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Research Article

The Impact Of Covid-19 On Volatility Connectedness In The Korean Stock Markets: Focusing On Firm Size

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ARTICLE INFO **ABSTRACT**

This study aims to analyze the impact of COVID-19 outbreak on the connectivity in Korean stock Markets. To achieve this, the connectivity of KOSPI and KOSDAQ markets' six size indices were analyzed using volatility spillover index (Diebold and Yilmaz, 2012). The major empirical results using the volatility spillover index are as follows. First, it was found that COVID-19 outbreak has increased the linkage between stock markets, as well as the amount of information between the markets, resulting in synchronization between the index. Additionally, the volatility spillover index provides information on the strength and direction of interdependence by measuring the directional spillovers and net spillovers. Second, COVID-19 outbreak has increased the volatility spillover index in KOSDAQ and KOSPI markets, with mid-cap companies in KOSDAQ market and the large-cap companies in KOSPI market showing the most significant increase in spillover effects due to higher levels of TO spillover. Third, the net spillover effects of small-sized companies in both markets have decreased. Rolling sample analysis using a 52-week window size confirms these results and shows that the volatility spillover index remained high throughout 2020 and early 2021, indicating that COVID-19 outbreak increased the effect of volatility spillover between markets. Finally, after analyzing the 52-week sample moving average, it was found that KOSPI small-cap, KOSDAQ mid-cap, and KOSDAQ small-cap index had a positive (+) net spillover effect, while KOSPI and KOSDAQ the large-cap indices had a negative (-) net spillover effect. The result is consistent regardless of time, except for KOSPI mid-cap index. Net spillover effect, which shows significant changes in KOSPI market during and after the COVID-19 period.

Keywords: spillover effects, COVID-19 pandemic, financial markets, firm size

1. Introduction

Infectious diseases like Severe Acute Respiratory Syndrome (SARS), which occurred in November 2002, and Middle East Respiratory Syndrome (MERS), which occurred in September 2012, have had significant impacts on the global financial market. Likewise, the outbreak of Coronavirus disease 2019 (COVID-19) has had a profound impact on the world physically, socially and economically in late 2019. The financial market, in particular, has been heavily affected by the pandemic, with many markets experiencing significant volatility around the world. The pandemic has generated an unprecedented level of uncertainty and risk in the financial market, which poses substantial challenges for investors and policymakers alike. It is, therefore, essential to examine in detail the effects of COVID-19 on the financial market, particularly in terms of volatility and market linkages, to develop effective strategies for managing the risks and addressing the challenges posed by the pandemic.

In December 2019, COVID-19 was first reported in Wuhan, China. On February 28, 2021, the World Health Organization (WHO) declared a Public Health Emergency of International Concern (PHEIC) for COVID-19 and raised the global risk assessment to "very high." On March 11, 2021, WHO declared COVID-19 a pandemic. The outbreak of COVID-19 has caused a shock to the financial market that is comparable in magnitude to previous financial crises such as the subprime mortgage financial crisis, European financial crisis, and US-China trade war. And it is still ongoing. The occurrence of COVID-19 has increased the volatility of the global financial market, and the declaration of the pandemic has caused the world financial market including the Korean stock market to experience a sharp decline.

Various methodologies have been employed to analyze this linkage including multiple regression analysis, Granger causality analysis, cointegration test, prediction error variance decomposition model, and vector autoregression model. Previous studies using these models have limitations in that those don't have sound theoretical background to constrain variables and decide variable order.

Recent studies have utilized the volatility spillover index to examine the effects of information spillover between various financial markets. These studies have explored spillovers between global equity markets (Diebold and Yilmaz, 2009), the UK and US spot and futures markets (Antonakakis et al., 2015), major financial institutions in the US and Europe (Diebold and Yilmaz, 2015), Asian-Pacific stock markets (Ko and Kang, 2016), Asian foreign exchange markets (Jung, 2022), real estate market (Jung and Park, 2022), Chinese stock market (Sun et al., 2021), Gulf Cooperation Council countries (Yousaf et al., 2022), Korean and Greater China stock markets (Park and Jung, 2022), and the Korean financial market (Chang, 2013; Jung, 2020). Stock market moves in the same direction, and the connectivity between markets is an important topic in finance for understanding the microstructure of financial markets (Bollen and Whaley, 2004; Chan et al., 1997; Engle, 2002; Eun and Shim, 1989). COVID-19 pandemic has had a significant impact on the global economy, including financial markets. Darmouni et al. (2022) examined the impact of the pandemic on corporate bond markets, while Jung et al. (2019) conducted an industry-level analysis to explore the net spillover effects of COVID-19. COVID-19 pandemic has further impacted the linkage of financial markets and caused changes in the stock market structure, such as an increase in retail investors' participation and restrictions on short selling in the Korean stock market. These structural changes are important since they affect portfolio performance directly (Al-Awadhi et al., 2020; Chen et al., 2018; Choi 2021). AI into stock marketing strategies has become increasingly common, as AI technologies offer capabilities for analyzing large volumes of data, identifying patterns, and making data-driven predictions. By leveraging AI algorithms, investors can enhance their decision-making processes and adapt to dynamic market conditions more (Rani et al., 2022).

Fig. 1 shows trends in new and cumulative COVID-19 confirmed cases in South Korea. On January 20, 2020, the first COVID-19 confirmed case was reported in Korea. On February 18, 2020, the number of COVID-19 confirmed cases in South Korea increased exponentially to 909 due to group infections at Shincheonji church of Jesus in Daegu and Daenam hospital in Cheongdo. As a result, the government raised the infectious disease crisis alert level to the highest on February 23, 2020, and began to take immediate actions. The Korean government decided to enforce physical distancing from May 6, 2020 and the number of COVID-19 confirmed cases decreased until August 2020. The number of confirmed cases rebounded with 1,240 new cases on December 25, 2020, which raised concerns on the reproliferation of COVID-19 cases. Till December 31, 2021 the cumulative number of confirmed cases exceeded 630,790.

