Z-Test	Contagion	σ	ρ_s^*	σ	ρ_t^*	Z-Test	Contagion
MY	0.577	0.107	0.543	0.014	−0.712	N	0.577	0.101	0.543	0.013	−0.670	N
PH	1.043	0.090	1.241	0.091	0.007	N	1.043	0.107	1.241	0.108	0.009	N
SG	0.632	0.082	0.527	−0.080	−1.237	N	0.632	0.069	0.527	−0.067	−1.032	N

Note-1. * is denoted significant at 10% level; 2. ρ_t and ρ_s are the correlation coefficients of stock returns before and after events before heteroscedasticity biases adjustment. On the other hand, ρ_s^* and ρ_t^* are the correlation coefficients of stock returns before and after events after heteroscedasticity biases adjustment; 3."N" denotes no contagion effect between two countries. "Y" denotes that there are contagion effects between two countries; 4. "n.a." means the event occurred in the country. In this table, the South Asian tsunami occurred in Indonesia; 5. "US" is United States, "TS" is Taiwan, "HK" is Hong Kong, "SB" is China, "JP" is Japan, "KR" is South Korea, "ID" is Indonesia, "TH" is Thailand, "MY" is Malaysia, "PH" is Philippines, and "SG" is Singapore.

Table 9. The Correlation Coefficients after heteroscedasticity biases adjustment: global financial tsunami.

	Before Adjustment						After Adjustment					
	Before Events		After Events				Before Events		After Events			
Country	σ	ρ_s	σ	ρ_t	Z Value	Contagion	σ	ρ_s^*	σ	ρ_t^*	Z Value	Contagion
US	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
TS	1.745	0.205	2.383	0.249	0.362	N	1.745	0.275	2.383	0.333	0.488	N
HK	1.885	−0.016	4.042	0.117	1.023	N	1.885	−0.034	4.042	0.247	2.197 **	Y
SB	2.827	0.035	2.816	0.032	−0.025	N	2.827	0.035	2.816	0.031	−0.025	N
JP	1.532	0.197	3.865	0.181	−0.129	N	1.532	0.469	3.865	0.434	−0.335	N
KR	1.393	0.097	3.374	0.205	0.851	N	1.393	0.231	3.374	0.468	2.092 **	Y
ID	1.594	0.117	2.856	0.066	−0.403	N	1.594	0.208	2.856	0.117	−0.720	N
TH	1.318	−0.130	2.771	0.220	2.725 ***	Y	1.318	−0.269	2.771	0.438	5.736 ***	Y
MY	0.930	−0.022	1.315	0.079	0.775	N	0.930	−0.031	1.315	0.111	1.096	N
PH	1.283	−0.104	2.626	0.559	5.661 ***	Y	1.283	−0.211	2.626	0.862	11.659 ***	Y
SG	1.314	0.336	2.778	0.322	−0.118	N	1.314	0.631	2.778	0.611	−0.252	N

Note-1. ** and *** are denoted significant at the 5% and 1% level; 2. ρ_t and ρ_s are the correlation coefficients of stock returns before and after events before heteroscedasticity biases adjustment. On the other hand, ρ_s^* and ρ_t^* are the correlation coefficients of stock returns before and after events after heteroscedasticity biases adjustment; 3."N" denotes no contagion effect between two countries. "Y" denotes that there are contagion effects between two countries; 4. "n.a." means the event occurred in the country. In this table, the global financial tsunami occurred in the United States; 5. "US" is United States, "TS" is Taiwan, "HK" is Hong Kong, "SB" is China, "JP" is Japan, "KR" is South Korea, "ID" is Indonesia, "TH" is Thailand, "MY" is Malaysia, "PH" is Philippines, and "SG" is Singapore.

Table 10. The Correlation Coefficients after heteroscedasticity biases adjustment: European debt crisis.

