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Co-Movement of Covid-19, The S&P 500 and Stock Markets in ASEAN: A Wavelet Coherence Analysis

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ABSTRACT

This study examined the co-movement of ASEAN stock markets, COVID-19 cases/deaths, and the United States (US) stock market using wavelet coherence analysis. The findings revealed that the US stock market remained significantly dominant and was more influential to the ASEAN market. Nevertheless, coherence between the ASEAN stock markets and COVID-19 cases/deaths were also found but was limited during the crisis, and the impact of the number of deaths was lower than the number of cases. The results presented a significant disparity in the co-movements of each country. Such a phenomenon is expected as individual countries' economies tend to be more divergent during crises. Through wavelet analysis, the irregularity and uncertainty of co-movements can be detected more clearly and accurately with the interpretation of a heatmap.

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INTRODUCTION

The novel nature of the SARS-CoV-2 (severe acute respiratory syndrome coronavirus 2) was confirmed by the World Health Organisation (WHO) on 9th January 2020. It has since become better known as coronavirus disease or COVID-19. COVID-19 was first discovered in three people with pneumonia related to a cluster of acute respiratory illness cases on 31st December 2019 in Wuhan, China. By 30th January 2020, the WHO proclaimed the outbreak a Public Health Emergency of International Concern (PHEIC), which served as an acute alert that the virus could potentially threaten humans worldwide and across geographical borders (Wilder-Smith and Osman, 2020). In Southeast Asia, Thailand was the first country other than China to report a positive test of COVID-19 on 13th January 2020, while the Philippines reported the first death outside of China.

COVID-19 entered Southeast Asia earlier than the rest of the world. Due to this situation, ASEAN governments executed quick containment responses by alerting the public about the pandemic. ASEAN governments implemented strict control measures, such as human movement restrictions, halting international travel, lockdowns, shutdowns, mass testing, and social distancing. These international and domestic policies have curbed the surge of COVID-19 cases and resulted in unprecedented disruptions, such as; reduced economic transactions, production delays in goods and services, drops in exports, and mismanagement of finances.

According to the World Bank (2021), COVID-19 has caused major disruptions in the global economy. Investments have been hindered by the uncertain nature of the post-pandemic landscape and government policies; human capital accumulation occurred due to education disruption; concerns about the ability of the global value chain and the course of the COVID-19 pandemic disordered tourism and trade. The emerging market like ASEAN economies were not spared from the financial turmoil, followed by the bearish global economic outlook due to the pandemic. Hence, the intention of this paper is to address the research question whether the COVID-19 or leading equity indexes, particularly, S&P 500 have moved the ASEAN equity market.

Many researchers have studied the influence of the COVID-19 pandemic on stock markets using various methods; however, most of the studies were conducted over a relatively brief period (Kamaludin et al., 2021). Little research has been conducted on the interaction between pandemic diseases and ASEAN stock performance. Furthermore, only limited research has been conducted on the impact of COVID-19 deaths, particularly in the ASEAN region. The economic and mortality impact of the COVID-19 pandemic has been widely discussed in media; however, more systemic evidence is needed to show their relationship.

By applying wavelet analysis, this paper answers the research question above through the co-movement of ASEAN stock markets with the number of COVID-19 cases/deaths and the S&P 500. In this paper, US financial market is studied as it is one of the main causes of a spillover effect to other markets and regions, as supported by Wongbangpo and Sharma (2002), Royfaizal et al. (2009), Caporale et al. (2022), among others. The wavelet technique, partial coherence, used is able to help identify the co-movement between ASEAN market and COVID-19/S&P 500 by partialling out the effect of other two common dependences. Thus, US stock market is also examined simultaneously with the COVID-19 pandemic.

Compared with previous literature, this paper has deepened the study of the COVID-19 pandemic and ASEAN stock markets by including COVID-19 deaths, longer sampling duration, wavelet methodology and Vietnam which was less studied as compare to ASEAN-5 in the context of COVID-19. Our findings are important to contribute insight on the ASEAN equity markets' responses during the pandemic risk through novel approach that captures both time and frequency dimensions.

Accordingly, this study comprises five sections. The introduction is followed by a literature review of related research studies. Next, the research methodology and data sources are discussed. The results are then discussed, followed by the study's conclusion.

LITERATURE REVIEW

COVID-19 and Stock Markets

In comparison with COVID-19, previous pandemics, such as; Bird Flu (H5N1), Swine Flu (H1N1), SARS, Ebola, and MERS, only left mild traces on the US stock market (Baker et al., 2020). Moreover, COVID-19 cases have amplified market volatility globally and in the US (Albulescu, 2021). Subsequently, stock markets from developed countries (Germany, Italy, Japan, Korea, Singapore, United Kingdom (UK), and the USA) showed tremendous drops after the outbreak (Liu et al., 2020), and the negative influence was short term (He et al., 2020). The stock market performances of African countries dropped significantly from -2.7% to -20% after the outbreak of COVID-19 (Takyi and Bentum-Ennin, 2020).

Al-Awadhi et al. (2020) showed that the total confirmed cases and deaths had a significant adverse impact on the composite stocks of the Hang Seng Index (HIS) and Shanghai Stock Exchange Composite Index (SSE Composite). After the Wuhan lockdown, significant negative cumulative abnormal returns were identified in 18 out of 21 tourism shares on Chinese stock exchanges (Liew, 2020). On the other hand, both non-financial and financial companies from China and the G7 countries experienced a significant surge in conditional correlations amongst their stock returns during the pandemic period. Stock markets and the service-oriented economy were significantly influenced by the COVID-19 pandemic (Baker et al., 2020). The increase in COVID-19 cases/deaths was reported to have caused powerful surges in market volatility and illiquidity. The stock market responded more aggressively to increases in COVID-9 cases than deaths. During the pandemic, investors sought safer commodities, such as gold, with less volatility (Ali et al., 2020).

Aftab et al. (2021) discovered that small and medium-sized enterprises (SMEs) encountered negative implications from the COVID-19 pandemic in the forms of; shortages of goods, transportation limitations, reductions in demand for products and services, decreased profits and sales, operational blockages, lockdowns, and employee reductions. The threat exposure of the COVID-19 pandemic to SMEs has been greater than to large firms (Utit et al., 2021). Okorie and Lin (2021) found that the COVID-19 outbreaks in Russia and India affected stock market information efficiency. The reduced market inefficiency implied that the returns and prices of stocks were less forecastable and predictable with the available data.