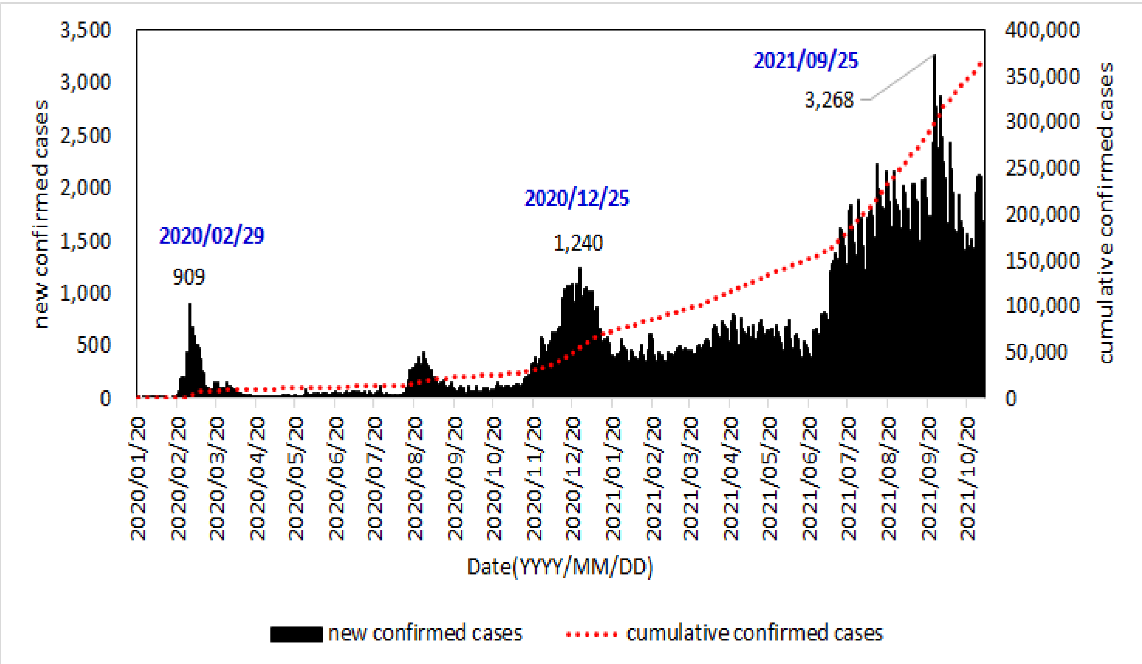

Fig. 1: Trends in COVID-19 confirmed cases (persons)
**Resource: http://ncov.mohw.go.kr*

Fig. 2 shows the trends of KOSPI and KOSDAQ indices. Before COVID-19, KOSPI and KOSDAQ indexes showed similar trends. KOSPI and KOSDAQ indices have shown a similar trend of decline in 2018 and stagnation in 2019. While the COVID-19 outbreak in China in 2019 did not have a significant impact on South Korea, it was only after the first case of COVID-19 was confirmed in South Korea that the stock market was affected.

On March 11, 2020, the declaration of a pandemic by the WHO resulted in a shock and fear in the stock market, with KOSPI index showing a decline of 8.39% (133.56 points lower than the previous day) and KOSDAQ index showing an even greater decline of 11.71%. Additionally, the market continued to decline for seven consecutive trading days until March 19, 2020, leading to the disappearance of one-fourth of the market capitalization. Most of the world's stock markets showed a significant decline. Governments of each country have implemented strong countermeasures against COVID-19, and implemented quantitative easing, interest rate cuts, bailouts, short-selling restrictions, etc. to stabilize the market. And on March 19, 2020, it recorded the lowest point (KOSPI 1457.64 points, KOSDAQ 428.35 points) and started a V-shaped rebound. The movement of the Korean stock market shows a very similar pattern. March 2020 was recorded as one of the most volatile months in the global stock market.

