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Volatility spillovers among Northeast Asia and the US: Evidence from the global financial crisis and the COVID-19 pandemic

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ABSTRACT

In this study, we investigate the dynamic connectedness between the volatility of Northeast Asia, namely South Korea, Japan, China, and the United States (US). Specifically, we employ Diebold and Yilmaz's (2012) spillover index to measure connectedness in stock market volatility. Furthermore, we analyze the dynamic connectedness during the global financial crisis (GFC) and COVID-19 pandemic periods to identify the changes in their relationship following the two crises. Our findings can be summarized as follows. First, the connectedness between the volatility of the four stock markets varies over time. However, the US has played a role as a net transmitter of volatility shocks during the entire period. Second, interdependence increased during the two crisis periods. Based on the total volatility spillover index, interdependence is stronger during the GFC than during the COVID-19 pandemic period. Third, the magnitude of volatility shock transmission to other countries is time-varying. In particular, for the South Korean stock market, the volatility shock transmitted from the Chinese stock market has been larger than that of the US market since 2015. These empirical findings have several important implications for portfolio managers, policymakers, and investors.

1. Introduction

Over the past few decades, cross-market linkage in global financial markets, especially stocks, has increased because of the development of information and communication technology and the increase in international trade (Badshah et al., 2018). The expanded interconnections between international financial markets have been crucial and essential for investors and policymakers because the dynamic connectedness of cross-markets affects the decision-making for portfolio management and contagion risk in financial markets. Therefore, the dynamics of the relationships among various financial markets have been widely investigated in academia. In fact, these crises have increased the importance of financial or economic linkages. In particular, according to several studies, financial crises, such as the 2008 global financial crisis (GFC), the European sovereign debt crisis, and the recent COVID-19 pandemic, intensify the interdependence between financial markets (Antonakakis and Vergos, 2013; Lien et al., 2018; Zhang et al., 2021a).

As for the stock market, which is the most common financial market, many studies have investigated the dynamic linkages across country stock markets (Ng, 2000; Lee, 2009; nath Mukherjee and Mishra, 2010; Huyghebaert and Wang, 2010; Singh et al., 2010; Joshi, 2011; Batareddy et al., 2012; Loh, 2013; Palamalai and Devakumar, 2013; Tiwari et al., 2013; Sugimoto et al., 2014; Rejeb and Arfaoui, 2016; Paramati et al., 2016; Jebran et al., 2017; Liu et al., 2017; Ahmed

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and Huo, 2019; Zhang et al., 2020b). Furthermore, the interdependence was measured in terms of the volatility of stock prices in previous studies (Ng, 2000; Lee, 2009; nath Mukherjee and Mishra, 2010; Singh et al., 2010; Joshi, 2011; Rejeb and Arfaoui, 2016; Jebran et al., 2017; Ahmed and Huo, 2019; Zhang et al., 2020b). There is also much literature on the dynamic connectedness between financial markets other than the stock market. Related studies are presented in Section 2.

Since the outbreak of COVID-19, there have been more than 198 million cases of COVID-19 and at least 4 million deaths worldwide.[1] These COVID-19 pandemics have dealt a serious blow to the economies of all countries around the world. Furthermore, some countries implemented various economic policies to prevent the economic downturn caused by the COVID-19 pandemic, such as interest rate cuts and COVID-19 relief aid packages. Consequently, market participants such as investors and policy markets were forced to face financial problems as well as health problems. In short, the COVID-19 pandemic has had a significant impact on the international financial market. Therefore, many studies have investigated the impact of the COVID-19 pandemic on the stock market (Al-Awadhi et al., 2020; Singh et al., 2020; Zhang et al., 2020a; Contessi and De Pace, 2021; Mazur et al., 2021; Guo et al., 2021).

Another worldwide financial crisis that has affected the world is the 2008 global financial crisis (GFC) triggered by the US subprime sector. Since the GFC originated in the financial market, many studies have dealt with the impact of the GFC on the stock market (Reinhart and Rogoff, 2008; Hwang et al., 2013; Liow, 2015; Li and Giles, 2015; Hemche et al., 2016; Bala and Takimoto, 2017; Allen et al., 2017; Kang and Yoon, 2019). Since the recent COVID-19 pandemic has caused enormous damage to the global economy, several scholars have conducted comparative studies on the impact of similar financial crises on the financial market: the GFC and the COVID-19 pandemic (Chang et al., 2020; Choi, 2020; Kinateder et al., 2021; Gunay, 2021; Choi, 2021).

We aim to investigate the volatility dynamics among these four countries: South Korea, China, Japan, and the US. Furthermore, we compare the dynamic changes during the GFC and COVID-19 pandemic to examine the transmission of volatility shocks between these four countries to identify the differences between normal periods and times of crisis. For this purpose, we employ the stock index as an indicator of a country's economy and calculate the volatility of the stock index: KOSPI, NIKKEI225, SSEC (Shanghai Composite Index), and S&P 500 indices for the four countries, respectively. Stock indices were used because they are widely accepted as the representative of a country's economic situation, and this study focuses on the relationship between the overall economic condition of the four countries, and not a specific industry.

To measure the dynamic linkage among the stock markets, we apply the Diebold and Yilmaz (2012) spillover index to the weekly volatility of the four stock indices (KOSPI, NIKKEI225, SSEC, and S&P 500). Based on the spillover index, we measure the volatility spillovers between the volatility indices of the four countries. Several studies examine the dynamic relationships between stock markets using the spillover index (Mensi et al., 2018; Kang et al., 2019; Shu and Chang, 2019; Zhang et al., 2021b; Li et al., 2021). In particular, we implement static spillover and rolling-window analysis to show how the linkages between stock markets evolve over time.

The relationships among the four countries were complicated, subtle, and changed over time. First, South Korea, China, and Japan have long had close geographical relations within Northeast Asian countries. Therefore, due to such geographical factors, there has long been a high economic dependence among the three countries, including trade. Second, the US has long played the role of a leading country in the global economy. Recently, China's influence on the global economy has grown, and the US and China have been competing with each other in terms of economic power. Therefore, we investigate not only the relationship between Northeast Asian countries, but also the relationship between China and the US, the world's economic stimulus, and its influence on South Korea and Japan.

