International Linkages of the ASEAN-5 Stock Markets: Evidence from Pre and During Covid-19 Pandemic

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International Linkages of the ASEAN-5 Stock Markets: Evidence from Pre and During Covid-19 Pandemic

Field of Study: Applied Financial Econometrics

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Abstract

This paper examines the linkages in volatility spillovers between the stock markets in the ASEAN-5 countries with the US stock markets using daily key indices data spanning from 1 January 2017 to 31 December 2020, focusing on the period before the Covid-19 and during the pandemic. Bivariate GARCH-BEKK model is employed to study the market interdependence, and the spillover effects are examined from two sources, namely past shocks and past volatility. The Covid-19 outbreak has roiled the global equity markets in early 2020 but quickly recovered later in the same year, posing some of the most volatile years for equities. The findings suggest that the past volatility effects are more substantial during the pre-pandemic period than past shock in all ASEAN-5 stock markets. Own-volatility spillover is stronger than cross-volatility spillover, suggesting the linkages between ASEAN-5 and the US are weak. In contrast to the pre-pandemic period, past shock effects for all ASEAN-5 markets increased significantly during the pandemic, implying an unexpected change in the structure of the macroeconomy. Cross-volatility spillover is generally higher than own-volatility for all ASEAN markets except Thailand and the Philippines, indicating market linkages were strengthened amidst the crisis.

Keywords: COVID-19 Pandemic; Linkages; Volatility Spillover; Stock Markets; GARCH-BEKK model

Abstrak

Makalah ini meneliti pertalian dalam bentuk kesan limpahan volatilitas antara pasaran saham anggota ASEAN-5 dengan pasaran saham Amerika Syarikat dengan menggunakan indeks-indeks utama harian menjangkau dari 1 Januari 2017 hingga 31 Disember 2020, fokus di tempoh sebelum pandemik Covid-19 dan tempoh masa pandemik. Model Bivariate GARCH-BEKK digunakan untuk meneliti kesan limpahan volatilitas terutamanya limpah dari dua punca, iaitu kejutan lalu dan volatilitas lalu. Wabak Covid-19 telah merusuk pasaran equiti dunia pada awal 2020 tetapi memulih dengan pantas kemudian dalam tahun yang sama. Hasil kajian ini terdapat semasa tempoh sebelum pandemik, kesan limpahan volatilitas lalu adalah lebih jelas daripada kejutan lalu di semua pasaran saham ASEAN-5. Kesan limpahan volatilitas sendiri adalah lebih kuat daripada kesan limpahan volatilitas menyeberang, mencadangkan pertalian antara pasaran ASEAN-5 dengan Amerika Syarikat adalah lemah dalam tempoh ini. Dalam tempoh masa pandemic pula, kesan kejutan lalu untuk semua pasaran ASEAN-5 meningkat bererti, mengimplikasikan perubahan di struktur makro-ekonomi yang tidak dijangkakan. Kesan limpahan volatilitas menyeberang adalah lebih meningkat kecuali pasaran saham Thailand dan Filipina, menunjukkan pertalian lebih kuat masa pandemik.

Kata kunci: Pandemik COVID-19; Pertalian; Limpahan Volatilitas; Pasaran Saham; model GARCH-BEKK

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Voo Su Yee

Matric Number: EQC180012 / 17043887

Signature:

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CHAPTER 1: INTRODUCTION

1.1 Background and Context

Globalisation strengthens the interaction between the financial markets worldwide, and as the connections between global economies are strained up, external disturbance to the financial markets is no longer domestic. No financial market is isolated in this rapidly changing world. Economic data, political roils, commodities disruption and any other overseas affairs could cause dramatic fluctuation in domestic financial markets.

The Covid-19 outbreak has sounded an alarm to international financial markets regarding the unique vulnerabilities and fragility that can quickly transpire and disseminate. The outbreak was then recognised as a pandemic by the World Health Organisation (WHO) in March 2020. Since then, the worldwide economic slowdown has been observed and has thrust several countries into recessions, with the probability of a broad economic depression ever increasing. The stock markets globally have also experienced volatile swing and plunged to multi-year lows.

The coronavirus first identified in December 2019 in Wuhan, located in the Hubei region of China. The outbreak has since been transmitted to the rest of the world. It has yet to come to an end until today. The pandemic has caused global travel restrictions where most countries closed their borders to contain the virus. This pandemic directly impacted the global economies as industries and businesses closed down and pragmatic shift in consumer behaviours.