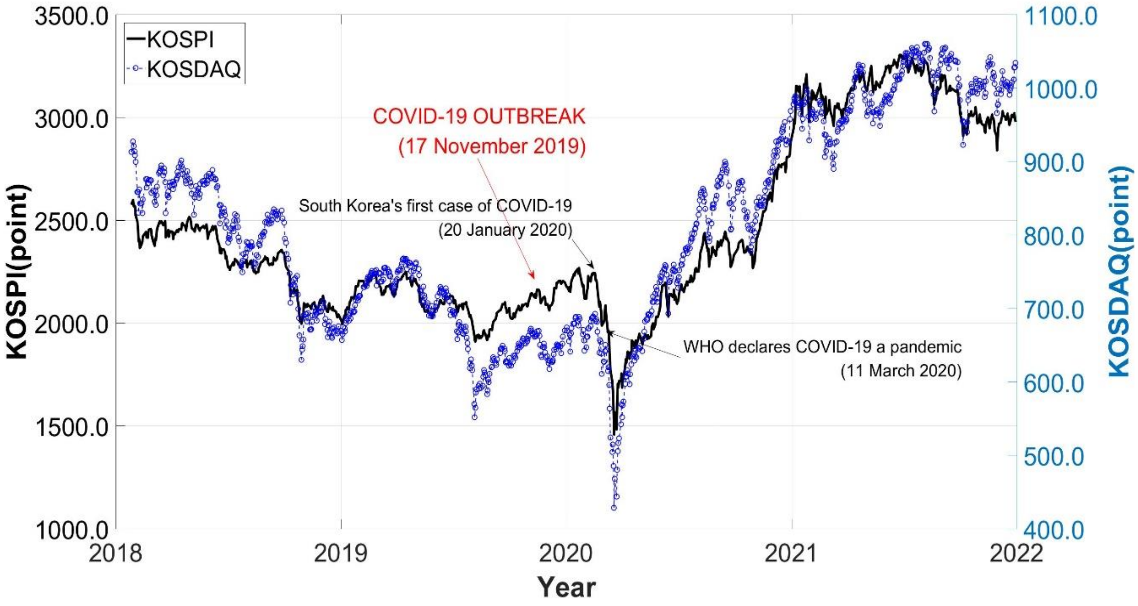

Fig. 2: KOSPI and KOSDAQ index trends from January 2018 to December 2021

Fig. 3 plots the KOSPI index's return (panel A) and KODAQ index's return (panel B). Since the outbreak of COVID-19 cases in South Korea, the volatility has increased significantly, and KOSDAQ market is more volatile than KOSPI market. And both indices show volatility clustering.

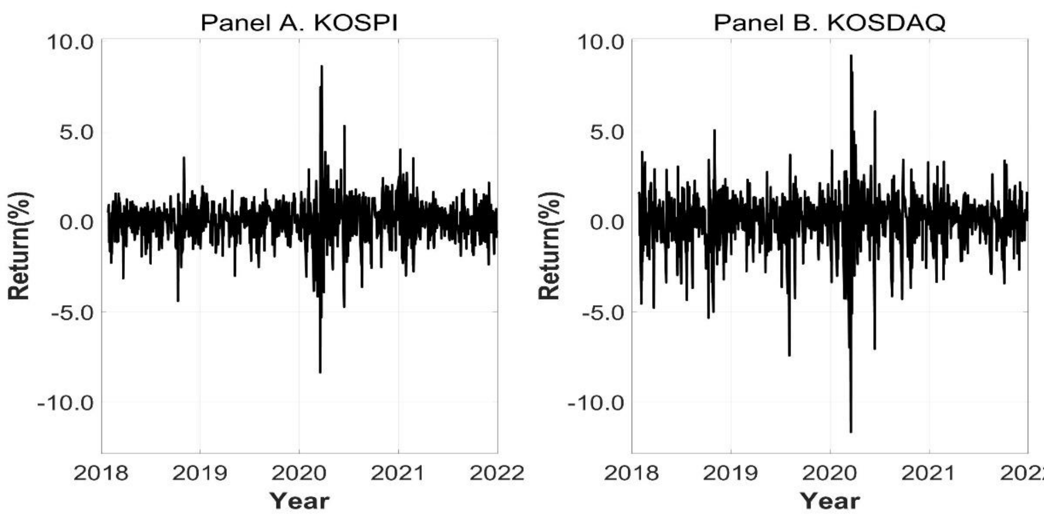

Fig. 3: KOSPI and KODAQ index returns from January 2018 to December 2021

Table 1 presents information on the days with the largest decline and the largest increase in KOSPI and KOSDAQ markets, sorted by company. The largest drop in the Korean stock market occurred on March 19, 2020, with the KOSDAQ market showing a bigger decline than the KOSPI market. Furthermore, when comparing the indices by size, KOSDAQ's small-cap index exhibited the largest decline, dropping by 13.98%. The day with the largest increase varied across the indices, occurring after March 19, 2020. When comparing the magnitudes of the changes, KOSPI, KOSPI's large-cap index, and KOSDAQ's large-cap index exhibit greater changes on the days with the greatest increases compared to the days with the greatest decreases. Conversely, KOSPI's mid-cap and small-cap index, as well as KOSDAQ's mid-cap index and small-cap index, experience larger decreases than increases.

Table1: The highest (lowest) volatility day from January 2018 to December 2021

	Lowest day				Highest day			
	date	previous close	close	daily change (%)	date	previous Close	close	daily change (%)
KOSPI	20200319	1,591.20	1,457.64	-8.39	20200324	1,482.46	1,609.97	**8.60**
KOSPI Large-cap	20200319	1,590.36	1,467.96	-7.70	20200324	1,496.41	1,630.87	**8.99**
KOSPI Middle-cap	20200319	1,528.29	1,346.10	**-11.92**	20200320	1,346.10	1,449.20	7.66
KOSPI Small-cap	20200319	1,244.87	1,081.17	**-13.15**	20200325	1,144.05	1,214.03	6.12
KOSDAQ	20200319	485.14	428.35	**-11.71**	20200320	428.35	467.75	9.20
KOSDAQ Large-cap	20200319	1,038.69	939.40	-9.56	20200320	939.40	1,037.98	**10.49**
KOSDAQ Middle-cap	20200319	441.86	383.57	**-13.19**	20200320	383.57	418.77	9.18
KOSDAQ Small-cap	20200319	1,594.91	1,371.87	**-13.98**	20200320	1,371.87	1,466.83	6.92

This study is organized as follows: Following Chapter 1, Chapter 2 describes the market capitalization-based index data used in the study, followed by the methodology of Diebold and Yilmaz (2012) on the volatility spillover index to analyze stock market connectivity. Chapter 3 presents the empirical results of the impact of COVID-19 on the connectivity of the Korean financial market, focusing on the index by firm size, and the robustness analysis through sample drift analysis. Finally, Chapter 4 discusses the conclusions and limitations of this study.