In the ASEAN context, the number of COVID-19 cases in Malaysia had a significant but minimal impact on the Kuala Lumpur Composite Index (KLCI). In contrast, the number of deaths had no significant impact (Chia et al., 2020). Furthermore, COVID-19 cases had a minimal and short-term negative impact on the Philippine Stock Exchange Index (PSEi) but only negligible long-term effects. (Camba and Camba Jr., 2020). Similarly, Gongkhonkwa (2021) mentioned that COVID-19 cases and deaths had a significant short-term influence on the trading value set by types of investors.

Nevertheless, Indrastuti (2021) discovered that the number of COVID-19 cases and deaths did not significantly influence the Jakarta Composite Index (JCI). However, the Indonesian index reacted positively to increased COVID-19 recoveries. Gongkhonkwa (2021) found that COVID-19 cases and deaths had a significant short-term influence on the trading value set by types of investors. In contrast with the ASEAN-5, the Vietnam Stock Index (VNI) performed in the opposing direction throughout the nationwide lockdown (Anh and Gan, 2020).

US and ASEAN Markets

The ASEAN-5 stock markets are integrated economically; however, the integration has been far from comprehensive (Click and Plummer, 2005). The stock markets in the ASEAN-5 countries have experienced long- and short-term relationships with macroeconomic variables. Additionally, they have been caused or were caused by equity prices or exchange rates (Wongbangpo and Sharma, 2002; Wong, 2017, 2018, 2019). Yang and Hamori (2014) discovered that ASEAN stock markets were only affected by the spillover effects from US monetary policy over tranquil periods. The US market has significantly driven the market performance of all ASEAN-5 countries. Singapore and Indonesia have been diverging markets, whereas Malaysia, the Philippines, and Thailand converged towards the group median. Indonesia has had a long-run co-integrating relationship with the US market (Lim, 2009).

It is believed that the US stock market has influenced Asian stock markets via; risk appetite channels, portfolio rebalancing and funding costs. In contrast, China has exerted its influence through trade linkages (Glick and Hutchison, 2013). Additionally, stock indices from ASEAN, the US, and China exhibited long-

range dependencies between 2002 and 2020 (Caporale et al., 2022). An interdependency regression was found between the US stock markets and ASEAN-5+3 (Korea, Japan and China) during the crisis and post-crisis periods (Royfaizal et al., 2009). In a different circumstance, the US showed a single directional volatility spillover to Thailand, Taiwan, Singapore, Japan, the Philippines, Malaysia, Hong Kong, and Korea during the US subprime credit crisis and the Asian currency crisis (Lien et al., 2018).

Tan and Tse (2002) identified market tightness between Malaysia and Singapore. Changes in the US economic policy's uncertainty negatively affected the returns on the ASEAN-5 stock markets (especially Malaysia and Singapore) from 1985 to 2012. Nevertheless, Tan and Tse (2002) discovered Malaysia was an outlier. Between 1988 and 2000, they claimed that Japan and the US influenced Malaysia less after the economic crunch.

RESEARCH METHODOLOGY

The data used in this study comprised COVID-19 cases/deaths and stock exchange indices for; Malaysia, Indonesia, the Philippines, Thailand, Singapore, and Vietnam. The analysis in the research was conducted using a daily dataset from 30th January 2020 to 30th January 2021. The dataset of stock exchange indices for the sampled ASEAN countries and the S&P 500 were extracted from "Investing.com" (https://www.investing.com) and "Yahoo! Finance" (https://finance.yahoo.com). In contrast, data concerning COVID-19 cases/deaths were sourced from the WHO and Our World in Data. The information from Our World in Data relied on data from John Hopkins University (JHU), which publishes updates on confirmed COVID-19 cases/deaths for all countries. A confirmed case/death was defined as a person with laboratory confirmation of a COVID-19 infection, irrespective of clinical signs and symptoms (WHO, 2020). The dataset of non-trading days was omitted from the sample period.

Continuous Wavelet Transformation and Wavelet Coherence

The relationship between the variables stated can be encircled across time scales with the refined wavelet coherence methodology. The Morlet wavelet technique (Goupillaud et al., 1984) was employed in this study as the mother wavelet ψ, as suggested by Soares (2011), Barunik (2011), and Aguiar-Conraria et al. (2018).

The complex-valued function Morlet wavelet is expressed as:

$$\psi(t) = \frac{1}{\pi^{1/4}} e^{i\omega_0 t} e^{-\frac{t^2}{2}} \quad (1)$$

where the central frequency of the wavelet is denoted as ω_0. In this study, $\omega_0 = 6$ was used as it is the most frequently used setting in econometric applications (Aguiar-Conraria et al., 2008). The Morlet wavelet is complicated and analytical in a Gaussian envelope with excellent localisation in the time-frequency domain. Because of its real and imaginary properties, the wavelet can analyse both the amplitude and phase (Barunik, 2011).

Barunik (2011) mentioned that the Morlet wavelet is centred at the point $(0, \frac{\omega_0}{2\pi})$ in a time-frequency domain, i.e., for ω_0= 6, the frequency centre is obtained as $\mu_f = \frac{6}{2\pi} \approx 1$. The frequency-scale correlation can be written as below (Aguiar-Conraria et al., 2008):

$$f = \frac{\mu_f}{s} \approx \frac{1}{s} \quad (2)$$

Therefore, for the central frequency ω_0= 6, the wavelet scale s and the corresponding Fourier period are likely the same (Barunik, 2011). A windowing technique can be represented by a wavelet transform with variable-sized regions. Wavelet analysis can provide information despite applying shorter time intervals at high-frequency and longer time intervals at low frequency (Craigmile and Percival, 2006).

Compared with Discrete Wavelet Transformation (DWT), CWT can calculate wavelet coefficients at every possible scale and transpose them (Merry and Steinbuch, 2005). CWT can examine the signal at different resolutions with different frequencies by applying Multi-resolution Analysis (MRA). The multi-

resolution time-frequency plane can break down the signal into different resolutions. Therefore, CWT was applied, determined by the convolution of the wavelet function and signal between the stock market and other independent variables. CWT can trace the transitional changes of economic data across time and frequencies regardless of nonlinear relations, strongly nonstationary, and at numerous times noisy.