In particular, the four countries have close economic relations. First, the US, with the largest nominal gross domestic product (GDP) in the world,[2] has maintained strong economic ties with China, Japan, and South Korea. Japan, in particular, has been an important economic partner of the US, and is the world's second-largest economic power. After the Korean War, economic relations with Korea were established, as economic aid had a great influence on the economy, society, and politics (Manyin et al., 2016). However, the economic relationship between the US and China has dramatically changed. It grew stronger from 2001 and reached its peak in 2017.[3] Since then, due to the trade war between the two countries, the relationship has weakened, mutually affecting the two economies (see "The US–China Economic Relationship"). For example, the US exported $130 billion worth of goods to China in 2017, but exports decreased to $106 billion in 2019, owing mostly to the tariffs implemented during the China–US trade war (Liu and Woo, 2018). However, in terms of international trade, China, Japan, and South Korea were the first, fourth, and seventh largest US trading partners for imports, and third-, fourth-, and seventh-largest for exports in 2020, respectively.[4] Moreover, Japan has the largest foreign investment in US treasury securities according to the report.[5]

Second, since its defeat in the Pacific War, Japan achieved enormous manufacturing-based economic growth. The economic success of Japanese manufacturers was proved by "Made in Japan"'s products (Nagashima, 1977). According

1 According to the WHO Coronavirus (COVID-19) Dashboard, August 4, 2021.

2 According to International Monetary Fund (IMF) data.

3 "The US–China Economic Relationship", OXFORD ECONOMICS, January 2021.

4 Foreign Trade in United States Census, https://www.census.gov/foreign-trade/statistics.

5 "U.S.-Japan Relations", Congressional Research Service, May 2021.

to a report from the Korea Economic Institute,[6] until the 1980s, due to Japan's advanced economic power, economic aid was provided to Korea, such as official development assistance and foreign direct investment. Although this aid helped South Korean economic development, focused on the manufacturing sector, it also caused increased economic dependence on Japan. Since China joined the World Trade Organization (WTO) in 2001, it has achieved rapid economic growth. In this process, the Chinese economy made great progress in labor-oriented industries and was also called the "the world factory" (Li et al., 2007; Wang and Li, 2017). Therefore, external economic dependence on developed countries has inevitably increased. According to the Korea International Trade Association,[7] China amounted for about 25.8%, the US about 14.4%, and Japan about 4.9% of South Korea's total exports in 2020, ranking first, second, and fifth, respectively. China accounted for 23.3%($ 10.9 billion), US for 12.3% ($ 5.7 billion), and Japan for 9.9%($ 4.6 billion) of imports, and are ranked first, second, and third, respectively. Moreover, the sum of exports to, and imports from the three countries accounted for 45.2% and 45.4% of South Korea's total exports and imports, respectively. Therefore, the economic relationship between these countries is essential for South Korea, which is highly dependent on the external economy.

Lastly, economic conflicts have recently arisen as a side effect of these serious economic relationships. For instance, Japanese semiconductor materials are essential for the South Korean semiconductor industry. Japan used this industrial structural relationship to impose export restrictions on South Korea in July 2019 (see Goodman et al. (2019) and Deacon (2021)). Moreover, the US–China trade war and Korean Terminal High Altitude Area Defense(THAAD) based on military issues (Juan et al., 2017), have caused economic conflicts among the four countries. Several studies on the impact of China–US trade on neighboring countries have been reported (Li et al., 2018; Pangestu, 2019; Itakura, 2020). However, they still have important economic relationships with these all four countries as economic partners.

Moreover, the GFC and the COVID-19 pandemic are strongly related to the four countries. Since the GFC was triggered by the subprime mortgage crisis in the US, it had a huge impact on global financial markets. The COVID-19 pandemic first broke out in China, but in the early stages, there were many confirmed cases in the US and South Korea, and it hit the economies of the two countries. Accordingly, it is meaningful to examine the dynamic volatility linkages among the four countries.

Therefore, this study provides the following main contributions to the financial literature. First, the analysis of dynamic connectedness between these four stock markets is a very interesting topic for market participants who participate in the stock market and policy makers who manage the market, since the analysis helps to understand the relationships between the volatility shocks in the stock markets. Second, we investigate the dynamic linkages between the four stock markets, which are mainly affected by the COVID-19 pandemic. South Korea and Japan are geographically close to China, where COVID-19 originated. The US has suffered significant economic damage due to the pandemic. Therefore, examining the dynamic connectedness between these four countries contributes to the existing literature. Lastly, our results are helpful to portfolio managers, investors, and policymakers. During a crisis period, investors and portfolio managers pay more attention to portfolio decisions. Volatility spillover analysis results can help asset allocation and hedge risk. Furthermore, the volatility spillover results provide policymakers with information about the net receivers and net transmitters of market shocks. Thus, policymakers can plan policies for market stability.

The remainder of this paper is organized as follows. In Section 2, we review the literature on the dynamics of financial markets. In Section 3, we define the volatility of the stock index and provide a preliminary statistical analysis of volatility. In addition, we briefly review the spillover index in this section. Section 4 presents the results of the static and rolling window analyzes. Finally, Section 5 provides a summary and concluding remarks.

2. Literature review

Many previous studies have investigated the dynamics of financial markets. In this section, we first categorize previous studies based on the asset class of connectedness. Second, we discuss the literature on the linkages among financial markets during several crisis periods.

2.1. Dynamic connectedness of financial assets

Many researchers have investigated the dynamic relationships between financial assets. First, as a single financial asset, there are many studies on the dynamic connection between cross-border stock markets (Ng, 2000; nath Mukherjee and Mishra, 2010; Batareddy et al., 2012; Palamalai and Devakumar, 2013; Sugimoto et al., 2014; Paramati et al., 2016; Mensi et al., 2018; Tissaoui and Zaghdoudi, 2020). In their studies, they investigated the dynamic relationship between stock markets of different countries, regionally and economically relevant, such as the Pacific-Basin equity markets, the US and Japan, and developing countries.

Second, research on dynamic linkages among commodity markets has also been actively reported. In particular, the relationship between commodity assets has been a primary concern (Wang et al., 2019; Zhang and Broadstock, 2020; Wang et al., 2020; Lovcha and Perez-Laborda, 2020; Yip et al., 2020). In particular, they examine the relationship between oil and several commodity assets, such as oil and agricultural products, oil and natural gas, and oil and gold.

6 "Korea's Economic Relations with Japan" Korea's Economy, July 2017.