2. Data and Methodology

2.1. Data

The data were collected for indices from the Fnguide database. Six indices were used by market capitalization size of KOSPI and KOSDAQ markets, which represent the Korean stock market. The index by market capitalization in KOSPI market consists of the large-cap stocks ranked 1st to 100th, mid-cap stocks 101st to 300th, and small-cap stocks in order of largest market capitalization among companies in KOSPI market. The index by market capitalization of KOSDAQ market also consists of three indices by market capitalization and the number of constituent stocks in the mid-cap stock index ranges from 101st to 400th, with 100 more stocks than KOSPI mid-cap stock index. Stocks included in the index are regularly changed twice a year. The sample period ranges from January 25, 2018, to December 31, 2021, and is divided into two subperiod. The subperiod is divided based on January 20, 2020, when the first confirmed case of COVID-19 is reported in Korea. The first subperiod (before COVID-19) is from January 25, 2018, to January 19, 2020 and the second subperiod (after COVID-19 outbreak) is from January 20, 2020 to December 31, 2021.
The index's volatility was measured using the high (H) and low (L) values of the daily index data collected as follows.

$$\widehat{\sigma} = \sqrt{0.361(\log(H_t) - \log(L_t))^2} \quad (1)$$

Table 2 presents summary statistics for pre-COVID-19 (Panel A) and post-COVID-19 (Panel B). It appears that the KOSDAQ has greater volatility than the KOSPI. Volatility has increased after COVID-19 outbreak regardless of the market. The smaller firms in the KOSPI have higher volatility, while larger firms in the KOSDAQ have higher volatility. Interestingly, this pattern is consistent across both before and after COVID-19 outbreak periods. The minimum value of volatility is higher for large-sized firms, while the maximum value of volatility is higher for small-sized firms.
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Table 2: Summary statistics of daily six size-based indices' volatility (%)

Panel A. Before COVID19 outbreak								
	Min.	Median	Mean	Max.	Std.	Skew.	Kurt.	No.
KOSPI large-cap	0.2434	0.5794	0.6305	2.1250	0.2580	1.5448	6.9531	484
KOSPI mid-cap	0.2040	0.5812	0.6721	2.8408	0.3826	2.2735	10.3598	484
KOSPI small-cap	0.1744	0.5268	0.6732	3.9423	0.4851	2.5808	12.2269	484
KOSDAQ large-cap	0.3065	1.0194	1.1689	4.7751	0.5927	1.9173	8.5778	484
KOSDAQ mid-cap	0.2357	0.7295	0.8879	4.5503	0.5697	2.6095	13.3889	484
KOSDAQ small-cap	0.1564	0.5994	0.7714	5.4441	0.6019	3.0712	17.2288	484
Panel B. After COVID19 outbreak								
KOSPI large-cap	0.2886	0.7906	0.9540	7.1531	0.6445	3.6657	25.7224	484
KOSPI mid-cap	0.1777	0.7776	0.9553	9.1073	0.7260	4.4809	39.3078	484
KOSPI small-cap	0.1698	0.6701	0.8895	9.8500	0.7739	4.8224	44.3353	484
KOSDAQ large-cap	0.3121	1.0157	1.2435	10.0531	0.8516	4.0208	31.6534	484
KOSDAQ mid-cap	0.2394	0.8436	1.1073	11.8953	0.9644	4.5543	39.5912	484
KOSDAQ small-cap	0.1917	0.7233	1.0046	11.0725	0.9350	4.5260	37.5905	484

Table 3 shows the correlation matrix. The lower diagonal of the matrix represents the value of the correlation coefficient, while the upper diagonal of the matrix represents the P-value of the correlation coefficient. The correlation coefficient values are positive and significant at the 1% level. In the pre-COVID-19 period, larger indices tend to have relatively lower correlation coefficients with other indices. The highest correlation coefficients are between the small-cap KOSPI and KOSDAQ indices, which have the lowest market capitalization. Both markets have high correlations between mid-cap and small-cap stocks. As mentioned earlier, COVID-19 outbreak has caused an increase in correlations between indices, as does an increase in average volatility.

Table 3. Correlation Matrix Of Daily Six Size-based Indices' Volatility

Panel A. Before COVID19 outbreak						
	KOSPI large-cap	KOSPI mid-cap	KOSPI small-cap	KOSDAQ large-cap	KOSDAQ mid-cap	KOSDAQ small-cap
KOSPI large-cap	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000
KOSPI mid-cap	0.6237	1.0000	0.0000	0.0000	0.0000	0.0000
KOSPI small-cap	0.4922	0.8476	1.0000	0.0000	0.0000	0.0000
KOSDAQ large-cap	0.4944	0.6505	0.6843	1.0000	0.0000	0.0000
KOSDAQ mid-cap	0.5502	0.8098	0.8841	0.7998	1.0000	0.0000
KOSDAQ small-cap	0.5069	0.8133	0.9467	0.7091	0.9376	1.0000
Panel B. After COVID19 outbreak						
KOSPI large-cap	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000
KOSPI mid-cap	0.8674	1.0000	0.0000	0.0000	0.0000	0.0000
KOSPI	0.8174	0.9355	1.0000	0.0000	0.0000	0.0000

small-cap						
KOSDAQ large-cap	0.8394	0.8709	0.8726	1.0000	0.0000	0.0000
KOSDAQ mid-cap	0.8418	0.9149	0.9500	0.9256	1.0000	0.0000
KOSDAQ small-cap	0.8032	0.9084	0.9719	0.8833	0.9677	1.0000

2.2. Methodology

To obtain the impulse responses from each index to all other indices and define the volatility spillover matrix, the framework described by Diebold and Yilmaz (2012) was followed.
To measure the forecast error variance in the VAR model, a covariance stationary N-variable VAR (p) was considered then divided by the forecast error variance decomposition matrix as follows:

$$\theta_{ij}^{G}(H) = \frac{\theta_{ij}^{ij} \sum_{h=0}^{H-1} \left(e'_{ij} A_h \, \Sigma \, e_j\right)^2}{\sum_{h=0}^{H-1} \left(e'_{ij} A_h \, \Sigma A_h \, e_j\right)} \quad (2)$$