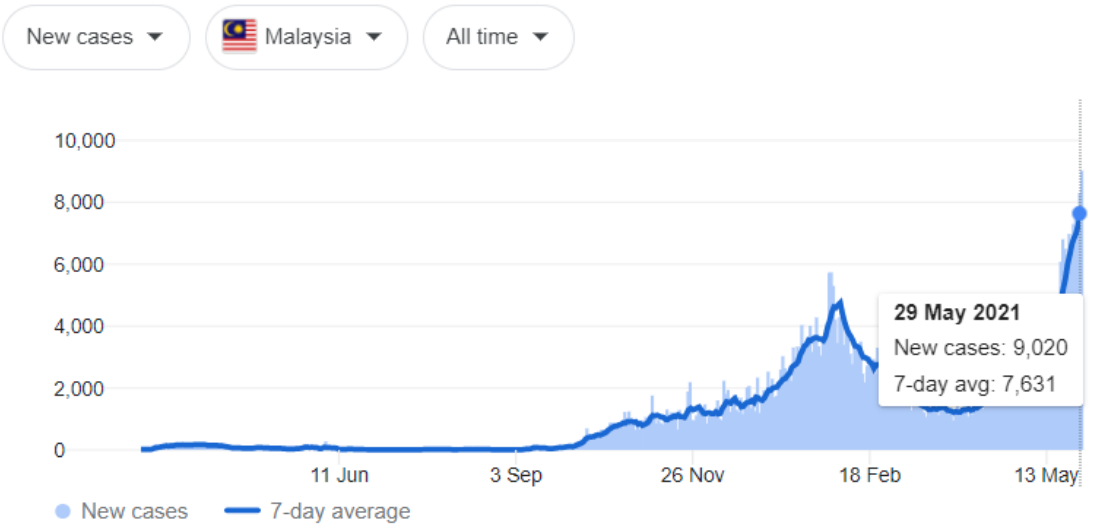
For example, the travel and tourism industry is among the most affected sectors with a massive fall of demand amid borders closed down. According to the latest statistics from

the United Nations World Tourism Organization's (UNWTO), the World Tourism Barometer shows the international tourist arrivals fell by 72% in January-October 2020. This percentage represents 900 million fewer arrivals which translated into a loss of US$935 billion in export revenues from international tourism, compared to the same period in 2019. Similarly, the aviation and transportation industry took a direct hit as well. The International Air Transport Association (IATA) announced that global passenger traffic for 2020, measured by revenue passenger kilometres (RPKs), fell by 66% compared to 2019, the sharpest traffic decline in aviation history.

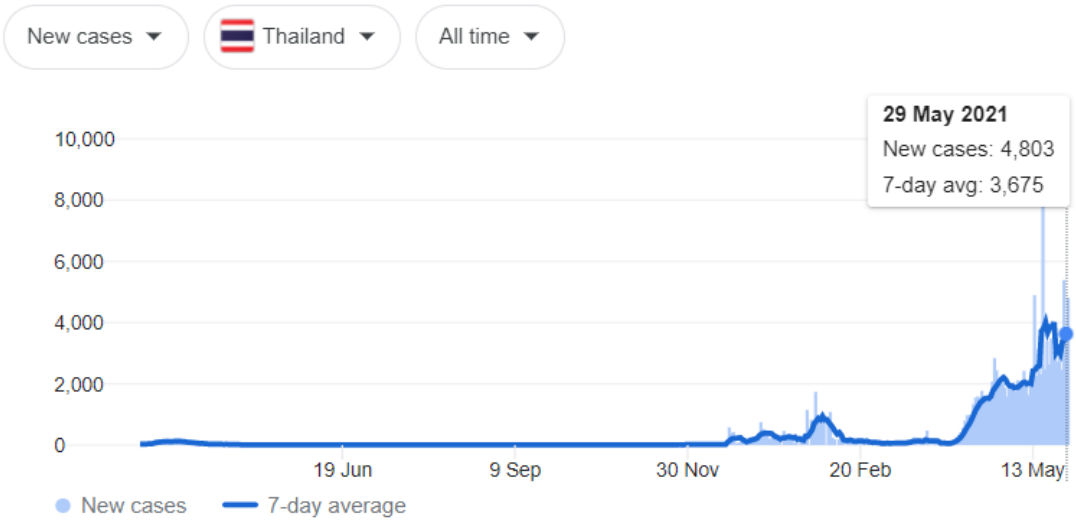
With aviation and shipping on a halt and most economic sectors shutting down, the oil prices had been pressured. OPEC+ was expected to cut crude productions at their March 2020 meeting, but the event took an unexpected turn with Russia refusing to comply and decided to increase its production instead. Saudi Arabia decided to apply pressure by announcing crude price discounts to its customers and will subsequently increase its production. This series of events led to a plunge in oil prices on 9 March 2020 in the magnitude of more than 20%. Subsequently, the price declined to US$9.12 per barrel on 21 April 2020.

The massive halt in global economic activities, coupled with dropping in commodity prices, has also spooked the global stock markets. The month of March 2020 saw one of the most severe market crashes in history. On March 9, the Dow fell 7.79%, then on March 12, the Dow fell 9.99%, almost a correction in a single day. On March 16, it lost 12.93%, and it was the third-worst single-day loss in American stock market history.