The CWT of a time series $x(t)$ is the function of two variables, $W_x(t,s)$ concerning a given wavelet ψ, is shown as:

$$W_x(t,s) = \frac{1}{\sqrt{|s|}}\int_{-\infty}^{\infty} x(t)\bar{\psi}\ (\frac{t-T}{s})dt \tag{3}$$

where the length of the wavelet is governed by s, the scaling factor (also referred to as the daughter wavelet), whereas t is a translation parameter adjusting the wavelet location in time. $T \in \Re$ is a location parameter, and $s \neq 0$ is a scale smoothing parameter. In other words, they respectively control the location and the width along the function $\psi(\frac{t-T}{s})$ of the t-axis. Scaling is either compressing a wavelet for $|s| < 1$ or dilating a wavelet for $|s| > 1$. In addition, translation means shifting a wavelet's position in time. The over-bar at wavelet, $\bar{\psi}$ Denotes a complex conjugate, which combines equal real and imaginary parts.

In the circumstance of two time series, cross-wavelet transformation (XWT or wavelet coherence) will be shown by the WTC of each time series to measure the correlation in the time-frequency domain. Any change can be observed in the restrained variances through the cross-wavelet spectra, which will identify a particular location of the significance of co-movement between the two time series. The XWT method developed by Goupillaud et al. (1984) was applied for the wavelet coherence transformation of two time series x and y, and it is expressed as:

$$W_{xy}(\tau,s) = W_x(\tau,s)\ W_y^*(\tau,s) \tag{4}$$

where $W_x(\tau,s)$ and $W_y^*(\tau,s)$ are defined in (3), and the * denotes the complex conjugate form. Cross-wavelet power is calculated by applying the absolute form of $\left|W_{xy}(\tau,s)\right|$. Thus, the squared wavelet coherence coefficient expressed by Torrence and Compo (1998) is as follows:

$$R_t^2(s) = \frac{\left|S\left(s^{-1}W_t^{xy}(s)\right)\right|^2}{S(s^{-1}|W_t^x(s)|^2)S\left(s^{-1}\left|W_t^y(s)\right|^2\right)}, 0 \leq R_t^2(s) \leq 1 \tag{5}$$

where s denotes a smooth operator along the wavelet axis in both time and scale. It can be achieved by convolution with a constant-length window function. Without smoothing, coherency is identical to one at all scales and times. Based on XWT, normalisation through the product of individual smoothed wavelet power spectra in each series is the result of wavelet coherence from $x(t)$ and $y(t)$ (Torrence and Compo, 1998; Torrence and Webster, 1999).

Partial Wavelet Coherence

If two or more series are presented, and only the relationship of the two is needed for access, the effect of other series is always critical to be considered. Therefore, in the time-frequency domain, to examine the interdependency between two variables, the effect of other variables shall be eliminated. This concept is known as Partial Wavelet Coherence (PWC). The idea of partial correlation is the extension of the correlation method in coherence. After removing the influence of x_2, the squared partial wavelet coherence coefficient of (y, x_1) is given by Torrence and Compo (1998) and Torrence and Webster (1999), among others.

$$RP^2(y,x_1|x_2) = \frac{|R(y,x_1) - R(y,x_2).R(y,x_1)*|^2}{[1-R(y,x_2)]^2[1-R(x_2,x_1)]^2} \tag{6}$$

Test of Significance

A definite duration of time series could be missing in processing the CWT along the series studied. Thus, a cone-of-influence (COI) was plotted to isolate the area in which CWT suffered from the edge effects. The edge effect is unavoidable when the wavelet is near the data boundary and "sees" the data outside the

observation interval. It is due to incomplete information on the boundary area (Su et al., 2021). The size of the COI gives the decorrelation time for a single spike in a time series at each scale (Torrence and Compo, 1998). The COI is identified with a black bell curve in the PWC plot, and the blurred section below the bell curve is not considered.

This study used the same model as Aguiar-Conraria and Soares (2014). Each new sample and series was fitted by an ARMA(1,1) via bootstrapping or by drawing errors from a Gaussian distribution. The variance of the model was equivalent to the approximated error terms. The black contour (island) designated the 5% significance level base.

RESULTS AND DISCUSSION

Descriptive Analysis

Table 1 presents the summarised statistics of the variables for the seven sampled stock markets. The highest degree of unconditional standard deviation was found in the PSEi, whereas the lowest was found in the KLCI. The high standard deviation in the PSEi and JCI showed a greater price range between the daily stock prices and their means. Furthermore, the KLCI, Stock Exchange of Thailand (SET), and the S&P 500 showed negative skewness as the markets generated few significant losses and frequent small gains in the sampling period. On the contrary, the positive skewness in the Straits Times Index (STI), VNI, JCI, and the PSEi was due to the few significant market gains and frequent small market losses in the sampling period. The kurtosis of the SET was close to zero (-0.01), and a normal distribution was expected from the market. The KLCI and VNI had positive kurtosis, which indicated that the distribution was light-tailed, while the PSEi, STI, JCI, and the S&P 500 had negative kurtosis with heavy-tailed distributions.

Table 1 Descriptive Statistics of ASEAN Market Indexes, 30th January 2020 - 30th January 2021

	KLCI	STI	SET	VNI	JCI	PSEi	S&P 500
Mean	1515.19	2688.89	1337.06	904.85	5248.72	6300.18	3256.39
Std. Error	5.93	13.79	7.41	7.02	35.50	42.21	22.25
Median	1524.76	2605.56	1335.72	890.61	5114.92	6150.70	3315.57
Std. Dev.	93.46	218.51	115.57	112.50	552.25	660.62	353.86
Sample Variance	8734	47744	13355	12656	304982	436420	125218
Kurtosis	0.22	-0.07	-0.01	0.34	-0.64	-0.90	-0.18
Skewness	-0.80	0.92	-0.25	0.55	0.34	0.14	-0.51
Range	464.86	998.07	522.85	534.99	2497.58	2883.78	1617.96
Minimum	1219.72	2233.48	1024.46	659.21	3937.63	4623.42	2237.40
Maximum	1684.58	3231.55	1547.31	1194.20	6435.21	7507.20	3855.36
Sum	375767	674910	324904	232547	1270191	1543544	823866
Count	248	251	243	257	242	245	253

Table 2 illustrates the summarised statistics of COVID-19 cases from the six sampled ASEAN countries. Indonesia and the Philippines had the highest standard deviation in terms of the number of cases. Thailand and Vietnam had the highest positive kurtosis and skewness. This outcome showed that the cases in both countries had light-tailed distributions because of the few occurrences of high numbers of cases and many small cases. However, a leptokurtic distribution could be seen in the cases of; Malaysia, Singapore, Thailand, and Vietnam.