To obtain pairwise directional connectedness from index j to index i, Diebold and Yilmaz (2012) used the following method. Each entry of the generalized variance decomposition matrix was normalized by the row sum. This normalization procedure ensures that the sum of connectedness from index j to all other indices is equal to unity, which facilitates the interpretation of pairwise connectedness measures as the relative importance of shocks from index j to index i.

$$\widetilde{\theta_{i,j}^{g}}(H) = \frac{\theta_{ij}^{G}(H)}{\sum_{j=1}^{N} \theta_{ij}^{G}(H)} \quad (3)$$

Table 4 presents the volatility spillover matrix. The last row represents the TO spillover, while the last column represents the FROM spillover. The intersection of the last row and the last column represents the Total Spillover (TSI).

Table 4: Volatility spillover index's matrix

	x_1	x_2	$\cdots$	x_5	x_6	SP_i
x_1	$\widetilde{\theta}_{11}$	$\widetilde{\theta}_{12}$	$\cdots$	$\widetilde{\theta}_{15}$	$\widetilde{\theta}_{16}$	$\sum_{j=1, j\neq 1}^{n} \widetilde{\theta}_{1j}$
x_2	$\widetilde{\theta}_{21}$	$\widetilde{\theta}_{22}$	$\cdots$	$\widetilde{\theta}_{25}$	$\widetilde{\theta}_{26}$	$\sum_{j=1, j\neq 2}^{n} \widetilde{\theta}_{2j}$
$\vdots$	$\vdots$	$\vdots$	$\ddots$	$\vdots$	$\vdots$	$\vdots$
x_5	$\widetilde{\theta}_{51}$	$\widetilde{\theta}_{52}$	$\cdots$	$\widetilde{\theta}_{55}$	$\widetilde{\theta}_{56}$	$\sum_{j=1, j\neq n-1}^{n} \widetilde{\theta}_{5j}$
x_6	$\widetilde{\theta}_{61}$	$\widetilde{\theta}_{62}$	$\cdots$	$\widetilde{\theta}_{65}$	$\widetilde{\theta}_{66}$	$\sum_{j=1, j\neq n}^{n} \widetilde{\theta}_{nj}$
SP_i^{TO}	$\sum_{i=1, i\neq 1}^{n} \widetilde{\theta}_{i1}$	$\sum_{i=1, i\neq 2}^{n} \widetilde{\theta}_{i2}$		$\sum_{i=1, i\neq 5}^{n} \widetilde{\theta}_{i5}$	$\sum_{i=1, i\neq n}^{n} \widetilde{\theta}_{in}$	TSI $= \frac{1}{n} \sum_{i,j=1, i\neq j}^{n} \widetilde{\theta}_{ij}$

Notes: This table presents the six-variable of the volatility spillover. TO volatility spillover is shown in the last row and is calculated by summing the values in the column for that variable minus its own effect. FROM volatility spillover appears in the last column and is calculated by summing the values in the row of *the variable minus its own effect. TOTAL volatility spillover (TSI) is the sum of all TO volatility spillover (or FROM volatility spillover) divided by the number of variables (n=6).*

TO volatility spillover, SP_i^{TO} (also referred to as "TO spillover"), can be used to calculate the directional volatility spillovers transmitted by market i to all other markets j (i ≠ j) as follows:

(4) $$SP_i^{TO} = \sum \tilde{\theta}^{G}_{ji,s}(H) \times 100$$

FROM volatility spillover, SP_i^{FROM} (also referred to as "FROM spillover"), the directional volatility spillovers received by market i from all other markets j (i ≠ j) can be calculated as follows:

(5) $$SP_i^{FROM} = \sum \tilde{\theta}^{G}_{ij,s}(H) \times 100$$

The net spillover index, NET (also referred to as "NET spillover") can be obtained by calculating the difference between Equations (3) and (4), as follows:

(6) $$NET_i = SP_i^{to} - SP_i^{from}$$

Lastly, a total volatility spillover index (TSI) can be obtained by summing up the directional spillovers received by each market from all other markets, as well as the directional spillovers transmitted by each market to all other markets.

(7) $$TSI\ (H) = \frac{{}_{i \neq j}}{\sum^{N} \tilde{\theta}^{G}(H)} \times 100$$

3. Empirical Results

Table 5 presents the results of measuring the volatility spillover effect. TO spillover effect is stronger for KOSDAQ mid-cap, KOSDAQ small-cap, KOSPI small-cap, KOSPI mid-cap, KOSDAQ large-cap, and KOSPI large-cap. In other words, the volatility outflow spillover effect is stronger for the KOSDAQ than for the KOSPI, especially for small and mid-cap stocks than for large-cap stocks. The same pattern is observed for the volatility inflow spillover effect.

Table 5 also shows that COVID-19 outbreak has increases the total volatility spillover effect by 7.9%, from 71.1% to 79%. In other words, the outbreak of COVID-19 increases the linkage between stock markets, and it can be seen that the amount of information between the markets increases, resulting in synchronization between the indexes. These results are consistent with the previous literature's suggestion that events such as COVID-19 increase the interconnectedness of financial markets.

This study is unique in that it also provides information on the strength and direction of interdependence. The results for complex directional spillovers and net spillovers can be seen more intuitively in Fig. 4.