	Before Adjustment						After Adjustment					
	Before Events		After Events				Before Events		After Events			
Country	σ	ρ_s	σ	ρ_t	Z Value	Contagion	σ	ρ_s^*	σ	ρ_t^*	Z Value	Contagion
US	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
TS	1.284	0.086	1.167	0.109	0.172	N	1.284	0.079	1.167	0.099	0.157	N
HK	1.711	0.275	1.334	0.163	−0.902	N	1.711	0.218	1.334	0.128	−0.713	N
SB	1.895	0.147	1.503	0.254	0.851	N	1.895	0.117	1.503	0.204	0.682	N
JP	1.295	0.056	1.357	0.045	−0.084	N	1.295	0.058	1.357	0.047	−0.088	N
KR	1.198	−0.054	1.101	0.090	1.096	N	1.198	−0.049	1.101	0.082	1.008	N
ID	1.442	0.204	1.245	0.217	0.104	N	1.442	0.177	1.245	0.189	0.091	N
TH	1.573	0.159	1.388	0.109	−0.385	N	1.573	0.140	1.388	0.096	-0.340	N
MY	0.658	0.041	0.506	0.171	1.005	N	0.658	0.032	0.506	0.132	0.775	N
PH	1.327	0.142	1.091	−0.028	−1.305	N	1.327	0.117	1.091	-0.023	-1.074	N
SG	1.238	0.121	0.874	0.234	0.892	N	1.238	0.086	0.874	0.168	0.637	N

Note 1. ρ_t and ρ_s are the correlation coefficients of stock returns before and after events before heteroscedasticity biases adjustment. On the other hand, ρ_s^* and ρ_t^* are the correlation coefficients of stock returns before and after events after heteroscedasticity biases adjustment; 2. "N" denotes no contagion effect between two countries. "Y" denotes that there are contagion effects between two countries; 3. "n.a." means the event occurred in the country. In this table, the European debt crisis occurred in the United States; . "US" is United States, "TS" is Taiwan, "HK" is Hong Kong, "SB" is China, "JP" is Japan, "KR" is South Korea, "ID" is Indonesia, "TH" is Thailand, "MY" is Malaysia, "PH" is Philippines, and "SG" is Singapore.

Table 11. Unit root test results.

	Japan's 3.11 Earthquake			China's Sichuan Earthquake			Hurricane Katrina		
	ADF	**PP**	**KPSS**	**ADF**	**PP**	**KPSS**	**ADF**	**PP**	**KPSS**
US	−9.21 ***	−18.19 ***	0.17	−3.703 ***	−17.854 ***	0.141	−16.417 ***	−16.420 ***	0.047
TS	−10.75 ***	−12.16 ***	0.21	−9.582 ***	−14.822 ***	0.408	−15.057 ***	−15.059 ***	0.125
HK	−14.11 ***	−14.13 ***	0.16	−10.544 ***	−18.075 ***	0.321	−15.093 ***	−15.091 ***	0.084
SB	−14.66 ***	−14.66 ***	0.16	−15.801 ***	−15.820 ***	0.047	−15.050 ***	−15.051 ***	0.085
JP	−9.05 ***	−15.67 ***	0.11	−3.807 ***	−15.871 ***	0.257	−15.221 ***	−15.217 ***	0.110
KR	−13.41 ***	−13.41 ***	0.16	−2.912 **	−14.302 ***	0.253	−14.066 ***	−14.024 ***	0.071
ID	−8.18 ***	−13.30 ***	0.13	−3.319 **	−11.797 ***	0.261	−13.018 ***	−12.980 ***	0.219
TH	−14.47 ***	−14.50 ***	0.07	−2.983 **	−14.105 ***	0.358	−13.994 ***	−13.995 ***	0.086
MY	−13.34 ***	−13.33 ***	0.25	−14.230 ***	−14.217 ***	0.131	−13.666 ***	−13.702 ***	0.082
PH	−13.25 ***	−13.15 ***	0.11	−8.730 ***	−12.183 ***	0.063	−12.527 ***	−12.440 ***	0.055
SG	−7.37 ***	−13.28 ***	0.09	−10.428 ***	−16.119 ***	0.407	−12.073 ***	−14.907 ***	0.049
	South Asian Tsunami			**Global Financial Crisis**			**European Debt Crisis**		
	ADF	**PP**	**KPSS**	**ADF**	**PP**	**KPSS**	**ADF**	**PP**	**KPSS**
US	−15.812 ***	−15.811 ***	0.176	−14.754 ***	−19.032 ***	0.166	−16.344 ***	−16.326 ***	0.128
TS	−14.345 ***	−14.350 ***	0.059	−9.531 ***	−15.387 ***	0.168	−6.687 ***	−13.883 ***	0.133
HK	−15.287 ***	−15.287 ***	0.167	−16.568 ***	−17.002 ***	0.057	−12.128 ***	−16.049 ***	0.190
SB	−7.894 ***	−15.388 ***	0.036	−15.673 ***	−15.674 ***	0.292	−14.512 ***	−14.511 ***	0.328
JP	−15.414 ***	−15.435 ***	0.068	−16.533 ***	−17.026 ***	0.056	−7.923 ***	−16.280 ***	0.126
KR	−14.947 ***	−14.941 ***	0.058	−15.373 ***	−15.379 ***	0.037	−15.961 ***	−15.982 ***	0.062
ID	−12.454 ***	−12.455 ***	0.154	−8.861 ***	−12.074 ***	0.144	−15.922 ***	−15.945 ***	0.094
TH	−14.411 ***	−14.387 ***	0.078	−9.188 ***	−14.641 ***	0.077	−15.821 ***	−15.821 ***	0.079
MY	−6.627 ***	−12.655 ***	0.155	−13.384 ***	−13.317 ***	0.074	−13.012 ***	−13.097 ***	0.124
PH	−9.589 ***	−11.992 ***	0.079	−13.355 ***	−13.225 ***	0.076	−13.997 ***	−13.929 ***	0.087
SG	−17.367 ***	−17.360 ***	0.037	−10.340 ***	−16.231 ***	0.055	−15.762 ***	−15.764 ***	0.105