7 https://stat.kita.net.

In addition, with the recent growing interest in cryptocurrencies, including Bitcoin, the dynamic relationship between cryptocurrencies has been investigated (Yi et al., 2018; Ji et al., 2019; Li et al., 2020; Fasanya et al., 2020).

Third, some scholars investigate dynamic links between across assets, such as between stock and commodity markets, and stock and FX markets (Rehman et al., 2018; Nasreen et al., 2020; Bahloul and Khemakhem, 2021; Nekhili et al., 2021; Bouri et al., 2021a). Furthermore, several studies have focused on the interconnection between oil and stock markets because of the essential and critical role of oil in the global economy (Singh et al., 2018; Malik and Umar, 2019; Choi and Hong, 2020; Okorie and Lin, 2020).

Lastly, the interrelation between the economic policy uncertainty (EPU) index developed by Baker et al. (2016) and financial assets has been investigated in many recent studies. The dynamic relationships with all of the financial assets mentioned above have been investigated, such as equity (Xia et al., 2020; He et al., 2020), oil (Antonakakis et al., 2014; Chen et al., 2019; Sun et al., 2020), FX (Al-Yahyaee et al., 2020; Abid, 2020), and Bitcoin (Cheng and Yen, 2020). According to their results, the relationship between EPU and each asset is significant, and in most cases, the relationship becomes stronger during times of crisis.

2.2. The interconnection and crisis

Many researchers have explored the dynamic relationships between financial markets during crisis periods. Therefore, we classify existing studies based on the time of crisis.

First, there are studies that investigate the linkages between financial markets during the 1997 Asian currency crisis. Since the crisis was caused by a crash in the foreign exchange (FX) markets, several studies have examined the dynamic linkages among cross-border FX markets (Meng and Huang, 2019; Bouri et al., 2020; Boubaker et al., 2021), FX, and stock markets (Fang and Miller, 2002; Pan et al., 2007; Yang et al., 2014). The relationships between stock markets in Asia were also investigated during the crisis (In et al., 2001; Corsetti et al., 2005; Chiang et al., 2007; Huyghebaert and Wang, 2010; Manopimoke et al., 2018; Lien et al., 2018). In particular, according to several studies (Huyghebaert and Wang, 2010; Li and Giles, 2015), the US had a huge impact on Asian financial markets during the Asian financial crisis.

Second, since the GFC has caused great damage to the global economy, there has been much research into the dynamic relations across countries and various financial asset markets. In the study of dynamic relations between countries, the stock market was mainly used (Liow, 2014; Mensi et al., 2016; Bala and Takimoto, 2017; Lien et al., 2018). This is because across financial assets, dynamic relationships between assets such as stock, bond, oil and gold were investigated (Maghyereh et al., 2016; Roy and Roy, 2017; Trabelsi, 2019; Balli et al., 2019). In summary, the relationships between countries or financial assets vary over time and increase during the GFC period.

Third, another example is the European sovereign debt crisis. During the European debt crisis, various financial problems, such as the collapse of financial installations and high governance debt, occurred. Accordingly, many studies have examined the dynamic connections between European financial markets during the crisis period, for example, dynamic connectedness in stock (Tamakoshi and Hamori, 2013; Diebold and Yilmaz, 2015), bonds (Calice et al., 2013; Bekiros et al., 2018), credit default swaps (Alter and Beyer, 2014; Broto and Perez-Quiros, 2015; de Boyrie and Pavlova, 2016), and FX (Karfakis and Panagiotidis, 2015; Baruník et al., 2017) markets.

Lastly, the recent COVID-19 pandemic is triggered by health problems, but it has already caused great damage to the global economy. Therefore, as in the case of the GFC, several studies investigate the dynamic connectedness between countries and between financial assets. For example, Polat (2021) investigated the interdependence of systemic risk in 11 European countries by using the composite indicator of the systematic stress series. Bouri et al. (2021a) display a dynamic return connectedness across various assets (gold, oil, equity, currency and bond). Umar et al. (2021b) examined the volatility spillovers among emerging markets and US government bonds.

This study enhances the existing literature on the dynamic connectedness among Northeast Asian countries(South Korea, Japan, China) and the US. Moreover, we contribute to the literature by clarifying the influence of the GFC and the COVID-19 pandemic on their relationship. Furthermore, our empirical findings are important and useful for market participants in the stock markets of four countries.

3. Data and methodology

3.1. Data description

In this study, we employ the KOSPI, NIKKEI225, SSEC, and S&P 500 indices from January 2000 to June 2021 to measure the volatility spillovers among the four countries. They are the main stock indices for each country. In addition, we define weekly volatility as stock indices. The estimated weekly volatility is 1101.

According to Garman and Klass (1980), the weekly variance of stock indices are defined as:

$$\tilde{\sigma}_t^2 = 0.511(H_t - L_t)^2 - 0.019\left[(C_t - O_t)(H_t + L_t - 2O_t) - 2(H_t - O_t)(L_t - O_t)\right] - 0.383(C_t - O_t)^2, \quad (1)$$

where H_t, L_t, C_t, and O_t are the high, low, closing, and opening prices of each stock index in week or month t(all in natural logarithms). In addition, they($\tilde{\sigma}_t^2$) annualize the variance as $\hat{\sigma}_t^W = 100\sqrt{50 \cdot \tilde{\sigma}_t^2}$ for weekly volatility. Fig. 3.1 displays the estimated weekly volatility of the four stock indices. In the figure, the weekly volatilities commonly display peaks in the GFC and the COVID-19 pandemic periods.

We also provide summary statistics for weekly volatility in Table 3.1. According to the table, they all have high kurtosis, and the average of SSEC and S&P500 are the highest and lowest, respectively.