Table 5: Volatility spillover effect before and after COVID-19 outbreak

Panel A. Before COVID19 outbreak (TSP = 71.1%)							
	KOSPI large-cap	KOSPI mid-cap	KOSPI small-cap	KOSDAQ large-cap	KOSDAQ mid-cap	KOSDAQ small-cap	FROM spillover
KOSPI large-cap	40.1	16.9	10.0	9.0	13.4	10.7	59.9
KOSPI mid-cap	7.6	26.5	19.5	10.1	18.6	17.7	73.5
KOSPI small-cap	3.7	17.2	25.8	10.1	20.5	22.7	74.2
KOSDAQ large-cap	5.5	13.0	14.4	30.5	21.1	15.5	69.5
KOSDAQ mid-cap	4.9	14.9	18.9	14.1	25.8	21.4	74.2
KOSDAQ small-cap	3.9	15.2	22.4	10.6	22.9	25.0	75.0
To spillover	25.6	77.3	85.2	54.0	96.5	87.9	426.3
NET spillover	-34.3	3.8	11.0	-15.5	22.3	12.9	-
Panel B. After COVID19 outbreak (TSP = 79.0%)							
KOSPI large-cap	25.0	15.0	13.6	16.2	15.7	14.5	75.0
KOSPI mid-cap	15.3	19.4	16.6	15.2	17.1	16.5	80.6
KOSPI small-cap	13.0	16.6	19.1	14.5	18.0	18.8	80.9
KOSDAQ large-cap	14.2	14.1	14.8	22.1	18.2	16.6	77.9
KOSDAQ mid-cap	13.3	14.9	16.6	16.5	20.0	18.7	80.0
KOSDAQ small-cap	12.4	15.3	18.0	15.0	19.0	20.3	79.7
To spillover	68.2	75.9	79.6	77.4	87.9	85.1	474.1
NET spillover	-6.8	-4.7	-1.3	-0.5	7.9	5.4	-

Fig. 4 presents the results regarding directional spillovers and net spillovers as measured in Table 5. The first row displays the TO spillovers, which indicate the impact of each index on other indices, while the middle row shows the FROM spillovers, which indicate the impact of other indices on each index. The last row provides the net spillover effects for each market.

It is found that in the KOSPI, the TO spillover effect is higher in the small-cap, mid-cap, and large-cap indices, while in the KOSDAQ, the TO spillover is higher in the mid-cap, small-cap, and the large-cap indices. Furthermore, it is confirmed that in both markets, the FROM spillover effect is significantly higher in the small-cap, mid-cap, and large-cap indices. Finally, the size effect shows that the large-cap indices exhibit a negative (-) size effect, while mid-cap and small-cap indices show a positive (+) size effect.

The outbreak of COVID-19 has increased the spillover of mid-cap companies in the KOSDAQ, the large-cap companies in KOSDAQ, and mid-cap companies in KOSPI market the most. This study confirms that the increase in spillover effects is mainly that this increase in spillover effects is mainly due to a higher level of TO spillover compared to FROM spillover. In contrast, it is found that the net effects of small-sized companies in both the KOSPI and KOSDAQ markets decrease.

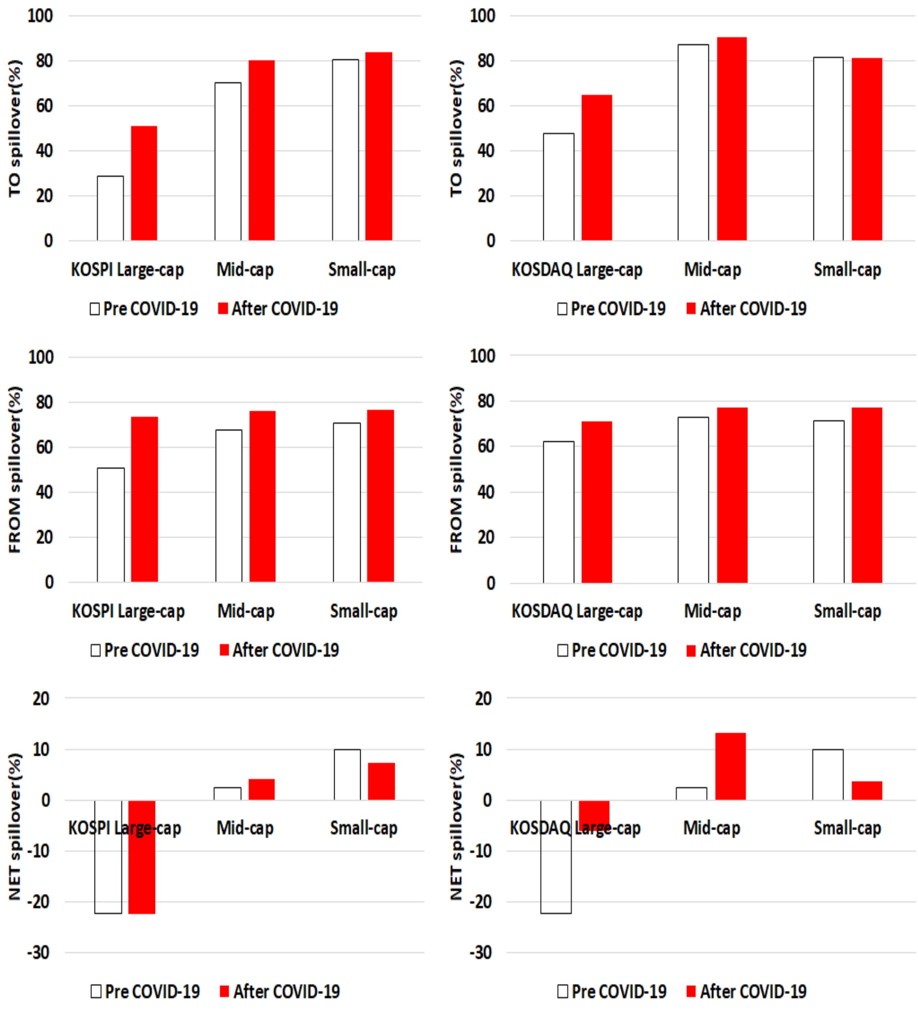

Fig. 4: TO, FROM, and NET spillover before and after COVID-19 outbreak

**Note: This figure shows the results in Table 5. This table shows the results of measuring the net spillovers. TO spillover denotes the direction spillovers to others, and From spillover denotes the direction spillovers from others. Net spillover is calculated by subtracting FROM spillover from TO spillover.*