Note *** is denoted significant at 1% level.

5.3. EGARCH Model

Because the GARCH model is unable to distinguish the different influences of positive and negative messages on volatility, the EGARCH model of Nelson (1991) is adopted in this paper to detect asymmetric volatility and volatility spillover and to compare the volatility of each country's stock returns before and after the crisis for asymmetry. The absolute value of the γ coefficient in Equation (7) represents the size of the asymmetry. If the absolute value of the γ coefficient of the two periods changes from small to large, the asymmetric volatility increased; the opposite represents a decrease. If the asymmetric volatility of a country's financial market increases after an event, volatility spillover occurred.

5.3.1. Japan's 3.11 Earthquake Disaster Event

Table 12 shows the asymmetric volatility series of γ coefficients of each country's stock price return rate. After the Japan 3.11 earthquake crisis, Taiwan, South Korea, Thailand and Malaysia presented a significant state, and the γ coefficients were negative, indicating that the stock price returns of these four countries exhibited asymmetric volatility after the earthquake.

The absolute changes in the γ coefficient can provide an understanding of the changes in asymmetric volatility, so we focus on the absolute values of the γ coefficients of each country's stock market before and after the earthquake when conducting t tests. Except for the United States, Indonesia, Thailand and Singapore, the degree of asymmetric volatility of the stock price returns of each country increased. In the 6 months after Japan's 3.11 earthquake, the Japanese stock market had a volatility spillover effect on the stock markets of other countries. Thus, in this earthquake case, the international transmission caused by the earthquake had a considerable degree of correlation.

5.3.2. Sichuan Earthquake

Regarding China's Sichuan earthquake, Table 13 shows the asymmetric volatility series of γ coefficients of each country's stock price return rate, as estimated using the EGARCH model. The γ coefficients were significantly negative for Hong Kong, Japan, South Korea, and Malaysia, meaning that these countries exhibited asymmetric volatility after the earthquake.

Observing absolute changes and different tests of the γ coefficient, in the 6 months after the earthquake, the absolute values of the γ coefficient increased significantly for Hong Kong and Thailand. Thus, the asymmetric volatility of stock price returns of these two countries increased significantly. After the earthquake, China's stock market had a volatility spillover effect on the stock markets of Hong Kong and Thailand. The Chinese economy is the second largest in the world and was in a pivotal position when the Sichuan earthquake occurred. Hong Kong and Thailand were affected, showing that international trade and transmission of crises exhibited a considerable degree of correlation.