Table 2 Descriptive Statistics of COVID-19 Cases, 30th January 2020 - 30th January 2021

Cases	Malaysia	Singapore	Thailand	Vietnam	Indonesia	Philippines
Mean	566.6	157.0	49.5	4.9	2881.7	1385.2
Standard Error	61.0	15.4	10.6	0.6	203.9	84.7
Median	70	32	6	2	1788	1189
Std. Dev.	960.3	245.3	164.8	9.6	3172.6	1325.3
Kurtosis	5.3	4.8	55.4	38.9	2.1	1.6
Skewness	2.2	2.1	6.7	5.2	1.5	1.2
Range	5725	1426	1742	98	13802	6725
Minimum	0	0	-10	0	0	0
Maximum	5725	1426	1732	98	13802	6725
Sum	140514	39717	12033	1247	697366	339379
Count	248	253	243	257	242	245

Table 3 shows the number of COVID-19 deaths by country. All the sampled countries presented a leptokurtic distribution with kurtosis greater than 3. The time series had fatter tails than the normal. Vietnam and Singapore were the highest among the sampled countries. Furthermore, COVID-19 cases in Vietnam and Singapore had light-tailed distributions because of the low number of high mortality and many low mortality cases. Each of the sampled ASEAN countries showed positive skewness. However, a leptokurtic distribution could be seen in the cases of; Malaysia, Singapore, Thailand, and Vietnam.

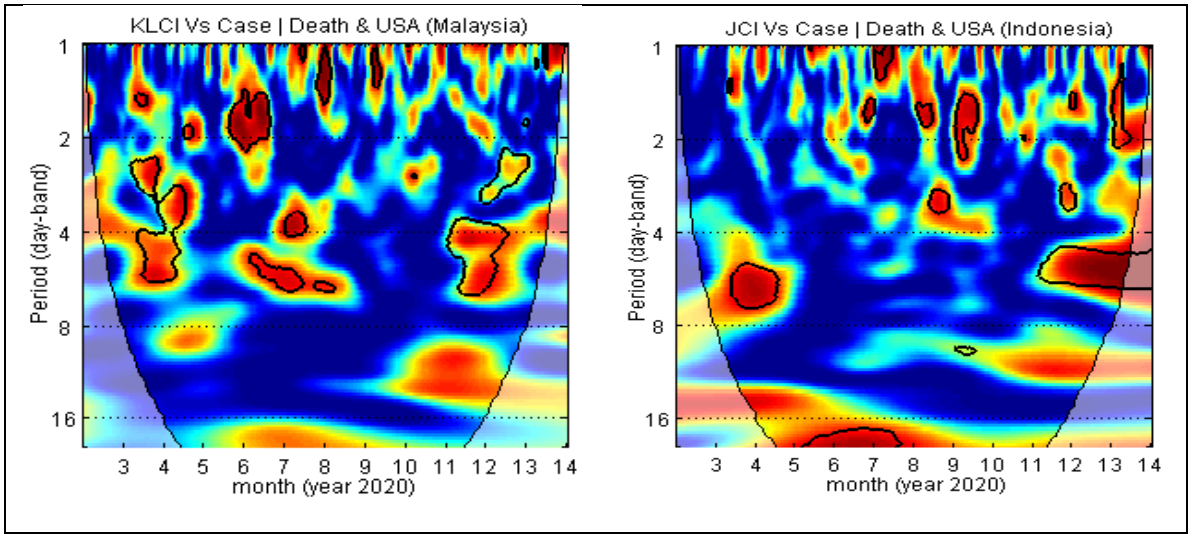
Table 3 Descriptive Statistics of COVID-19 Deaths, 30th January 2020 - 30th January 2021

Death	Malaysia	Singapore	Thailand	Vietnam	Indonesia	Philippines
Mean	2.07	0.06	0.21	0.09	83.17	27.49
Standard Error	0.21	0.02	0.04	0.03	5.15	2.13
Median	0	0	0	0	70.5	15
Std. Dev.	3.32	0.27	0.62	0.42	80.10	33.33
Sample Variance	11.00	0.08	0.38	0.18	6416.13	1110.59
Kurtosis	5.63	23.72	12.38	29.49	3.56	10.60
Skewness	2.26	4.71	3.40	5.26	1.61	2.58
Range	18	2	4	3	476	261
Maximum	18	2	4	3	476	259
Minimum	0	0	0	0	0	-2
Sum	514	16	52	24	20127	6735
Count	248	253	243	257	242	245

Coherence between COVID-19 Cases and ASEAN Stock Markets

The PWC plots for the number of cases and stock markets are conveyed in Figure 1. In Malaysia, not many islands (contours) were found. A medium-sized island was discovered from 21st May to 23rd June over the high-frequency band of 1.5–2 days. In the frequency bandwidth of 2–7 days, medium islands were detected from 6th March to 20th April, 3rd June to 16th July, 2nd November to 17th December and 28th November to 4th January 2021. In contrast, Singapore showed a few medium-size islands from 10th February to 13th March, 19th July to 8th August, 26th July to 7th September, 20th September to 4th October and 2nd November to 26th November over a short-term horizon of 1-4 days.

Both the PSEi and JCI had a comparable number of islands as the STI and KLCI. In the PSEi, medium islands were detected from 27th February to 18th March over the high-frequency band 2-3 days. A medium island was visible in the low-frequency band for 12-16 days from 25th March to 20th May. For the JCI, the finding revealed that high coherences were detected from 1st January 2021 to 15th January 2021, 5th November to 15th January 2021, 10th March to 18th April in high to intermediate frequency bands of 1-2 days, 4-7 days and 5-8 days, respectively. Beyond the frequency of 16 days, there was an island from 4th May to 20th July. The SET had two medium islands from 15th February to 2nd April and 28th August to 15th October over a medium frequency of 4-7 days and 14-16 days. Lastly, Vietnam had a large island from 24th February to 20th June with a 6-8 days bandwidth. Medium islands were also found from 8th December to 10th January 2021, 15th March to 30th April and 1st August to 1st September over 6-8 days, 12-14 days and 3-4 days.