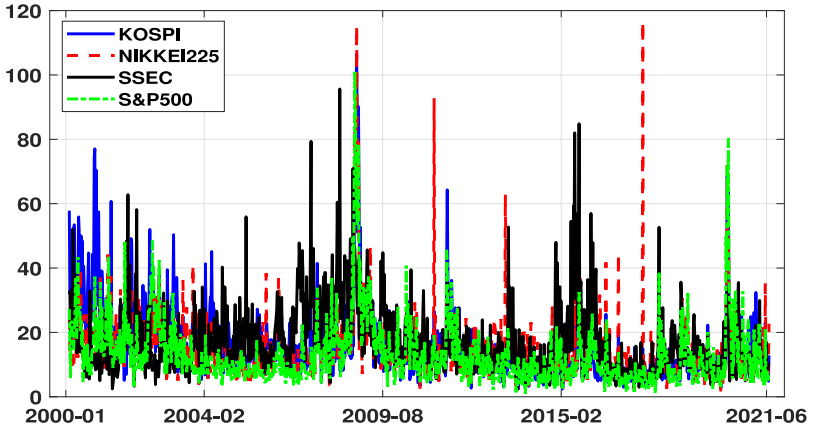


Fig. 3.1. Weekly volatility($\hat{\sigma}_t^W$) of KOSPI, TOPIX, SSEC, and S&P 500.

Table 3.1
Summary statistics for the weekly volatilities ($\hat{\sigma}_t^W$) of all stock indices for the full period (January 2, 2000–June, 2021).

Index	Obs.	Mean	Std.Dev.	Skewness	Kurtosis
KOSPI	1101	16.3	11.42	2.58	10.99
NIKKEI225	1101	15.5	10.14	3.83	26.79
SSEC	1101	17.27	10.92	2.08	7.09
S&P500	1101	12.99	9.86	3.07	15.97

3.2. The volatility spillover index

We briefly introduce the spillover index to measure the dynamic connectedness among the weekly volatility of stock indices.

Given an N-dimensional vector V_t, the covariance stationary N-variable VAR(p) can be written as

$$V_t = \sum_{i=1}^{p} \Phi_i V_{t-i} + \epsilon_t, \tag{2}$$

where Φ_i are the $N \times N$ autoregressive coefficient matrices to be estimated. In addition, ϵ is a vector of independently and identically distributed with a zero mean.

Because of the covariance stationarity, we obtain a moving average representation of VAR(p) in (2) as

$$V_t = \sum_{i=0}^{\infty} A_i \epsilon_{t-i}, \tag{3}$$

where the $N \times N$ coefficient matrices A_i such that the recursion of the form $A_i = \Phi_1 A_{i-1} + \Phi_2 A_{i-2} + \cdots + \Phi_p A_{i-p}$, $A_0 = I_N$, and $A_i = 0$ for $i < 0$.

Based on the generalized VAR framework (Koop et al., 1996; Pesaran and Shin, 1998), the H-step-ahead forecast error variance decomposition for $H = 1, 2, \ldots$, is computed as

$$\theta_{ij}(H) = \frac{\sigma_{jj}^{-1} \sum_{h=0}^{H-1} \left(e_i' A_h \Sigma e_j\right)^2}{\sum_{h=0}^{H-1} \left(e_i' A_h \Sigma e_j\right)}, \tag{4}$$

where Σ is the variance matrix of the error vector ϵ, σ_{jj} is the standard deviation of the error term of the jth stock market, and e_i is an $N \times 1$ vector with those for the ith elements, and zero if otherwise.

The $N \times N$ matrix $\theta(H) = \left[\theta_{ij}\right]_{i,j=1,2,\ldots,11}$ shows the impact of a volatility shock of the jth stock market on the forecast error variable of the ith stock market. As $\sum_{j=1}^{N} \theta_{ij}(H) \neq 1$, we normalize each entry by the row sum

$$\bar{\theta}_{ij}(H) = \frac{\theta_{ij}(H)}{\sum_{j=1}^{N} \theta_{ij}(H)}, \tag{5}$$

such that $\sum_{i=1}^{N} \bar{\theta}_{ij}(H) = 1$ and $\sum_{j=1}^{N} \bar{\theta}_{ij}(H) = N$.

Table 4.1
Summary of volatility spillovers among the four stock indices during the whole period. Notes: "From" = $TDS_{i\leftarrow\cdot}$, the total volatility spillovers received by the ith sector from all other sectors; "TO" = $TDS_{i\rightarrow\cdot}$, the total volatility spillovers transmitted from the ith sector to all other sectors; "TO(own)" = total volatility spillovers generated by the ith sector, including the contribution of its own; "NET" = NPS_i, the net spillovers (the difference between transmitted volatility shocks and received volatility shocks); "TSI" = the total spillover index.

	KOSPI	NIKKEI225	SSEC	S&P500	FROM
KOSPI	55.95	12.88	5.35	25.82	44.05
NIKKEI225	17.43	51.85	4.74	25.98	48.15
SSEC	4.05	2.79	88.45	4.71	11.55
S&P500	19.61	11.99	6.71	61.7	38.3
TO	41.09	27.66	16.8	56.51	
TO(own)	97.04	79.51	105.24	118.2	TSI
NET	−2.96	−20.49	5.24	18.2	35.51

As in Diebold and Yilmaz (2012), we define the total spillover index (:= TSI) as

$$TSI = \frac{\sum_{i,j=1,i\neq j}^{N} \bar{\theta}_{ij}(H)}{\sum_{j=1}^{N} \bar{\theta}_{ij}(H)} \times 100 = \frac{\sum_{i,j=1,i\neq j}^{N} \bar{\theta}_{ij}(H)}{N} \times 100. \tag{6}$$

Additionally, the total directional spillover received by stock market i from all other stock markets (:= $TDS_{i\leftarrow\cdot}$) is

$$TDS_{i\leftarrow\cdot} = \frac{\sum_{j=1,j\neq i}^{N} \bar{\theta}_{ij}(H)}{N} \times 100. \tag{7}$$

Similarly, the total spillovers transmitted by stock market i to all other stock markets (:= $TDS_{i\rightarrow\cdot}$) are

$$TDS_{i\rightarrow\cdot} = \frac{\sum_{j=1,j\neq i}^{N} \bar{\theta}_{ji}(H)}{N} \times 100. \tag{8}$$

Using the difference between the directional spillover indices (7) and (8), we can calculate the net spillovers from sector i to all other variables (= NPS_i):

$$NPS_i = TDS_{i\rightarrow\cdot}(H) - TDS_{i\leftarrow\cdot}(H). \tag{9}$$

4. Static and rolling window analysis

4.1. Static spillover analysis

In this section, we provide a static analysis of the interdependence volatility of the four stock indices. In particular, we implement static analysis for three periods: the whole period, the GFC period, and the COVID-19 pandemic period. The sub-periods for the two crises are the GFC period (from August 2007 to March 2009) and the COVID-19 pandemic period (from February 2020 to June 2021). Based on these sub-period analyzes, we present a comparison of the impact of the two crises on the relationship among the four countries. The static analysis results for the three periods are listed in Tables 4.1–4.3. We find the optimal lag order for weekly volatility in each static analysis based on the Akaike information criterion (AIC).