5.3.3. Hurricane Katrina

Table 14 presents the estimation results obtained using the EGARCH model for the third event, Hurricane Katrina in the United States. After the hurricane, Taiwan, Hong Kong, China, Japan and Indonesia showed significantly negative γ coefficients. That is, the stock price returns of these five countries exhibited asymmetric volatility after the hurricane.

Furthermore, after the hurricane, the absolute values of the γ coefficients increased significantly for Hong Kong, China and Indonesia. Therefore, the volatility spilled over to the stock price returns of these countries.

5.3.4. South Asian Tsunami

Table 15 shows the asymmetric volatility series of γ coefficients that are estimated using the EGARCH model for the fourth event, the South Asian tsunami. After the tsunami, the United States, Hong Kong, Japan and Singapore presented significantly negative γ coefficients. That is, the stock price returns of these four countries exhibited asymmetric volatility after the tsunami.

The absolute values of the γ coefficients increased significantly for the United States and Japan after the tsunami. Thus, the Indonesia stock market had a spillover effect on the stock markets of those two countries.

5.3.5. Global Financial Tsunami

Table 16 shows the asymmetric volatility series of γ coefficients of each country's stock price return rate, as estimated using the EGARCH model, for the fifth event, the global financial tsunami. After the financial crisis, Japan, Indonesia and Thailand showed significant negative γ coefficients. That is, the stock price returns of these three countries exhibited asymmetric volatility after the financial crisis.

The absolute value of the γ coefficients increased significantly for Japan, Malaysia and the Philippines after the financial crisis, meaning that the crisis had a spillover effect on the stock markets of these three countries.

5.3.6. European Debt Crisis

Table 17 shows the asymmetric volatility series of γ coefficients of each country's stock price return rate, estimated using the EGARCH model, for the final event, the European debt crisis. After the debt crisis, Japan, South Korea, and Indonesia showed significant negative γ coefficients. That is, the stock price returns of these three countries exhibited asymmetric volatility after the debt crisis.

The absolute values of the γ coefficients increased significantly for Japan, South Korea, and Indonesia after the debt crisis, meaning that the crisis had a spillover effect on the stock markets of three countries.

Table 12. The EGARCH model results: Japan's 3.11 earthquake.

Country	Before Event				After Event				Different Test		
	β_0	β_1	γ	ω	β_0	β_1	γ	ω	*t*-Test	Absolute of γ	Asymmetric Volatility
US	−0.094	−0.070	0.353 (0.007) **	0.870	−1.356	1.483	0.078 (0.648)	0.665	1.283 *	−	−
TS	−1.068	−0.446	0.135 (0.374)	−0.698	0.345	−0.715	−0.404 (0.005) **	0.448	2.592 ***	+	+
HK	−1.454	0.773	−0.071 (0.000) ***	−0.741	0.055	−0.054	0.103 (0.309)	1.009	0.307	+	+
SB	0.873	−0.763	0.098 (0.599)	−0.431	0.018	−0.289	0.137 (0.378)	0.286	−0.159	+	+
KR	0.545	−1.006	0.106 (0.507)	0.482	−0.066	0.074	−0.489 (0.001) **	0.884	2.713 ***	+	+
ID	−0.070	0.115	0.225 (0.012)	0.952	0.048	−0.023	0.111 (0.428)	1.019	0.687	−	−
TH	0.091	−0.175	0.357 (0.002) **	0.923	0.042	−0.025	−0.301 (0.005) **	0.955	4.133 ***	−	−
MY	−0.041	−0.498	0.096 (0.378)	0.721	−0.742	0.313	−0.480 (0.008) **	0.701	2.746 ***	+	+
PH	0.002	−0.296	−0.141 (0.502)	−0.635	−0.701	0.590	−0.291 (0.100)	0.382	0.550	+	+
SG	−0.199	−0.002	0.018 (0.867)	0.782	−0.292	0.340	0.001 (0.997)	0.946	0.107	−	-

Note-1. The number in parentheses is the *p*-value of coefficient γ; 2. *, ** and *** are denoted significant at the 10%, 5% and 1% level, respectively; 3. "+" and "−" are denoted changes increase and decrease.