Figure 1: Daily Covid-19 cases in ASEAN-5 countries and USA (Source: John Hopkins University)

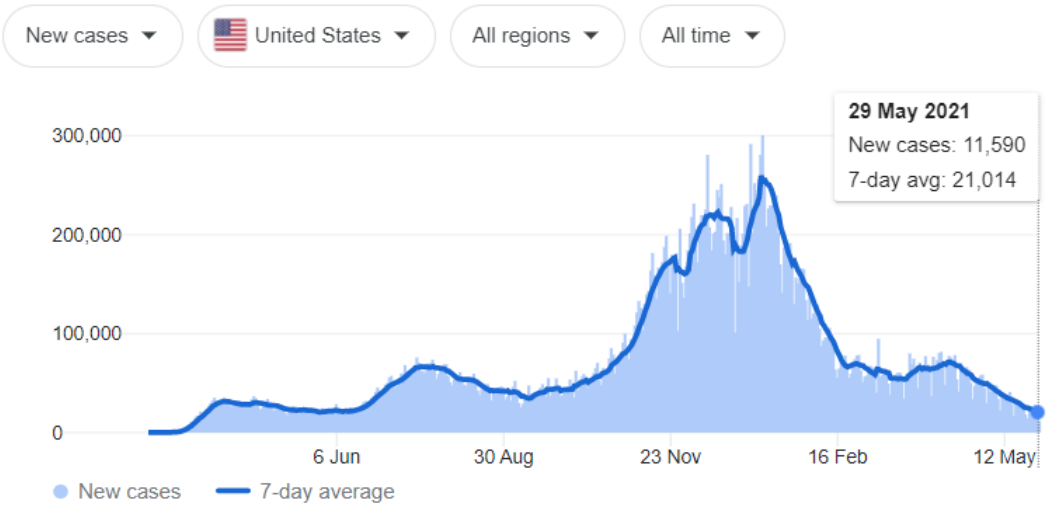

New cases
Malaysia
All time
10,000
8,000
6,000
4,000
2,000
0
11 Jun
3 Sep
26 Nov
18 Feb
13 May
29 May 2021
New cases: 9,020
7-day avg: 7,631
New cases
7-day average


New cases
Singapore
All time
1,500
1,000
500
0
7 Jun
31 Aug
24 Nov
17 Feb
13 May
29 May 2021
New cases: 33
7-day avg: 29
New cases
7-day average


New cases
Thailand
All time
10,000
8,000
6,000
4,000
2,000
0
19 Jun
9 Sep
30 Nov
20 Feb
13 May
29 May 2021
New cases: 4,803
7-day avg: 3,675
New cases
7-day average


New cases
Indonesia
All time
29 May 2021
New cases: 6,565
7-day avg: 5,712
15,000
10,000
5,000
0
19 Jun
9 Sep
30 Nov
20 Feb
13 May
New cases
7-day average


New cases
Philippines
All time
29 May 2021
New cases: 7,428
7-day avg: 5,481
15,000
10,000
5,000
0
15 Jun
6 Sep
28 Nov
19 Feb
13 May
New cases
7-day average


New cases
United States
All regions
All time
29 May 2021
New cases: 11,590
7-day avg: 21,014
300,000
200,000
100,000
0
6 Jun
30 Aug
23 Nov
16 Feb
12 May
New cases
7-day average

1.2 Problem Statement

Variations in stock prices during the Covid-19 outbreak represent challenges for policymakers because the interdependence in stock markets can have important implications for production costs, corporate profits, and employment rates and result in deviations from macroeconomic policies to enhance development and social welfare. The Covid-19 outbreak is a source of systematic risk; therefore, it is necessary to research the financial impacts of this pandemic. Current research on the linkages of ASEAN-5 stock markets during the pandemic is limited, and this study aimed to shed some light on the interdependence of ASEAN-5 stock markets during the pandemic.

1.3 Research Questions

This paper aims to answer two questions:

1) What are the primary sources of return and volatility spillover in each stock market of the ASEAN-5 countries during the Covid-19 pandemic?
2) Do the patterns of return and volatility spillover in ASEAN-5 stock markets differ before and during the Covid-19 pandemic?

1.4 Research Objectives

Two research objectives have been identified, which are:

1) To examine the linkages between the ASEAN-5 and US stock market during the Covid-19 pandemic; and
2) To examine the changes in the degree of linkages among the selected stock markets before and during the Covid-19 pandemic.

1.5 Significance of Study

The study aims to help portfolio managers and investors in the evaluation of investment and asset allocation decisions. Additionally, international portfolio managers and hedgers may understand how stock market volatility is interrelated over time. This situation might benefit them in forecasting the behaviour of the stock market by capturing the other market information, especially during this highly uncertain time of the pandemic. Other than that, the sources and directions of these spillovers can provide rich information for policymakers when preparing for future deterioration in circumstance or pandemics, should they arise.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

Globalisation and financial liberalisation transformed the developed and developing markets into a more integrated stature. The increase in the level of co-movement in different financial markets is not considered suitable for portfolio diversification. This swift transfer of information and capital restricted the benefits of international diversification in the long run due to an increase in cointegration. The events of Black Monday, the Asian financial crisis, and the Global financial crisis provided extensive shreds of evidence of integrated financial markets and their detrimental effects on portfolio investments.