Table 4.1 displays the whole sample connectedness of the volatility of the four stock indices. According to the Table, the total spillover index ('TSI') is 35.51%. In addition, the net directional spillovers ('NET') show that US and Chinese stock markets are net transmitters of shocks to other stock markets, whereas the South Korean and Japanese stock markets are net receivers of shocks.

The spillover analysis results of two sub-periods, the GFC and the COVID-19 pandemic, are given in Tables 4.2 and 4.3, respectively. The main comparisons of the two sub-period analyzes are as follows. First, based on the estimated TSI, their interconnection became much stronger during the COVID-19 pandemic than it was during the GFC period. In other words, the total transmission of volatility shocks between these four countries occurred more vigorously during the COVID-19 pandemic than during the GFC. Therefore, the COVID-19 pandemic had an even greater impact on the stock markets in the four countries compared to the GFC period in terms of interrelationships. These results are consistent with those of several studies (Umar et al., 2021a; Bouri et al., 2021b; Umar et al., 2021b; Mensi et al., 2021). Second, based on the net spillovers (NPS_i) for each volatility, the US stock market has a dominantly strong impact on the rest of the country's economy during the GFC. On the other hand, the US and South Korea, the major victims of COVID-19, affected the economy of the other two countries. That is, the two countries with serious health problems exercised a major influence on the linkages between them, although the source of the COVID-19 outbreak is known to be China.

Table 4.2
Summary of volatility spillovers among the four stock indices during the GFC period.

	KOSPI	NIKKEI225	SSEC	S&P500	FROM
KOSPI	26.6	21.98	1.9	49.53	73.4
NIKKEI225	19.01	30.5	2.86	47.63	69.5
SSEC	6.4	2.93	85.77	4.91	14.23
S&P500	10.07	22.43	2.13	65.37	34.63
TO	35.48	47.34	6.89	102.06	
TO(own)	62.07	77.84	92.66	167.43	TSI
NET	−37.93	−22.16	−7.34	67.43	47.94

Table 4.3
Summary of volatility spillovers among the four stock indices during the pandemic period.

	KOSPI	NIKKEI225	SSEC	S&P500	FROM
KOSPI	40.77	21.76	12.82	24.65	59.23
NIKKEI225	26.64	37.33	7.76	28.27	62.67
SSEC	15.76	8.23	64.55	11.45	35.45
S&P500	27.87	21.9	8.69	41.55	58.45
TO	70.28	51.89	29.27	64.37	
TO(own)	111.04	89.22	93.82	105.92	TSI
NET	11.04	−10.78	−6.18	5.92	53.95

4.2. Rolling window spillover analysis

To show the change in the relationship between the volatilities, we employ the rolling window analysis. In addition, we estimate the VAR model using 50-week rolling windows based on the 5-step-ahead forecast error.

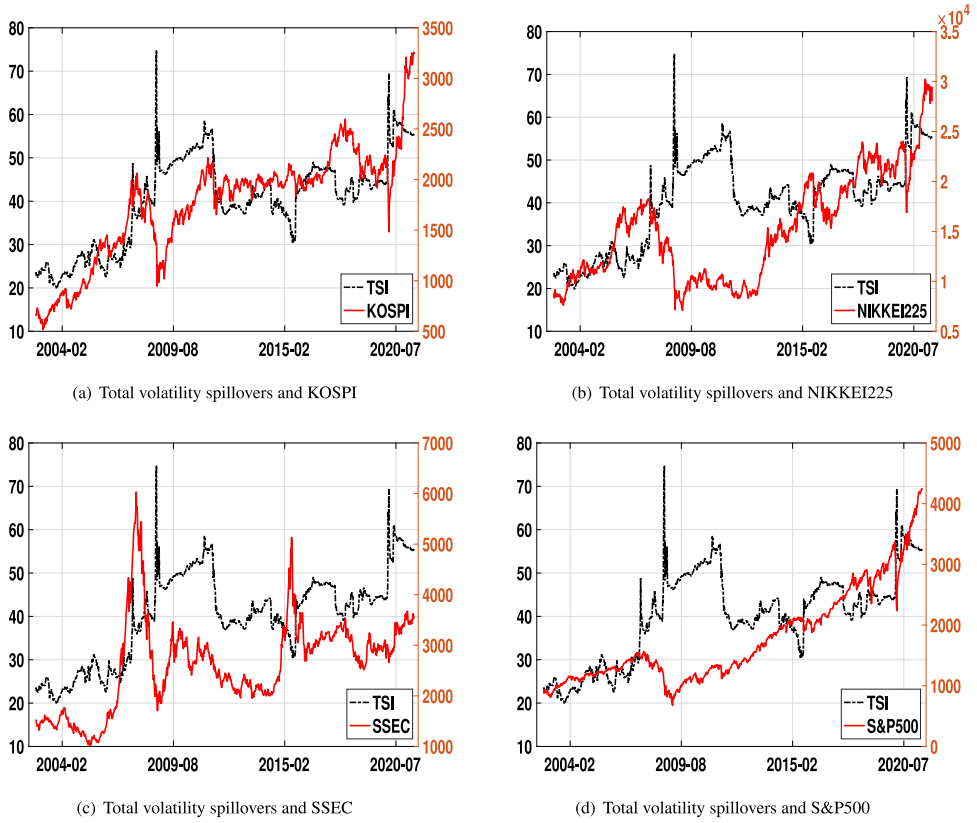
Fig. 4.1 shows the overall total volatility spillovers for each stock index. We also display the stock indices with the spillover indices in the subfigures. Several spikes are commonly found in each subfigure and we recognize two extreme spikes during the GFC and COVID-19 pandemic periods. Furthermore, in those two crises, the movements of the stock index and total spillover are inversely related. Therefore, as with the static analysis results, in times of crisis, the volatility spillovers of their stock markets was intensified. This result is consistent with the literature (Antonakakis and Vergos, 2013; Diebold and Yilmaz, 2015; Lien et al., 2018; Zhang et al., 2021a).