Table 13. The EGARCH model results: China's Sichuan earthquake.

Country	Before Event				After Event				Different Test		
	β_0	β_1	γ	ω	β_0	β_1	γ	ω	*t*-Test	Absolute of γ	Asymmetric Volatility
US	0.134	0.442	−0.036 (0.642)	−0.878	0.047	−0.025	−0.109 (0.181)	1.011	0.640	+	+
TS	1.468	−0.229	−0.381 (0.046) **	−0.423	−0.114	0.303	−0.195 (0.159)	0.881	−0.790	−	−
HK	0.451	1.073	0.200 (0.148)	0.207	−0.087	0.282	−0.583 (0.000) ***	0.943	3.952 ***	+	+
JP	0.159	−0.145	0.376 (0.020) **	0.967	0.071	−0.043	−0.171 (0.006) **	1.007	3.159 ***	−	−
KR	−0.203	0.303	0.382 (0.000) ***	−0.906	0.041	−0.008	−0.176 (0.004) **	1.011	4.992 ***	−	−
ID	−0.072	0.992	0.226 (0.260)	0.347	0.077	−0.085	−0.035 (0.586)	1.008	1.239 *	−	−
TH	0.069	−0.073	0.087 (0.383)	0.998	0.051	−0.040	−0.113 (0.054)	1.009	1.726 **	+	+
MY	−0.965	1.215	0.460 (0.011) **	0.685	0.170	−0.152	−0.243 (0.002) **	0.945	3.581 ***	−	−
PH	1.149	0.163	−0.128 (0.130)	−1.005	−0.365	0.696	0.102 (0.411)	0.783	−1.531 **	−	−
SG	−0.843	1.111	−0.015 (0.934)	0.888	−0.463	0.717	0.221 (0.186)	0.900	−0.959	+	+

Note-1. The number in parentheses is the *p*-value of coefficient γ; 2. ** and *** are denoted significant at 5% and 1% level; 3. "+" and "−" are denoted changes increase and decrease.

Table 14. The EGARCH model results: Hurricane Katrina.

Country	Before Event				After Event				Different Test		
	β_0	β_1	γ	ω	β_0	β_1	γ	ω	*t*-Test	Absolute of γ	Asymmetric Volatility
TS	−0.944	0.188	0.366 (0.021)**	−0.185	0.107	−0.247	−0.191 (0.021) **	0.837	2.722 ***	−	−
HK	−1.697	−0.598	−0.097 (0.471)	−0.768	−0.470	−0.055	−0.725 (0.001) ***	0.485	2.474 ***	+	+
SB	2.045	−1.336	0.031 (0.888)	−0.453	0.378	−0.653	−0.453 (0.029) **	0.462	1.589 *	+	+
JP	−0.699	0.541	0.576 (0.000) ***	0.657	0.085	−0.047	−0.349 (0.034) **	0.880	4.528 ***	−	−
KR	−0.544	−0.298	0.375 (0.003) **	−0.842	−0.339	0.749	0.004 (0.977)	−0.814	1.832 **	−	−
ID	0.162	−0.339	−0.181 (0.185)	0.661	0.201	−0.058	−0.559 (0.000) ***	−0.183	1.835 **	+	+
TH	0.232	−0.312	0.093 (0.376)	0.915	−0.763	−0.045	0.201 (0.271)	−0.379	−0.512	+	+
MY	0.139	−0.530	−0.053 (0.490)	0.788	−1.908	−0.183	0.178 (0.326)	0.045	−1.173	+	+
PH	−0.052	0.120	0.069 (0.381)	0.915	−0.257	0.198	−0.082 (0.520)	0.795	1.010	+	+
SG	−0.851	0.548	0.204 (0.215)	0.706	−1.009	−0.152	0.405 (0.008) ***	0.049	−0.903	+	+

Note-1. The number in parentheses is the *p*-value of coefficient γ; 2.*, ** and *** are denoted significant at the 10%, 5% and 1% level, respectively; 3. "+" and "−" are denoted changes increase and decrease.