2.2 The Concept of Volatility

In finance, volatility is the standard deviation of returns, which measure the dispersion of returns from the mean return over a certain period. A wide range of fluctuations of returns over a short period indicates high volatility. The concept of volatility is a critical feature in finance, as investors expect higher returns if the risk taken is higher. The trade-off between risk and return is a crucial concept in asset pricing, and risk is always related to the volatility of asset prices.

Volatility is not constant over time. Mandelbrot (1963) first observed that significant changes in prices tend to be followed by large changes (for any sign) while small followed by small. This phenomenon is called volatility clustering. Jones, Kaul and Lipson (1994), Brooks (2014), and Ramathan and Gopalakrishan (2013) suggested that new information are the primary source of price volatility. Market participants react and interpret the new information and adjust the market prices, leading to high fluctuations. However, Lux and Marchesi (1998)

argued that after an outbreak of volatility, the market would return to equilibrium sooner or later as fundamentalists stabilise the market.

Black (1976) also suggested the concept of leverage effect, which is the tendency for volatility to increase more after a significant fall in prices rather than an increase of the same amount. The volatility is generally stable and low in normal times, but volatility tends to surge in crisis periods. Schwert (1989) and Wang, Li, and Huang (2020) stated that the average volatility is much higher during the recession and financial crisis periods.

2.3 Causes of Market Linkages

The global market linkage is believed to be caused by various channels that connect markets and transmit information. Dornbusch, Park, and Claessens (2000) contended two causes of financial contagion conceptually. Similarly, Forbes and Rigobon (2000) also categorised how shocks are propagated internationally across financial markets into two broad groups. The first category emphasises spillovers resulted from interdependence among economies, also known as “fundamentals-based contagion”. In contrast, the second category is not linked to any macroeconomic fundamentals but rather the result of the behaviour of market participants.

2.3.1 Fundamental Causes

Fundamental-based contagion includes macroeconomic shocks transmitted through trade links. Dornbusch, Park, and Claessens (2000) argued that when a country faced a financial crisis, its currency would depreciate sharply, leading to capital outflows. Thus any trading partner to a crisis country would then experienced a decline in exports to the crisis country and hence a deterioration in the trading account.

Studies also identified various global shocks that can trigger market co-movements. Some common global causes such as a rise in the interest rate, contraction of the supply of capital, or a decline in demand could simultaneously affect the fundamentals of several countries. Then the stock markets of these countries affected by the aggregate shock would move together.

2.3.2 Investors' Behaviour

Separately, investors' behaviour also allows shocks to spill over from one market to another. For example, in the wake of a financial crisis, the losses may induce institutional investors to sell off their asset holdings to raise liquidity in anticipation of future redemptions by their clients. Valdes (2000) argued that to face these problems, the institutional investors might have no choice but to hold onto illiquid assets and sell other liquid assets. By doing so, the original disturbance can spread across different financial instruments and markets.

Another cause of contagion relates to information asymmetry. In the absence of better information, investors may believe that a financial crisis in one country could lead to similar crises in other countries. Calvo and Mendoza (1998) showed that the reduced incentives involved in gathering country-specific information could lead to herd behaviour in the presence of information asymmetries. Lux (1995), Hirshleifer and Teoh (2001) also found that herd behaviour occurred as investors attempt to draw information from what others do, causing contagion across markets. Reputation considerations may also urge even the smart money to follow the crowd.

2.4 Modelling Volatility Spillover

There are few main approaches in studying the spillover effect available in financial literature. The main one focused on correlation coefficients, the creation of spillover index, and the ARCH/GARCH family models. The first approach studied the effect using correlation coefficient, which is the most straightforward method. This approach measures the correlation in returns between markets during a stable period and after a shock. If the correlation coefficient increases significantly after a crisis, this suggests that the transmission mechanism between the two markets strengthen after the shock. King and Wadhwani (1990), Lee and Kim (1993), and Calvo and Reinhart (1996) all found a statistically significant increase in cross-market correlation coefficients during the crisis.

The second approach is a relatively new technique, called the spillover index, first proposed by Diebold and Yilmaz (2009). The spillover index is constructed based on the forecast error variance decomposition of the vector autoregression (VAR) model. It can measures both the total and directional volatility spillovers. This framework, however, relies on Cholesky-factor identification of VAR, so the resulting variance decompositions are dependent on variable ordering. One would prefer a spillover measure that does not affect by the ordering of variables.

The third and most common approach is using the Autoregressive Conditional Heteroskedasticity (ARCH) model first proposed by Engle (1982). It is extended to generalised ARCH (GARCH) by Bollerslev (1986), which recognises the difference between conditional and unconditional variance, allowing for the conditional variance to change over time due to past errors. The GARCH model also allows for more extended memory and a more flexible lag

structure. A multivariate GARCH model specifically allowed one to deal with multiple time series to model their volatility and inter-dependencies.