In Fig. 4.2, we display the rolling net volatility spillovers for the stock indices. With a few exceptions, all stock markets are neutral in terms of net volatility spillovers. However, in times of crisis, each market responds differently. During the GFC period, it can be seen that the US stock market plays the role of a strong net transmitter of volatility shocks to others, while the rest of the countries are net recipients of volatility shocks. In other words, we can conclude that the shock of the GFC crisis in the US was transmitted to the rest of the three countries. This is also supported by other studies (Lien et al., 2018; Prasad et al., 2018). On the other hand, during the COVID-19 pandemic, the US and South Korean stock markets were net transmitters of volatility shocks, while the other two countries were receivers of volatility shocks. In addition, the degree of shock spillover was weaker than that of the GFC. Unlike the GFC, the impact of the pandemic occurred simultaneously around the world, and the damage caused by the pandemic in South Korea and the US was large in the early days. This can be one of the reasons for such results.

We estimate the dynamic total directional spillover received ($TDS_{i\leftarrow\cdot}$) and transmitted ($TDS_{i\rightarrow\cdot}$) for each stock market to measure the impact of individual countries on each stock market. The total directional spillovers received from other stock markets and transmitted to other stock markets are shown in Figs. 4.3 and 4.4, respectively. The results for each country are summarized as follows.

First, the South Korean stock market, as a shock transmitter, has made a significant transmission of shock to the US stock market. While the extent of its transmission decreased during the GFC period, the extent of its transmission to the three countries increased during the COVID-19 pandemic (Fig. 4.3-(a)). As a shock receiver (Fig. 4.4-(a)), prior to 2015, the US stock market had the largest impact on the South Korean stock market among the three stock markets. In particular, shock transmission was greatest during the GFC period. After 2015, the influence of the Chinese market was greater than that of the US market. However, during the pandemic, the impact of the US stock market was greater.

Second, in the Japanese stock market, the impact of the Japanese stock market on the US and South Korean stock markets is almost identical, while its impact on the Chinese stock market is the smallest in most periods. During the GFC period, there was no significant change in the influence of the Japanese stock market on other countries, but during the pandemic, its impact on the stock market in the US and South Korea increased rapidly (Fig. 4.3-(b)). Based on Fig. 4.4-(b), before the 2010s, among the three countries, the US stock market had the greatest influence on the Japanese stock market. However, after that, the South Korean stock market has affected the Japanese stock market in much the same way as the US stock market. Over the entire period, the Chinese stock market had the least impact on the Japanese stock market. During the GFC period, the US stock market and the US and South Korean markets during the pandemic had a greater impact on the Japanese stock market than usual.



(a) Total volatility spillovers and KOSPI

(b) Total volatility spillovers and NIKKEI225

(c) Total volatility spillovers and SSEC

(d) Total volatility spillovers and S&P500

Fig. 4.1. Total volatility spillovers among the stock indices and their price based on the weekly frequency.

Third, in the Chinese stock market, based on sub Figs. 4.3-(c) and 4.4-(c), the impact of the Chinese stock market on the stock markets of the three countries was modest until 2015, except in 2011.[8] However, after 2015, the impact on the South Korean and US stock markets increased. After the pandemic, the impact of the Chinese market returned to its former level. Occasionally, the stock markets of South Korea, Japan, and the US have the greatest influence on the Chinese stock market. Recently, the Japanese stock market has had the least impact, but after the pandemic, the three influences have become similar. However, during the GFC period, the influence of the US was the greatest.

Finally, for the US stock market, according to sub Fig. 4.3-(d), before 2018, the impact of the US stock market on the Chinese market was the least, but from 2018, the impact on the Chinese stock market increased, and the impact on the Japanese stock market was relatively small. For most of the period, the US stock market had the greatest impact on the South Korean stock market. During the GFC period, volatility shocks were transported at almost the same level to the three countries, and even during the pandemic period, volatility shocks were transmitted at a large level, but the level was lower than that of the GFC. Except for a few short periods of time, the overall South Korean stock market had the biggest impact on the US stock market, but the level was small compared to that of the other three countries. During the GFC period, shock transmission from the other three countries was low, and during the pandemic period, South Korean stocks had the biggest impact on the US stock market for the entire period. Recently, the influence of the Chinese stock market has been decreasing (Fig. 4.4-(d)).

5. Concluding remarks

In this study, we investigate how volatility shocks are transmitted across four stock markets (South Korea, Japan, China, and the US) by using the spillover index. The four countries have very close geographical, political, and military ties. The examination of connectedness among the stock market has increasingly been important in practice. For example, it has been utilized in risk management, portfolio allocation, and economic policies (Diebold and Yılmaz, 2014; Minoiu et al.,

[8] The European sovereign debt crisis peaked between 2010 and 2012. Sub Fig. 4.3-(c) shows a large change in the directional spillover during the European sovereign debt crisis period. However, the rest of the subfigure did not show much change during that period. In addition, from the plot of total volatility spillover and net spillover, there was no significant change during the crisis period. Therefore, this study does not discuss the European sovereign debt crisis.

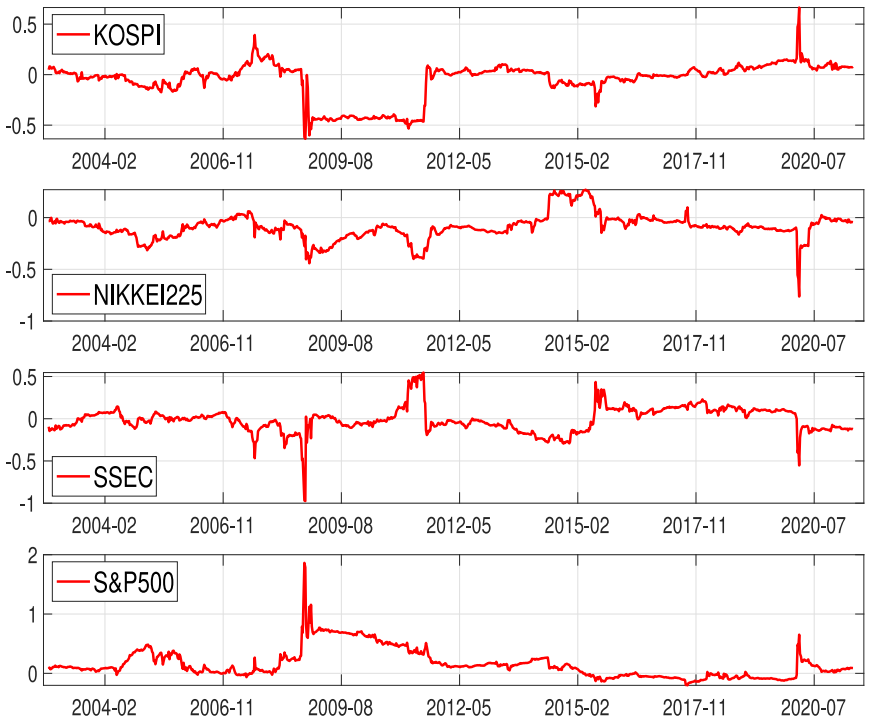


Fig. 4.2. Rolling net spillover estimates for the four volatility.