Table 15. The EGARCH model results: South Asian tsunami.

Country	Before Event				After Event				Different Test		
	β_0	β_1	γ	ω	β_0	β_1	γ	ω	*t*-Test	Absolute of γ	Asymmetric Volatility
US	0.079	−0.174	0.110 (0.252)	0.934	−1.002	0.160	−0.313 (0.035) **	−0.016	2.394 ***	+	+
TS	0.449	−1.405	1.189 (0.000) ***	−0.013	0.421	−0.961	−0.105 (0.301)	0.610	5.883 ***	−	−
HK	0.390	−1.005	−0.284 (0.052) *	0.543	0.109	−1.181	−0.453 (0.010) *	0.301	0.741	+	+
SB	0.776	0.189	0.171 (0.034)	−0.975	1.372	−0.516	0.249 (0.043) **	−0.856	−0.528	+	+
JP	0.164	−0.208	−0.189 (0.053) *	0.937	0.331	−0.663	−0.510 (0.005) **	0.780	1.560 *	+	+
KR	0.188	−0.244	0.223 (0.142)	0.734	0.337	−0.479	−0.116 (0.206)	0.840	1.912 **	−	−
TH	−0.089	0.127	−0.001 (0.996)	0.931	−0.033	−0.618	0.221 (0.211)	−0.781	−1.049	+	+
MY	−2.082	−0.577	0.211 (0.332)	−0.806	0.090	−0.759	0.007 (0.955)	0.640	0.800	−	−
PH	−0.053	0.029	0.463 (0.008) **	0.563	−0.239	0.405	−0.125 (0.370)	0.514	2.638 ***	−	−
SG	−0.576	−0.760	−0.294 (0.092) *	0.015	−0.258	−0.543	−0.561 (0.001) **	0.520	1.077	+	+

Note-1. The number in parentheses is the *p*-value of coefficient γ; 2.*, ** and *** are denoted significant at the 10%, 5% and 1% level, respectively; 3. "+" and "−" are denoted changes increase and decrease.

Table 16. The EGARCH model results: global financial crisis.

Country	Before Event				After Event				Different Test		
	β_0	β_1	γ	ω	β_0	β_1	γ	ω	*t*-Test	Absolute of γ	Asymmetric Volatility
TS	−0.274	0.434	0.023 (0.881)	0.812	0.983	−0.763	0.281 (0.055) *	0.677	−1.204	+	+
HK	0.075	0.011	0.248 (0.019) **	0.941	1.526	1.312	−0.134 (0.201)	−0.560	2.567 ***	−	−
SB	0.165	−0.136	0.157 (0.055)	0.972	1.210	−0.397	0.152 (0.363)	0.526	0.027	−	−
JP	0.021	−0.013	−0.009 (0.935)	1.012	−0.070	0.221	−0.343 (0.009) **	0.973	1.988 **	+	+
KR	0.460	−0.334	−0.155 (0.333)	−0.351	0.496	0.565	−0.134 (0.448)	0.530	−0.085	−	−
ID	−0.064	0.051	0.242 (0.000) ***	1.039	−0.017	−0.028	−0.140 (0.029) **	1.012	4.078 ***	−	−
TH	−0.097	0.148	−0.192 (0.082) **	0.948	−0.151	0.367	−0.310 (0.025) **	0.900	0.670	+	+
MY	−0.829	0.576	−0.108 (0.441)	−0.061	−0.143	0.184	0.199 (0.258)	0.810	−1.365 ***	+	+
PH	0.766	−0.314	−0.220 (0.133)	−0.405	1.219	−0.195	0.251 (0.117)	0.107	−2.172 ***	+	+
SG	−0.152	0.203	0.164 (0.163)	0.910	0.020	1.324	0.043 (0.753)	0.196	0.665	−	−

Note-1. The number in parentheses is the *p*-value of coefficient γ; 2.*, ** and *** are denoted significant at the 10%, 5% and 1% level, respectively; 3."+" and "−" are denoted changes increase and decrease.

Table 17. The EGARCH model result: European debt crisis.