This paper will focus on using the GARCH model to study the spillovers, as the GARCH model is more efficient after enhancement. The volatility is modelled as a function of both squares of historical observations and the variance of error terms. The presence of past variance of error terms enables GARCH to track the deviation or persistence of the variance around the mean more accurately.

2.5 Past Studies on Market Linkages

In term of statistical viewpoint, the financial markets' return/ mean spillover reflected the first-moment distribution. In contrast, the volatility spillover effect reflects the second-moment relationship, in which market volatility is influenced not only by its own but also by volatility coming from other markets. The volatility spillover effect exists widely in different financial assets in different regions. With the ever-increased importance of developing markets, the interaction between developing and developed markets has been attracted by financial economists. For example, Vo and Tran (2019) employed an augmented EGARCH model with an ICSS algorithm to investigate volatility spillovers from the US equity market to ASEAN stock markets from Aug 2001 to Dec 2016. They documented a significant volatility spillover from the US to ASEAN equity markets which suggest emerging markets are affected by even small innovations in developed markets.

Common findings are that linkages between financial markets inclined to increase in the period of high volatility. Engle, Gallo and Velucchi (2012); Lee (2009); Lien et al. (2018); In et al. (2001); Chancharoenchai and Dibooglu (2014) studied the volatility spillover and

financial contagion among Asian countries during the 1997 Asian financial crisis, and all found that the crisis contributed to more evidence of higher volatility spillover. Similar research interests also identified for the 2008 global financial crisis. Mixed results were found in the literature. Akca and Ozturk (2016); Jebran et al. (2017); Baur (2012); Kim, Kim and Lee (2015) found that the financial markets became more integrated in the crisis period with more volatility spillover relative to the non-crisis period.

However, Lee and Goh (2016) contended otherwise. They examined the linkages in the form of stock returns and volatility spillovers among the ASEAN-5 markets and their relationship with the Hong Kong and US markets by using the multivariate BEKK GARCH model during the Pre-crisis period (2 Jan 2002 - 15 Aug 2007), Crisis period (29 Sep 2008 - 27 Feb 2009), and Post-crisis period (7 May 2009 - 29 Dec 2011). The authors found that the US market is the primary source of the mean spillover effects. Past-volatility spillover effects from both US and HK markets are more extensive than those from the ASEAN markets, albeit the persistence is reduced after the crisis. Past-shock spillovers are lesser in impact for the post-crisis period. However, shocks due to bad news from the US market are much stronger after the crisis.

Similarly, Ngo (2018) investigated the returns and volatility spillovers between China and 4 Southeast Asian stock markets (Vietnam, Thailand, Singapore and Malaysia) using a bivariate GARCH-BEKK model for the pre-and post-global financial crisis periods. He found the stock return linkage between China and other markets is remarkable during and after the financial crisis. In contrast, the volatility spillover is less apparent during the sub-prime crisis. However, there exists significant unidirectional volatility spillover from China to other 4 Southeast Asian markets in the same period.

There is also another interesting study on the linkages between ASEAN-5 markets on different macroeconomic periods. For example, Darinda and Permana (2019) applied the MGARCH-BEKK model to examine the relationship between global macro shocks (represented by Brent crude), cross-market linkages (represented by USA's Dow Jones Industrial Average Index), and economic fundamental (represented by each country exchange rate with USD) through spillovers to ASEAN-5 stock markets during "High-Oil Price" era (2 Jan 2012 – 5 Dec 2014) as well as "Low-Oil Price" era (8 Dec 2014 – 30 Jun 2017). They found a higher rate of volatility transmission of Brent crude at low oil price era and a lower rate of volatility transmission of US stock market at low oil price era. Different exchange rate volatility transmission rate is identified where lower volatility transmission rate is observed in Indonesia, Thailand, Philippines at low oil price era, while Malaysia and Singapore showed inversely.

On the most recent Covid-19 outbreak crisis, Wang et al. (2020) studied the dynamic change of volatility spillovers between major international stock markets (US, UK, Japan, HK, and China) during the Covid-19 pandemic Diebold and Yilmaz's connectedness index. They found that the US and UK stock markets are main spillover transmitters while China and Japan stock markets are spillover recipients during the pandemic. They also identified that the total volatility spillover in March 2020 reached the highest level in the recent ten years.

In addition, Ngo (2020) employed Diebold and Yilmaz's spillover index and the wavelet coherence approaches to investigate the impact of return spillovers and dynamic time-frequency linkages between crude oil prices and five European stock markets. These countries are the UK, France, Germany, Spain, and Italy during the Covid-19 pandemic. He highlighted

that the return transmission is more apparent during the Covid-19 crisis and that the transmitter-recipient relationship is different during the pandemic compared to the pre-pandemic.

Following these developments, this paper examines the linkages of ASEAN-5 stock markets in terms of return and volatility spillovers while considering the effect of the Covid-19 outbreak crisis. This research initiative has not been sufficiently explored in the literature.