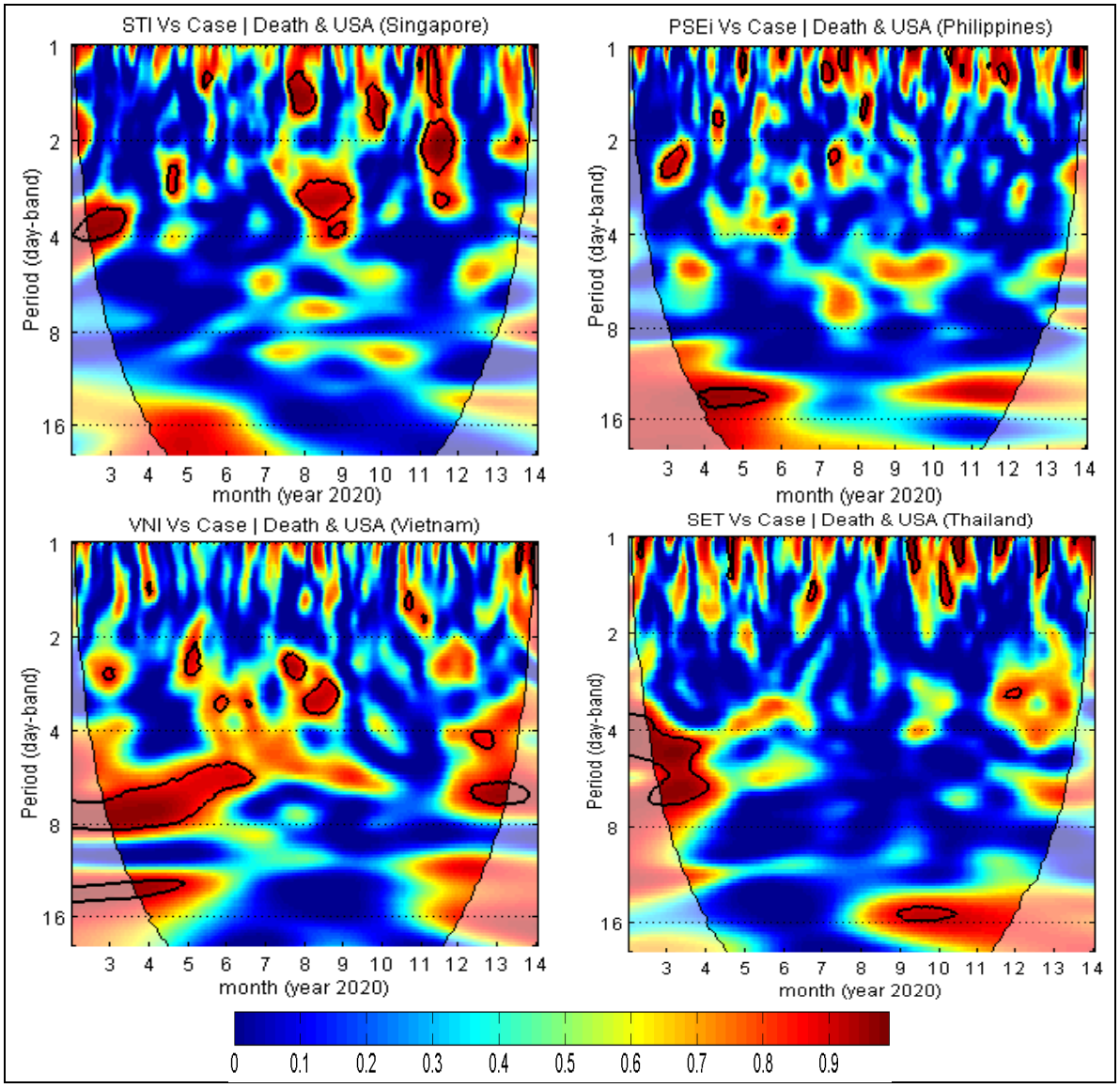


Figure 1 PWC Plot of ASEAN Market and Covid-19 Cases

Coherence between COVID-19 Deaths and ASEAN Stock Markets

The PWC plots for the number of COVID-19 deaths and stock markets are conveyed in Figure 2. In Malaysia, a medium island was identified from 12th December to 10th January 2021 and from 3rd November to 18th December over 2-3 days and 5-7 days, respectively. Two medium islands were found in Singapore from 10th February to 15th March and 2nd October to 22nd October in high frequency 2-4 days. Two medium islands were visible in the JCI from 21st October to 2nd December (1.5–3.5 days), 22nd March to 3rd May (5–6 days), and 27th November to 15th January 2021 (5–7 days).

Three medium islands were visible in the PSEi from 27th February to 21st March (2–3 days), 1st October to 4th December (8-9 days), and 20th July to 2nd November (beyond 16 days). The SET and VNI had the least number of islands among the sampled ASEAN markets. One medium island was detected from 2nd December to 8th January 2021 in the SET with 4 days bandwidth.