2015; Hamill et al., 2021; Urom et al., 2021). Furthermore, we analyze the dynamic connectedness between volatility shocks during the two crises, the GFC and the COVID-19 pandemic. Studies comparing the two crises, the COVID-19 pandemic and the GFC, have consistently been reported, as both the COVID-19 pandemic and the GFC have had a significant impact on the global financial market.

We expand the current literature on the dynamic connectedness between volatility shocks in the four stock markets. Furthermore, we contribute to the studies by investigating how the linkages among them vary within the two crisis periods, the GFC and the COVID-19 pandemic through the static and rolling window spillover analysis. The empirical results of the analysis provide several interesting conclusions with useful practical implications. Our main findings are summarized as follows.

First, the total connectedness and net connectedness between the volatility of the four stock markets vary over time. In particular, the degree of change over time strengthened during the crisis period. However, the US has been persistently a net transmitter of volatility shocks, while Asian markets act as net receivers for a few short time periods.

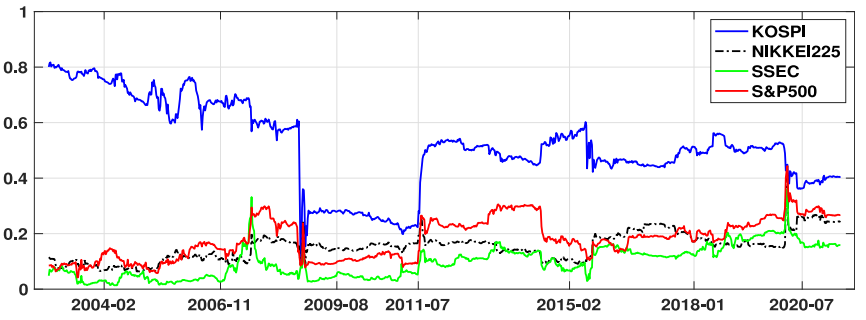
Second, according to both static and rolling window analysis, total dynamic connectedness increased in both crisis periods, but total connectedness in the GFC was greater than in COVID-19. In the case of the GFC, it was a financial crisis that started only in the US financial market, but in the case of the pandemic, it was a crisis caused by the occurrence of confirmed cases in each country and health problems. This difference seems to have caused the difference in the total connectedness of the examined stock markets between the two wish periods.

Third, the influence of the US and Chinese stock markets on the South Korean stock market has changed over time in terms of volatility shocks. Starting in 2015, China's volatility shock transmission was larger than that of the US stock market, and this trend continued after 2015 until the outbreak of the COVID-19 pandemic. South Korea's increased dependence on China's economy may be one of the reasons for this phenomenon.[9]

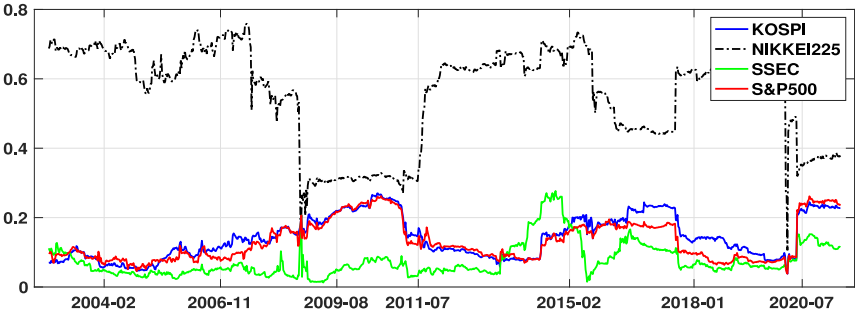
Based on our empirical findings, we have important implications for market participants. First, the empirical results suggest that the major stock markets that deliver shocks to countries change over time. Therefore, investors and policymakers should carefully consider dynamic linkages for their decisions according to investment horizons or their policies. However, the US stock market is consistently a net transmitter of volatility shocks to other stock markets. Accordingly, market participants should be able to respond to the crisis by understanding the role of net transmitters in the US stock market.

Second, the relationships among the four stock markets are highly sensitive to crises. This feature should be referred to in investment or policy decisions depending on the characteristics of the crisis, the GFC, and the COVID-19 pandemic. For

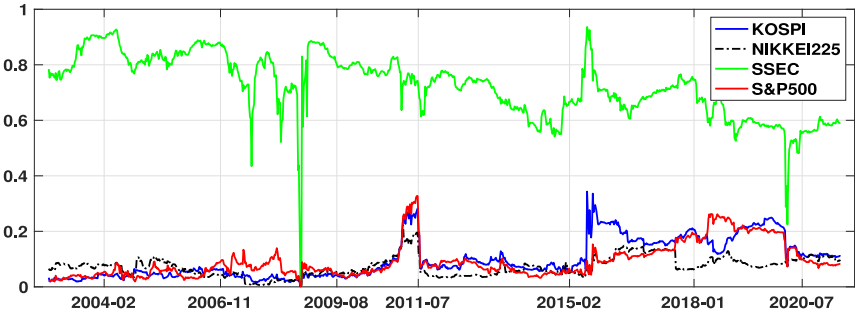
9 "South Korea's Economic Dependence on China", the diplomat, 2015.