CHAPTER 3: DATA AND METHODOLOGY

The data to be used in this study are the daily closing prices of the ASEAN-5 stock markets (Singapore, Malaysia, Thailand, Indonesia, and the Philippines) and the US stock market. Major stock indices of each country will be selected, namely the Straits Times Index (STI), FTSE Bursa Malaysia Kuala Lumpur Composite Index (FBMKLCI), Stock Exchange of Thailand Index (SET), Jakarta Composite Index (JCI), Philippines Composite Index (PCOMP), and S&P 500 Index (SPX). The S&P 500 Index represents the market indicator of the global financial centre. Daily data span from 1 January 2017 to 31 December 2020 to avoid the volatile period of the Brexit referendum and US Presidential Election in 2016. The data will be synchronised by omitting all the observations if a series has a missing value on a particular non-trading day and time zone differences.

Table 1: List of Variables

Variables	Description
Malaysia	Daily return of FBMKLCI (by taking the difference in log series)
Singapore	Daily return of STI (by taking the difference in log series)
Thailand	Daily return of SET (by taking the difference in log series)
Indonesia	Daily return of JCI (by taking the difference in log series)
Philippines	Daily return of PCOMP (by taking the difference in log series)
USA	Daily return of SPX (by taking the difference in log series)
MY_{t-1}	Lag 1 of Malaysia
SG_{t-1}	Lag 1 of Singapore
TH_{t-1}	Lag 1 of Thailand
ID_{t-1}	Lag 1 of Indonesia
PH_{t-1}	Lag 1 of Philippines
USA_{t-1}	Lag 1 of USA

Source: Bloomberg Terminal

Figure 2: Time series data for selected stock markets during the period of study.