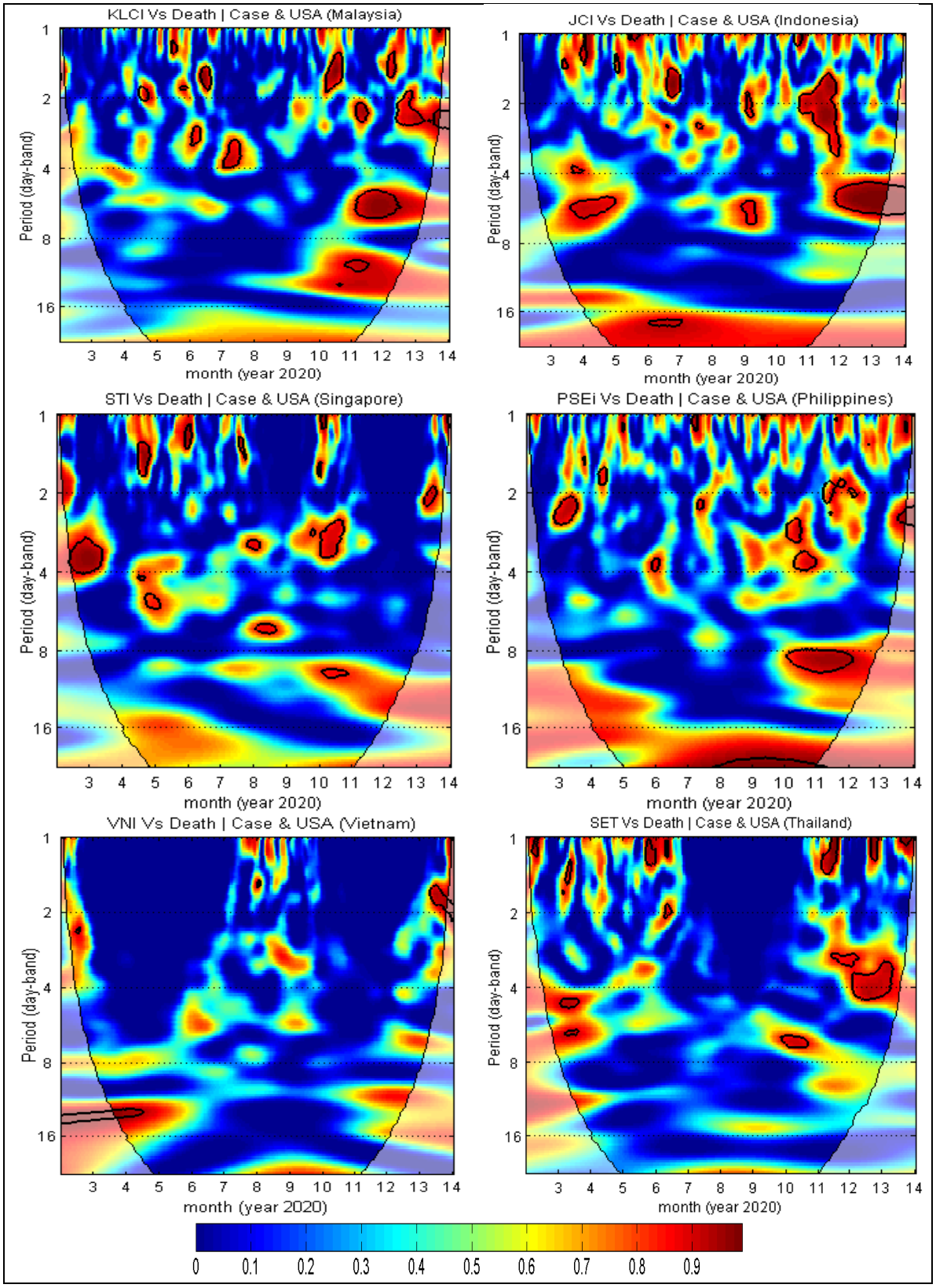


Figure 2 PWC Plot of ASEAN Market and Covid-19 Deaths

Coherence between the S&P 500 and ASEAN Stock Markets

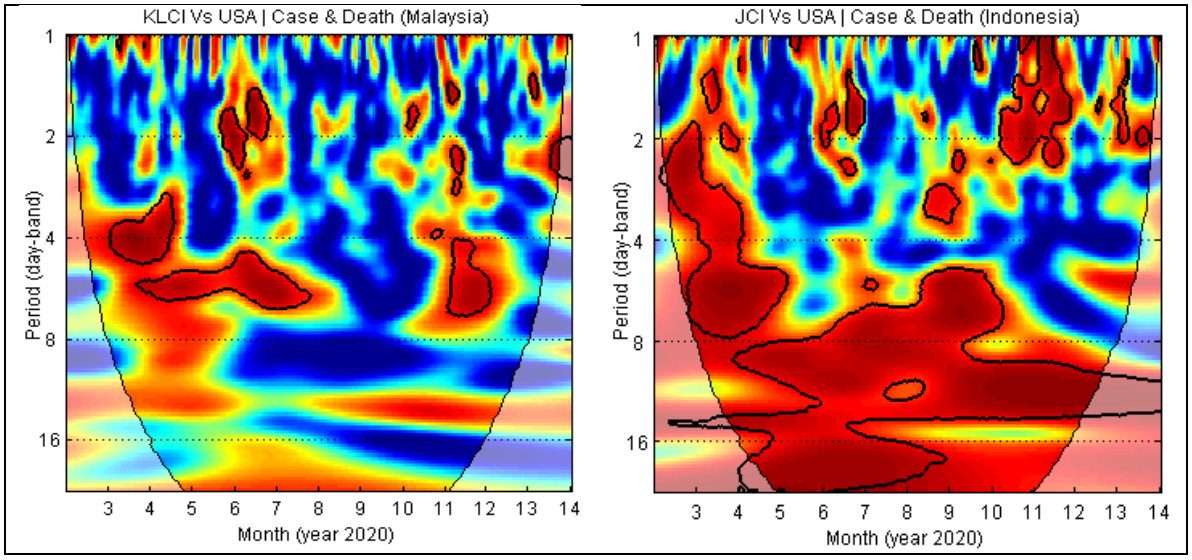
The PWC plots for the S&P 500 and each market are conveyed in Figure 3. More significant red islands are shown in the PWC plot, indicating strong dependency between the US and ASEAN stock markets. The PWC outcome from the S&P 500 was dissimilar from the COVID-19 "cases or deaths".

In the KLCI, there was evidence of a big island from 21st March to 27th July over medium frequency bands of 5–7 days. Medium islands were discovered from 2nd March to 22nd April (3–5 days), 22nd May to 9th June (1.5–2.5 days), 10th June to 28th June (1.5–2 days), and 3rd November to 3rd December (4–7 days). On the other hand, the STI showed a huge island from 8th March to 8th June over the intermediate and long-term horizon of 7–24 days. A big island was detected from 25th March to 24th June (1.5-8 days), whereby four medium islands were exhibited from 13th February to 20th March (3-4 days), 19th June to 14th July (1.5-3 days), 1st October to 24th November (1.5-4 days), 1st December to 25th January 2021 (1.5-2.5 days).

Additionally, the Thailand and Vietnam stock markets also indicated strong coherence with the US stock market compared with the COVID-19 variables. In the SET, medium-sized islands were found from 17th February to 8th April (4-6 days), 24th February to 8th May (6-9 days), 20th April to 18th June (6-7 days), 26th May to 24th July (1.5-3 days), 4th September to 18th September (1-2 days), 3rd October to 18th October (1-2 days), 15th September to 15th October (6-7 days), 2nd November to 25th November (6-7 days), 30th November to 10th January 2021 (6-7 days). Additionally, medium islands were found in the VNI from 8th February to 6th March (2-3 days), 12th March to 2nd June (12-16 days), 27th May to 21st July (1-4 days), 2nd June to 5th July (6-7 days), 15th August to 5th November (beyond 16 days), 8th September to 14th October (6-7 days), 15th October to 25th December (10-18 days), 20th October to 15th November (2-4 days), 3rd December to 3rd January 2021 (6-7 days).