Country	Before Event				After Event				Different Test		
	β_0	β_1	γ	ω	β_0	β_1	γ	ω	*t*-Test	Absolute of γ	Asymmetric Volatility
TS	0.271	−0.136	−0.213 (0.185)	0.245	−1.438	1.116	−0.148 (0.229)	−0.618	−0.319	−	−
HK	0.117	−0.107	0.064 (0.644)	0.982	0.601	−0.651	0.023 (0.884)	0.550	0.194	−	−
SB	1.296	−0.317	0.260 (0.059) *	0.079	0.633	−0.383	0.159 (0.390)	0.189	0.437	−	−
JP	0.181	−0.201	0.123 (0.049) **	0.966	−0.019	0.081	−0.391 (0.004) **	0.944	3.477 ***	+	+
KR	−0.321	−0.330	−0.076 (0.634)	−0.833	0.056	−0.154	−0.383 (0.000) ***	0.863	1.664 **	+	+
ID	0.679	0.059	0.357 (0.030) **	−0.351	0.704	−0.861	−0.833 (0.000) ***	0.439	5.246 ***	+	+
TH	−0.438	0.673	0.200 (0.231)	0.740	−0.187	0.273	−0.023 (0.766)	0.943	1.212	−	−
MY	0.078	−0.102	−0.036 (0.711)	0.979	−0.232	0.154	0.122 (0.213)	0.930	−1.147	+	+
PH	−0.570	1.024	−0.234 (0.228)	0.275	0.725	−1.016	−0.445 (0.077) *	−0.196	0.666	+	+
SG	0.060	−0.049	−0.075 (0.399)	0.996	−0.207	0.109	−0.231 (0.059) *	0.845	1.036	+	+

Note-1. The number in parentheses is the *p*-value of coefficient γ; 2. *, ** and *** are denoted significant at the 10%, 5% and 1% level, respectively; 3. "+" and "−" are denoted changes increase and decrease.

5.4. Summary

Table 18 summarizes how the aforementioned two research methods are used to analyze the degree of correlation and asymmetric volatility of each country's stock market before and after the six crises. In the 6 months after Japan's 3.11 earthquake, only South Korea's degree of correlation and asymmetric volatility significantly increased, showing a contagion effect. South Korea and Japan are neighbors, thus when a crisis occurs, the fall of one country produces a chain effect.

In the 6 months after the earthquake in Sichuan, China, the degree of correlation and asymmetric volatility of Hong Kong significantly increased, showing a contagion effect. Hong Kong has a high proportion of foreign ownership and neighbors, China.

In the 6 months after Hurricane Katrina, the degree of correlation and asymmetric volatility of Hong Kong increased significantly, showing a contagion effect. This shows that when Hurricane Katrina hit, the Hong Kong and US stock markets produced a considerable degree of correlation in transmission. According to the Census and Statistics Department of the Hong Kong government, Hong Kong's trade exports to the United States in 2012 were 12.8%, and because of their close trade, the Hong Kong stock market is affected by natural disasters in the United States.

In the discussion of the South Asian tsunami crisis, the degree of correlation and asymmetric volatility in the US stock market increased, producing a contagion effect. Because the disaster occurred in an only moderately developed region, the disaster did not have a notable impact. The impact of Indonesia on the United States comes from the relationship between trade and politics; the relationship indirectly affects the correlation between the stock markets.

The global financial tsunami data show that the degree of correlation and asymmetric volatility of the Philippines increased. Finally, the European debt crisis occurred only in European countries. In this paper, the United States is used as the main country of comparison. The test results showed no contagion effects. Other countries did not experience a contagion effect with the United States because of the European debt crisis. This also indicates that the event was not transmitted to other countries through the United States.

Table 18. Summary table.