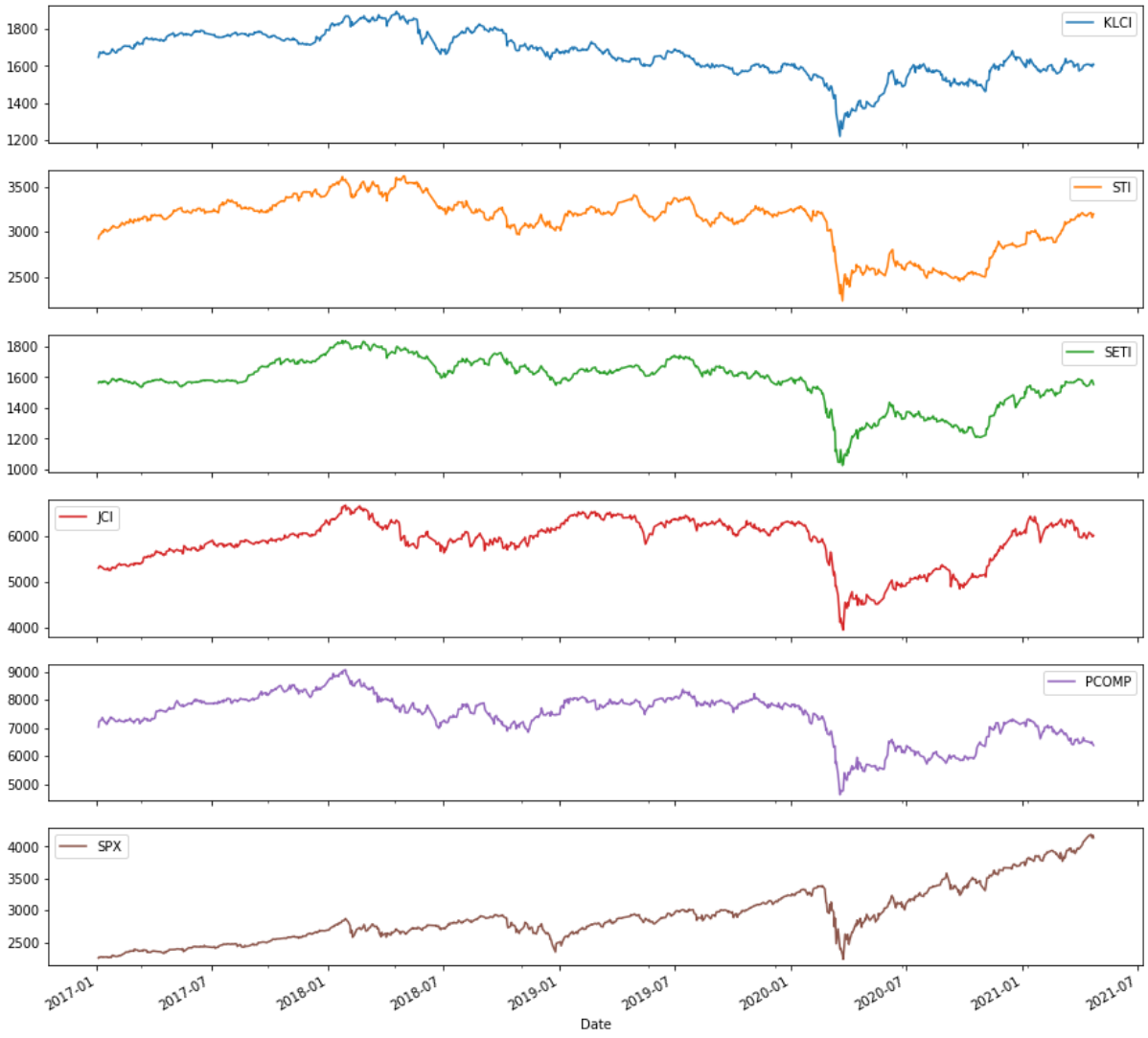


Figure 2 shows all the ASEAN-5 and US daily stock indices for the period of study. The US stock market hit an all-time high on 19 February 2020 before sliding and tumbled for the next month before staged a sharp rebound. In this paper, the beginning of 2017 till 19 February 2020 will be classified as a "pre-pandemic period", while 20 February 2020 and beyond will be classified as a "pandemic period" to study linkages between the selected stock markets.

Table 2: Chronology of Major Events.

DATE	EVENTS
2/19/2020	US stock market closed at an all-time high, with S&P500 closed at 3386.2
2/20/2020	Marked the first closed-down day for US stock indices before a series of daily plunges hit the markets
3/09/2020	On Covid-19 demand concerns, the Russia-Saudi oil price war began over the weekend. Brent plunged -26.7%.
	Also dubbed "Black Monday I" for the US stock market, S&P 500 dropped -7.6%
3/11/2020	WHO declared Covid-19 as a global pandemic
3/12/2020	Asia markets in the rout, the circuit breaker is triggered in Thailand, Philippines and Indonesia markets
	Dubbed "Black Thursday" for the US stock market, S&P 500 dropped -9.5%
3/16/2020	Dubbed "Black Monday II" for the US stock market, S&P 500 dropped -12%
3/23/2020	Marked the bottom for the US stock market in Covid-related meltdown
3/24/2020	Global stock markets staged a strong rebound in the next few months

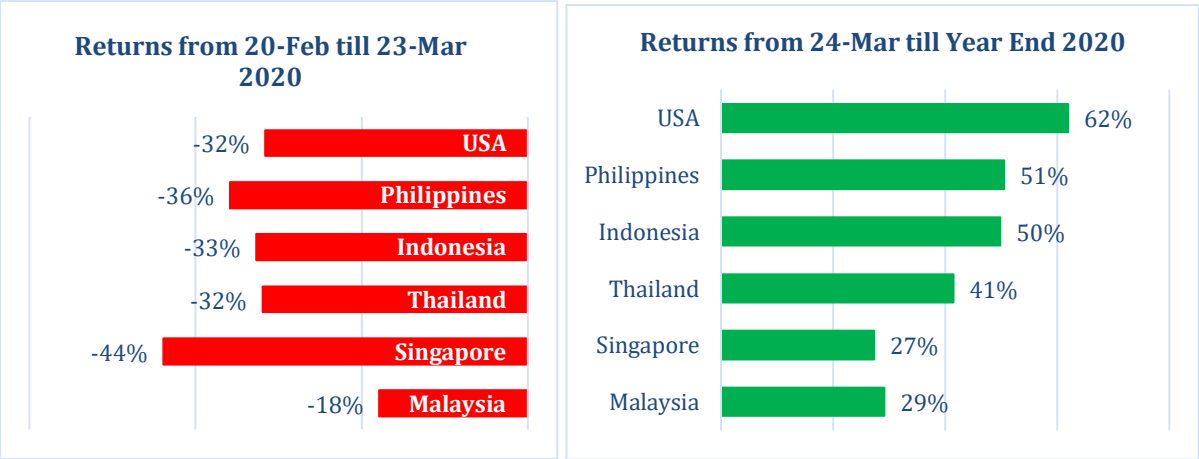


Figure 3: Stock market returns from 20/2/2020 till End of 2020.

Figure 4: Stock market Y-o-Y performance in 2020.

Table 2 showed the chronology of significant events that made headlines and shattered global markets. The meltdown in stock markets was rapidly evolving from February 20 to March 23, 2020. As shown in Figure 3, all the ASEAN-5 and US stock market indices dropped more than 30% except for Malaysia (dropped 18%). Singapore was the worst hit during the timespan, with a whopping 44% loss. The stock markets staged a strong rebound after that, till the end of 2020, all except Singapore markets recouped losses of the period February 20 – March 23. However, 2020 was not a great year for investors in Singapore, Thailand, the Philippines, and Indonesia on a year-on-year basis.