The PWC showed that the Philippine and Indonesian stock markets had the most significant coherence with the S&P 500. In the Philippines, a huge island was exhibited in the first half of 2020 (2nd March to 20th July) over a high-intermediate frequency horizon of 7–16 days. Subsequently, medium-size islands were seen from 11th February to 22nd March, 3rd March to 12th May, 19th March to 15th April, 3rd June to 18th July, 20th August to 8th September, 9th October to 24th November and 20th May to 6th November over 2-4 days, 3-6 days, 1-2 days, 2-3 days, 3-4 days, 3-4 days and beyond 16 days

A massive island was discovered in the JCI and S&P 500. The huge coherence island spanned the entire sampling period from 8th February to 20th December with a wide frequency spectrum of 2–16 days. The S&P 500 showed extreme co-movement with the JCI in the medium term. Lastly, two intermediate islands were seen from 6th October to 28th November (1-2 days) and 14th August to 5th September (3-4 days).



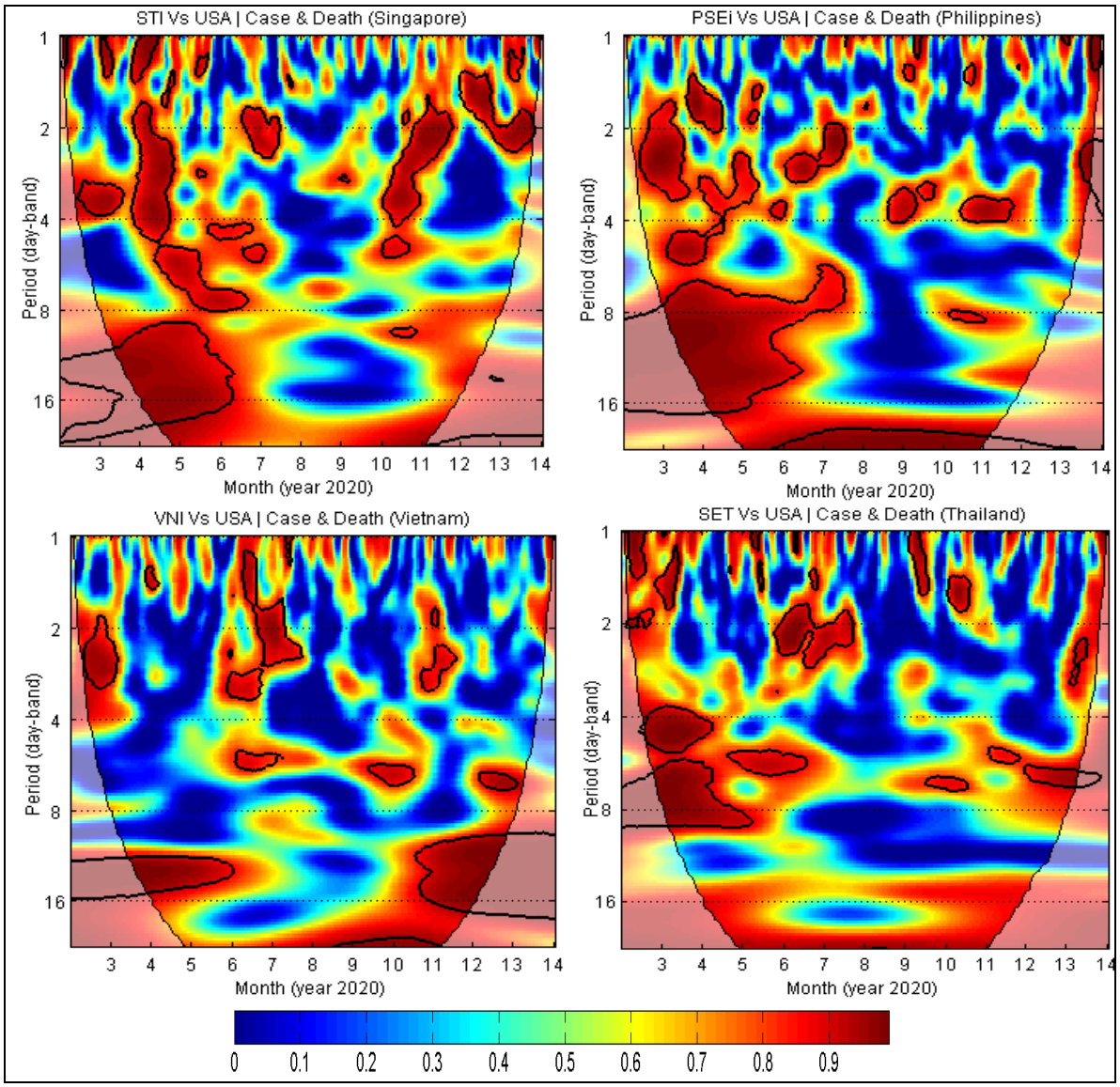


Figure 3 PWC Plot of ASEAN Market and S&P 500

COVID-19 Cases and ASEAN Stock Markets

The results showed that the coherence of ASEAN stock markets and the number of COVID-19 cases were not strong during the pandemic. Through visual inspection, the stock markets in Malaysia, the Philippines, and Indonesia presented more coherence with the number of COVID-19 cases compared with other nations. The results were in line with Kamaludin et al. (2021).

The PSEi had a significant volume of high-frequency coherence between May and October 2020, which came after implementing the Enhanced Community Quarantine (ECQ) in the Philippines. Camba and Camba Jr. (2020) also claimed that the increasing number of cases would have a significant but minimal effect on the PSEi. Moreover, the PWC plot showed that this effect was negligible in the long term. In Indonesia, COVID-19 cases had short and medium-term coherence effects on the JCI when the reported cases surged significantly towards the end of the sampling period. Conversely, Indrastuti (2021) reported that the number of COVID-19 cases and deaths had no significant influence on the JCI. The PWC plot showed that significant coherence was detected in both the number of COVID-19 cases and deaths in April and after November 2020. Therefore, COVID-19 cases had an impact on the JCI. The results aligned with Chia et al. (2020), who claimed that the number of cases had a significant but minimal impact on the KLCI. The findings in this study showed that the effects of COVID-19 cases in Malaysia had short- and medium-term co-movement with the KLCI.