Previous studies have suggested that the results of volatility spillover analysis can vary depending on the analysis method and sample period. Therefore, rolling sample analysis was employed in this study, specifically rolling window analysis, to enhance the robustness of the results. To conduct the rolling sample analysis, the weekly volatility was measured and a window size of 52-weeks was used to measure the volatility spillover index for each week, with the window moving one week at a time. The results of the total volatility spillover index are presented in Figure 5 and the net directional spillover effects of six indices in Fig. 6. Some interesting empirical results and important insights from the robustness test was obtained. The total spillover of COVID-19, which occurred in Wuhan, China at the end of 2019, did not appear to have a significant impact and rather showed a decreasing trend in Fig. 5. Meanwhile, the total spillover has increased since the first COVID-19 confirmed case was reported which date on January 20, 2020, and since March 11, 2020, the volatility spillover index exceeds 80%. In other words, an increase in market volatility and connectivity increases the total transfer effect. The period includes a period when the market plunges and a period when the market rebounds in a V-shape. The volatility spillover index maintained a high level of 80% or more from early 2020 to early 2021. The volatility spillover index drops below 80% in early 2021 as the COVID-19 vaccine is developed and distributed in Korea at the end of 2020. The volatility spillover index can be seen to represent the time-varying information transfer effect well, and it reaffirms that the outbreak of COVID-19 has increased the effect of volatility spillover between markets.

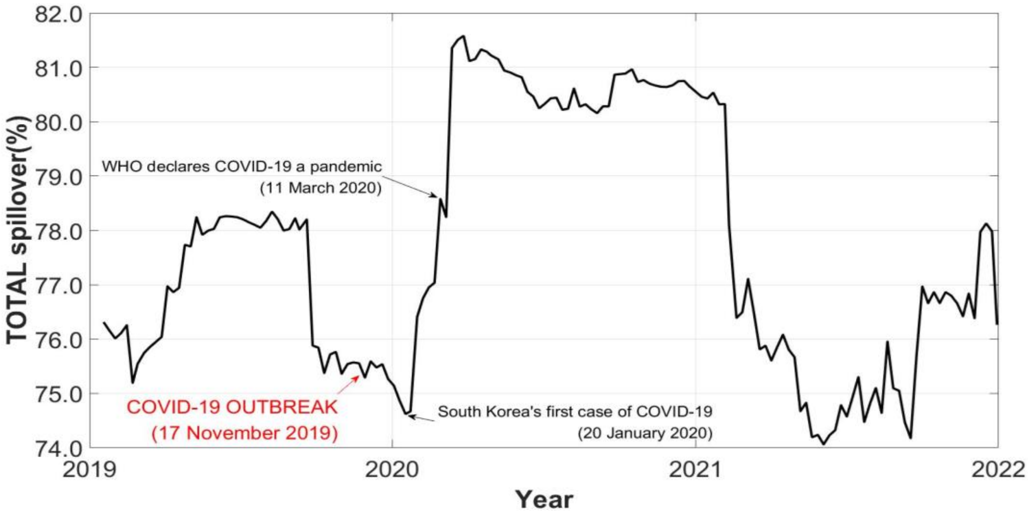

Fig. 5: Rolling sample analysis: TOTAL volatility spillover effect

**Note: This table shows the results of the rolling sample analysis from January 2018 to December 2021. Volatility measures weekly volatility, and the sample window is 52 weeks.*

Fig. 6 shows the results of the net spillover effect through a 52-week sample moving average analysis. KOSPI small-cap, KOSDAQ mid-cap, and small-cap index have a positive (+) net spillover effect, and that KOSPI large-cap index and KOSDAQ large-cap index have a negative (-) net spillover effect, and that the net spillover is consistent regardless of time. On the other hand, KOSPI mid-cap index shows a negative (-) net spillover effect just before the outbreak of COVID-19 and a positive (+) net spillover effect after the outbreak of COVID-19.