	Japan's 3.11 Earthquake			China's Sichuan Earthquake			Hurricane Katrina		
Country	**Adjusted Correlation**	**Contagion Effect**	**Asymmetric Volatility**	**Adjusted Correlation**	**Contagion Effect**	**Asymmetric Volatility**	**Adjusted Correlation**	**Contagion Effect**	**Asymmetric Volatility**
US	+	N	−	+ *	Y	+	n.a.	n.a.	n.a.
TS	+	N	+ *	+ *	Y	−	−	N	−
HK	+	N	+	+ *	Y	+ *	+ *	Y	+ *
SB	−	N	+	n.a.	n.a.	n.a.	+	N	+ *
JP	n.a.	n.a.	n.a.	+ *	Y	−	−	N	−
KR	+ *	Y	+ *	+ *	Y	−	+	N	−
ID	−	N	−	+ *	Y	−	+	N	+ *
TH	−	N	−	+	N	+ *	−	N	+
MY	−	N	+ *	+	N	−	+	N	+
PH	+	N	+	+ *	Y	−	−	N	+
SG	+	N	+	+ *	Y	+	−	N	+
	South Asian Tsunami			**Global Financial Crisis**			**European Debt Crisis**		
Country	**Adjusted Correlation**	**Contagion Effect**	**Asymmetric Volatility**	**Adjusted Correlation**	**Contagion Effect**	**Asymmetric Volatility**	**Adjusted Correlation**	**Contagion Effect**	**Asymmetric Volatility**
US	+ *	Y	+ *	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
TS	+	N	−	+	N	+	+	N	−
HK	+	N	+	+ *	Y	−	−	N	−
SB	+	N	+	−	N	−	+	N	−
JP	+	N	+ *	−	N	+ *	−	N	+
KR	+	N	−	+ *	N	−	+	N	+
ID	n.a.	n.a.	n.a.	−	N	−	+	N	+
TH	+	N	+	+ *	Y	+	−	N	−
MY	−	N	−	+	N	+ *	+	N	+
PH	+	N	−	+ *	Y	+ *	−	N	+
SG	−	N	+	−	N	−	+	N	+

Note- 1. "N" denotes no contagion effect between two countries. "Y" denotes that there are contagion effects between two countries. 2. * denotes significant adjusted correlation or asymmetric volatility. 3. "+" and "−" are denoted changes increase and decrease.

6. Conclusions

This paper studies the contagion effects of major catastrophic events and global financial crises that occurred during the past decade. First, we use the heteroscedasticity bias correlation coefficient method to test the degree of comovement between the stock markets of other countries and the stock market of the country in which the crisis occurred. The heteroscedasticity bias correlation method only considers the correlation between two countries' stock markets and does not consider the impact of asymmetric volatility. Then, we use the EGARCH model to detect the degree of volatility spillover of the country in which the crisis occurred in other countries.

The empirical results find that the contagion effects created by the 3.11 earthquake in Japan and the Sichuan earthquake in China on the stock markets of the neighboring Asian countries, South Korea and Hong Kong were stronger than those on other countries. In the global financial tsunami, the country affected by the US stock market was the Philippines. With Hurricane Katrina, the country affected by the US stock market was Hong Kong, whose economy is in a pivotal global position. In the South Asian tsunami, only the US stock market was influenced by Indonesia's stock market. Because the disaster occurred in a moderately developed region, the disaster did not have contagion effects on other countries. Finally, regarding the European debt crisis, this study did not detect any contagion effect in the sample stock markets. In the event of a natural disaster, the stronger the economy of a country, the more that trading partner countries and neighboring countries are affected; a less powerful economy exerts a weaker or sometimes no influence over its trading partner countries. We find that when a natural disaster occurs in an economically stronger country, the trading rivals are more affected; when it occurs in an economically weaker country, the trading rivals are relatively less affected or not affected at all. Therefore, the stronger a country's economy, the more obvious the contagion effect created in other international stock markets by a natural disaster. However, mostly neighboring developing countries are affected.

This paper uses two financial crises and four natural disaster events for discussing contagion effects on eleven stock markets. However, some major events are not included in this paper, such as the Asian financial crisis. Furthermore, the international stock markets investigated can be extended to include those of other noteworthy countries, such as the United Kingdom. This paper applies adjusted correlation and the EGARCH model to analyze contagion effects. Other methodologies for estimating asymmetric volatility can be used, such as other ARCH or GARCH models. Thus, for further research, other methods can be employed to analyze and compare contagion effects among international stock markets.

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