Singapore and Thailand exhibited minimal coherence in the PWC plots. The surge of COVID-19 cases in Singapore between April and August 2020 did not significantly impact co-movement. The result in the VNI

was consistent with Anh and Gan (2020), and Vietnam was among the very few countries globally that positively influenced stock performance with the lockdown. The positive outcome in the Vietnam market was due to the improved trust of investors towards the Vietnamese government's reactions to the pandemic (Vo and Doan, 2021). The low coherence could have been due to the very low number of cases. In Thailand, the SET showed a long-term coherence after September, as COVID-19 cases started to incline by the end of 2020. However, the connectedness was generally low due to the low number of cases before December. The result was in line with Gongkhonkwa (2021), who claimed that the pandemic only had a short-term impact on the Thai stock market.

This study showed limited co-movement between ASEAN stock markets and COVID-19 daily cases during the pandemic. The spot of coherence in each market varied differently in the given time and frequency domain. The Rational Expectation Theory explained the limited interaction of the market and COVID-19 cases, as the spillover effect of the virus had been lessened by the pandemic stimulus packages that were supported by governments several times in 2020. Investors were hopeful of economic revival from tax cuts and increased government spending. The impact of the recession was lessened by the injection of money from governments, and thus, the ripple effect of COVID-19 cases was relatively weak. The result was also in line with Vasileiou's (2021) finding, contradicting the Efficient Market Hypothesis (EMH). The market seemed to ignore the health risk of the pandemic significantly, and stock prices were not often incorporated with all the available information. This behaviour can also be explained by De Bondt and Thaler (1985), who found that investors overacted to the news about stimulus packages. Due to this reason, the impact of cases was underestimated.

Most people "overreact" to unexpected and dramatic news events (stimulus packages and lockdowns). The results showed that the insignificant co-movement at low frequency revealed the ignorance of the market to the underlying long-term damage of the virus to survivors and the economy.

COVID-19 Deaths and ASEAN Stock Markets

Singapore, Thailand, and Vietnam showed widespread low coherence in the PWC plots in pandemic fatalities. These countries' low COVID-19 death rates may have contributed to the stock market's very low coherence with death.

The stock markets in Malaysia, the Philippines, and Indonesia presented considerable coherence towards the end of the sampling period. Yet, the impact on the stock markets was negligible amid the increasing death tolls. The result was supported by Al-Awadhi et al. (2020), among others, who highlighted the negligible correlation between total confirmed COVID-19 deaths and the stock market.

The Rational Expectation Theory can explain the minimal significant coherence between deaths and markets. Noy et al. (2020) and Lee et al. (2020) showed that the alleged COVID-19 deaths did not necessarily translate into economic turmoil in the long term. The impact of behavioural finance declined when people understood the virus better and were less concerned. The direct cost of COVID-19 due to illness and mortality was lower than the indirect losses from the pandemic. Therefore, the findings concluded a limited number of significant co-movements between ASEAN stock markets and the COVID-19 daily death count during the pandemic.

The S&P 500 and ASEAN Stock Markets

All six sampled ASEAN stock markets were seen as strongly coherent with the US market compared with COVID-19 cases/deaths. Grounded by the strong coherence PWC result from Kamaludin et al. (2021), this study's findings confirmed overwhelming co-movement of the US market with the PSEi, JCI, and STI. The PWC result of the JCI confirmed Lim's (2009) finding regarding the long-run co-integrating relationship between Indonesia and the US market during the crisis. However, the coherence between the JCI and S&P 500 reduced when COVID-19 cases increased at one point. In October–November 2020, a significant short-term co-movement in the JCI was detected. On the other hand, the PSEi encountered strong coherence with the S&P 500 from February to July 2020. Similarly, this relationship reduced tremendously when COVID-19 cases surged from July to August 2020, followed by a drop in the PSEi price to its lowest since June 2020.

Moderate coherence on the SET was noticed at about the same time and frequency domain; this result aligned with Kamaludin et al. (2021). Thailand had short- and medium-term coherence with the S&P 500 between January and August, which could have been due to the global stock market recovery and the low

level of the country's COVID-19 cases. Compared with other ASEAN markets, the KLCI had the least co-movement with the S&P 500. The result provided plausible evidence to Tan and Tse (2002), who verified that Malaysia had the least coherence with the US than other ASEAN nations. Nonetheless, Kamaludin et al. (2021) showed a low coherence frequency in April, not found in the PWC.

The psychology of behavioural finance had pushed ASEAN stock markets into becoming bear markets when COVID-19 emerged as a global pandemic. However, this study showed significant coherence between all ASEAN stock markets and the US stock market in June–July 2020 and October–November 2020. Several factors could have caused this situation. Firstly, a surprising positive earnings season in the US was released by corporations, especially big banks and mega-cap tech stocks. Secondly, unexpected news was released during the kickoff season when general investors anticipated negative corporate earnings due to the US economic slowdown in the second quarter of 2021. The US real gross domestic product (GDP) in the third quarter of 2020 increased at an annual rate of 33.4% (BEA, 2020).

ASEAN stock markets were more correlated with the US stock market than the number of cases and fatalities during the COVID-19 crisis. In line with the hypothesised association, there was a significant co-movement between ASEAN stock markets and the S&P 500 during the COVID-19 pandemic.

CONCLUSIONS

This study examined the co-movement of COVID-19 cases/deaths and the S&P 500 concerning ASEAN stock markets during the pandemic. Based on the wavelet results, the US stock market remained significantly dominant. As discussed in the empirical literature on financial markets, it has proven to be the most influential market in ASEAN stock markets. Moreover, the individual stock indices did not significantly correlate with the number of COVID-19 cases/deaths compared to the US stock market. This outcome indicated that news about the pandemic only brought about changes in stock market prices over the short term and took into account that the US stock market dominates and influences stock markets in ASEAN countries.

During the crisis period, the results were intuitive enough to inform investors and policymakers that failure to consider the time-frequency domain of the pandemic and the market would probably cause an inaccurate assessment of the threat of the COVID-19 virus to the economy. Overall, this study serves to remind investors not to panic sell stocks as the surge in the number of new COVID-19 cases/fatalities did not continue to impact the market. On the other hand, the movement of the US stock market may have been the key barometer to driving the stock movement in ASEAN.

Stock market movements are country-dependent, and not every sampled ASEAN stock market shared the same level of reaction to COVID-19 as the US stock market. Governments and policymakers of financial institutions should pay close attention to determine how to effectively and immediately rescue the market when a new variant of COVID-19 or a pandemic appears. Countries globally are currently experiencing high inflation with historically low interest rates. There remains a dilemma for affected ASEAN countries on whether their governments should stop offering economic stimulus packages amid the increasing number of COVID-19 cases/deaths.

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