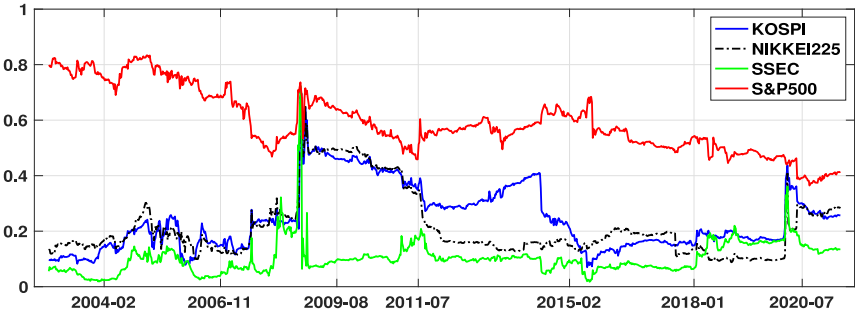
(a) From KOSPI to other stock markets



(b) From NIKKEI225 to other stock markets



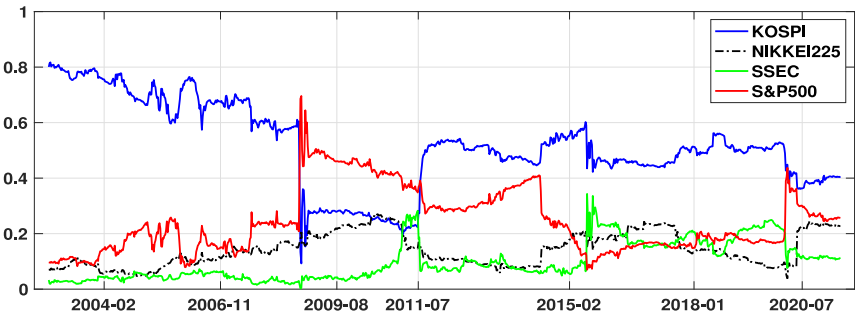
(c) From SSEC to other stock markets



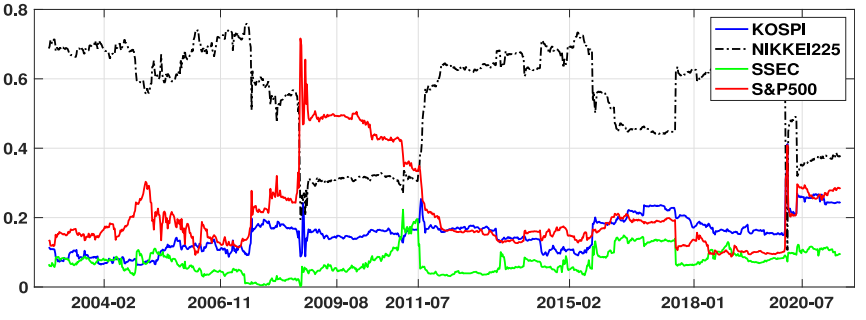
(d) From S&P500 to other stock markets

Fig. 4.3. Dynamics of volatility spillovers to other countries.

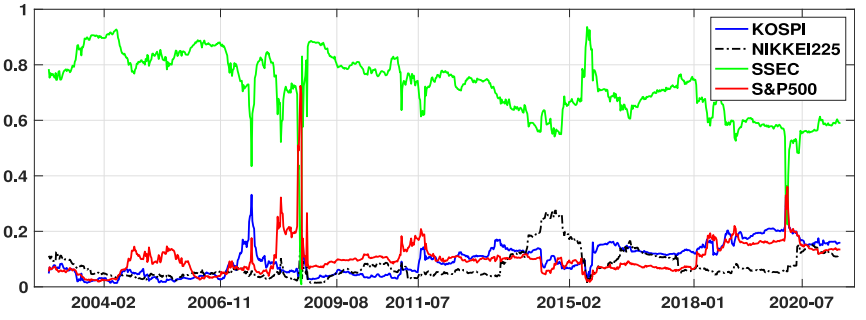
example, during the pandemic, both the US and South Korean stock markets transmitted volatility shocks to the Chinese and Japanese stock markets, while the US was only a net transmitter of volatility shocks in the GFC period.



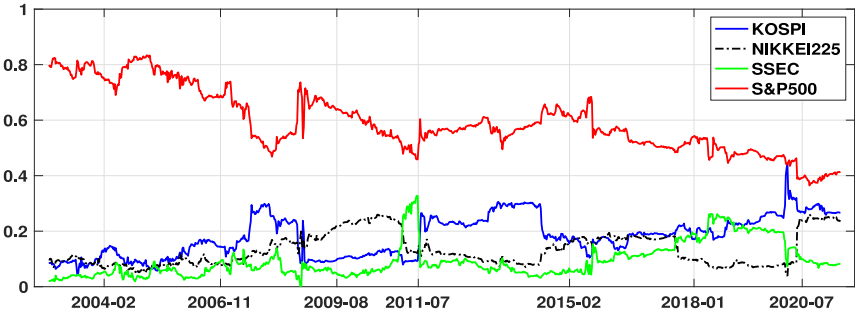
(a) From other stock markets to KOSPI



(b) From other stock markets to NIKKEI225



(c) From other stock markets to SSEC



(d) From other stock markets to S&P500

Fig. 4.4. Dynamics of volatility spillovers from other countries.

Third, policymakers can use spillover analysis results to establish future foreign policy. In particular, regime-dependence volatility spillovers from the Chinese and US stock markets to the South Korean stock market

should be considered as the main factor for investment strategy or establishment of economic policies. For South Korea, establishing and developing relations with China and the US is one of the most important tasks at hand (Sohn, 2019; Leipziger and Dahlman, 2019).

Overall, according to the volatility spillover results, market participants such as portfolio managers or investors can develop strategies to avoid contagion risk during a crisis period by computing dynamic hedge ratios or optimal portfolio weights. The same holds true for policymakers in mitigating the contagion effects of the stock market. In particular, risk managers or policymakers should pay attention to the dynamic connectedness of volatility based on the net transmitter or receiver of volatility shocks in order to relieve the contagion risk from the interdependence of stock markets.

Finally, as part of future studies, we suggest extending our analysis to other financial assets, such as bonds, foreign currency, and CDS(Credit Default Swap) markets in the four countries. This study will help us better understand the relationships among the four countries. Furthermore, applying our study results to sectors such as health care and energy will allow us to investigate the industry-specific relationship between China, the US, Japan, and South Korea, and further identify how the COVID-19 pandemic affected particular industries in these countries. In addition, it is also meaningful to investigate how EPU, which indicates the degree of market uncertainty, or the price of oil, which plays a major role in the global economy, affects the relationship between the four countries.

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