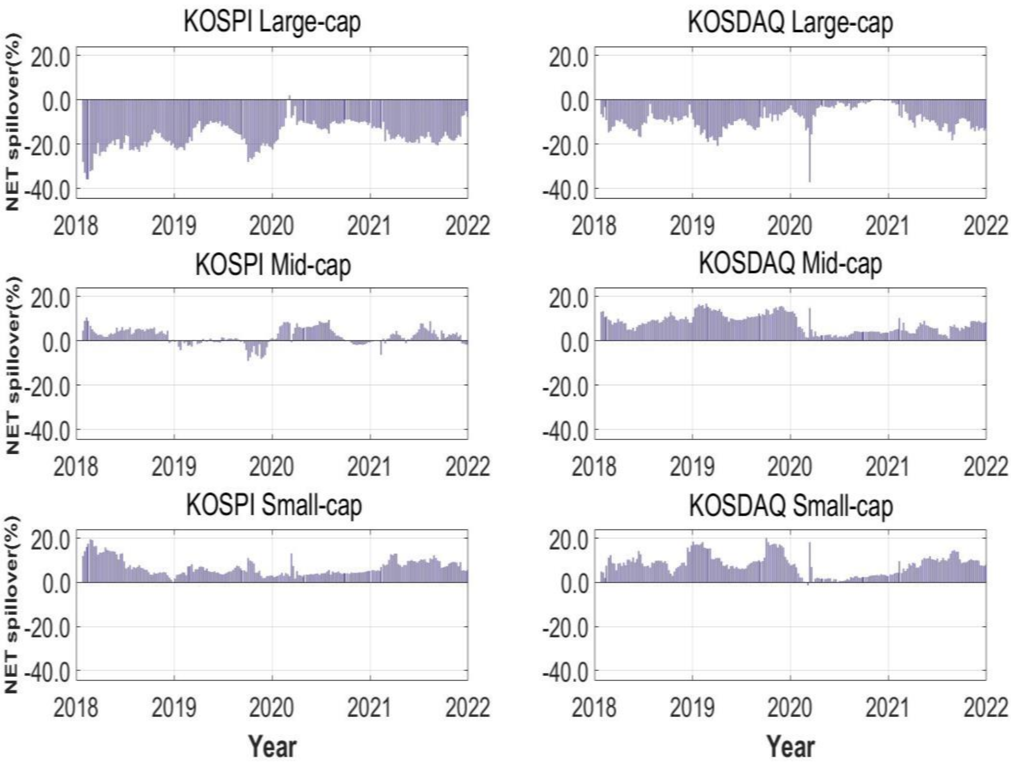

Fig. 6: Rolling sample analysis: NET Spillover Effect by firm size

**Note: This table shows the results of the moving sample analysis for the net spillover effect. The results are presented in order of large, medium, and small scale by size. Volatility measures weekly volatility, and the sample window is 52 weeks.*

4. Conclusions

This study aims to analyse the connectivity size indices in the Korean stock market. This study analyses the stock market linkage was analysed by measuring the volatility spillover index between the returns of six indices in the Korean stock market. The impact of COVID-19 on the connectivity of the Korean stock market was confirmed by comparing the information spillover effect in the period before and after COVID-19.

The results indicate that the COVID-19 has increased the linkage between stock markets, resulting in synchronization between indices. The volatility spillover index provides information on the strength and direction of interdependence between markets, with mid-cap companies in KOSDAQ market and the large-cap companies in the KOSPI market showing the most significant increase in spillover effects. The net spillover effects of small-sized companies in both markets have decreased. The study also revealed that the volatility spillover index remained high throughout 2020 and early 2021, indicating that COVID-19 outbreak increased the effect of volatility spillover between markets. Finally, the net spillover effect analysis shows that KOSPI large stocks became dependent, while KOSPI midcap index became a leading market during and after the COVID-19 period. This study contributes to the literature on the interconnectedness of stock markets during significant events such as COVID-19 and provides insights into the volatility spillover effects in KOSPI and KOSDAQ markets.

The increased linkage between financial markets due to COVID-19 outbreak has significant implications for portfolio management and investment strategies. The findings of this study suggest that investors need to consider the interdependence between markets when constructing portfolios. The volatility spillover index provides valuable information for portfolio diversification and risk management, particularly during times of market stress. The results show that companies in the KOSDAQ market are more sensitive to the volatility spillover effects, indicating that investors should pay closer attention to these sectors. Additionally, the net spillovers of mid and large-cap stocks in KOSDAQ market increase, suggesting that these firms may be strongly affected by market contagion. Portfolio managers may consider adjusting their investment strategies to account for the increased linkage between markets, such as incorporating more diverse assets to reduce risk exposure. The results also suggest that investors may consider reducing large and mid-cap stocks in KOSDAQ market to capitalize on the higher sensitivity to the volatility spillovers. Furthermore, the net spillover effect analysis highlights the shifting dynamics of the markets during and after the COVID-19 period, which may provide valuable insights for investors seeking to capitalize on new trends. Overall, this study suggests that investors need to carefully consider the interdependence between markets and incorporate these dynamics into their investment strategies to maximize returns and manage risks effectively.

Also, these findings suggest that policymakers need to pay closer attention to system-wide risks and incorporate these dynamics into their risk management frameworks. The increased interdependence between markets during times of market stress may amplify the transmission of risks and increase the likelihood of systemic risk events. Therefore, it is essential for policymakers to consider the interconnectedness of financial markets and the potential for contagion effects when designing regulatory and supervisory policies. Regulators may consider implementing macroprudential policies that aim to reduce systemic risk by addressing the risks arising from market interconnections. Additionally, policymakers may consider enhancing the transparency and disclosure of financial institutions' interconnectedness and risk exposures to better understand the potential contagion risks. Overall, this study highlights the importance of considering the increased linkage between financial markets and the higher volatility spillover effects during significant events such as COVID-19. Policymakers need to incorporate these dynamics into their risk management frameworks to mitigate system-wide risks effectively and maintain the stability of the financial system.

There are several limitations to this study that need to be addressed in future research. First this study only considers KOSDAQ and KOSPI markets in South Korea, which may limit the generalizability of the findings to other markets. Future studies may consider examining the linkage between financial markets in other countries to provide more comprehensive insights into the interconnectedness of global financial markets. Second, this study only examines the volatility spillover effects during the COVID-19 period, and future studies may consider examining the volatility spillover effects during other significant events or periods of market stress. Third, this study only considers the net spillover effect of different-sized companies in KOSDAQ and KOSPI markets, and future studies may consider examining the spillover effects of other factors such as industry sectors or macroeconomic indicators. Finally, this study does not consider the impact of other potential factors that may affect the linkage between financial markets, such as political events or changes in regulatory policies.

In light of these limitations, future research could focus on developing more sophisticated models that reflect the market interdependence and the spillover and consider the impact of different policy interventions on market interdependence and volatility spillover effects to inform the development of more effective risk management frameworks.

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6. References

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