3.1 Unit Root Test

Unit root test will be carried out to ensure the data do not contain unit root or are stationary. For this study, Augmented Dickey-Fuller unit root test is chosen, with the test equation as follow:

$$\Delta Y_t = \mu + \beta t + \delta Y_{t-1} + \sum_{i=1}^{m} \alpha_i \Delta Y_{t-i} + \varepsilon_t \quad (1)$$

The hypothesis to be tested is $H_0: \delta = 0$ against $H_a: \delta < 0$, where the lag length m is determined such that ε_t is not autocorrelated. If H_0 is rejected, the series Y_t is said to be stationary. A stationarity test is also conducted to confirm the result of the unit root test. Kwiatkowski, Phillips, Schmidt and Shin (KPSS) test is used in this study, with the following test equation:

$$Y_t = \mu + \beta t + \rho Y_{t-1} + \varepsilon_t \quad (2)$$

Where under the null hypothesis, the series Y_t is stationary.

3.2 GARCH-BEKK

Bivariate GARCH model will be used to explore empirically the linkages of the selected stock markets, particularly between the US stock market and other ASEAN-5 markets. Let the return of the stock market be defined as $r_{i,t} = ln\ ln\ p_{i,t} - ln\ ln\ p_{i,t-1}$, where p_t is the stock market index. The mean of the process of the bivariate GARCH model is defined as:

$$r_t = \mu + \Gamma r_{t-1} + \varepsilon_t$$

$$\frac{\varepsilon_t}{I_{t-1}} \sim N(0, H_t) \quad (3)$$

where $r_t = (r_{1t}, r_{2t})'$ is a 2 x 1 vector of daily returns at time *t*. μ represents 2 x 1 vector of constants. Γ is a 2 x 2 matrix for parameters associated with the lagged returns. $\varepsilon_t = (\varepsilon_{1t}, \varepsilon_{2t})'$ is the 2 x 1 vector of random errors, representing the shock of each stock market. I_{t-1} represents the information available to all the markets at time t-1. H_t is the conditional variance-covariance matrix, of which the diagonal elements represent the variance whereas the non-diagonal elements represent covariance, can be stated as follows:

$$H_t = \begin{bmatrix} h_{11,t} & h_{12,t} \\ h_{21,t} & h_{22,t} \end{bmatrix}$$

Engle and Kroner (1995) introduced Baba Engel Kroner Kraft (BEKK) model, which guarantees by construction that the variance-covariance matrices in the system are positive definite. The compact form of the BEKK model is defined as:

$$H_t = C'C + A'\varepsilon_{t-1}\varepsilon'_{t-1}A + B'H_{t-1}B \quad (4)$$

Where *A*, *B*, and *C* are matrices of parameters to be estimated.

$$C = \begin{bmatrix} c_{11,t} & c_{12,t} \\ c_{21,t} & c_{22,t} \end{bmatrix}$$

$$A = \begin{bmatrix} \alpha_{11,t} & \alpha_{12,t} \\ \alpha_{21,t} & \alpha_{22,t} \end{bmatrix} \quad , \quad B = \begin{bmatrix} \beta_{11,t} & \beta_{12,t} \\ \beta_{21,t} & \beta_{22,t} \end{bmatrix}$$

The model may be untenable due to the large number of parameters that need to be estimated. When restrictions are imposed on the *A* and *B* matrices, a diagonal version of the BEKK model is obtained, containing fewer parameters. The diagonal version of the BEKK model can be formulated as follows:

$$h_{ii,t} = c_{ii} + \alpha_{ii}^2 \varepsilon_{i,t-1}^2 + \beta_{ii}^2 h_{ii,t-1} \quad (5)$$

$$h_{ij,t} = c_{ij} + \alpha_{ii}\alpha_{jj}\varepsilon_{i,t-1}\varepsilon_{j,t-1} + \beta_{ii}\beta_{jj}h_{ij,t-1} \quad (6)$$

where c_{ii} and c_{ij} are constants, α_{ii} is the diagonal element of *A*, and β_{ii} is the diagonal element of *B*. The term α_{ii}^2 is the coefficient of lagged own-volatility shocks of market i, and β_{ii}^2 is the coefficient of lagged own volatility of market i.

These specifications imply that the volatility spillovers within one series depend on past volatility spillovers (the effects of past volatility) and past shocks (the effects of past squared innovations). The co-volatility spillovers are due to the past co-volatility and cross-products of past disturbances between two markets (i and j). The effects are given by the cross-products of diagonal elements of *A* ($\alpha_{ii}\alpha_{jj}$), *B* ($\beta_{ii}\beta_{jj}$) respectively. Under the assumption of conditional normality, the parameters of these models are estimated by maximising the log-likelihood function:

$$L(\theta) = -\frac{TN}{2} ln\ ln\ (2\pi)\ - \frac{1}{2}\sum_{t=1}^{T} \quad (ln\ ln\ |H_t|\ + \varepsilon_t' H_t^{-1} \varepsilon_t)$$

Where θ denotes the vector of all the unknown parameters to be estimated.

CHAPTER 4: RESULTS AND DISCUSSIONS

	Malaysia	Singapore	Thailand	Indonesia	Philippines	USA
Pre-pandemic						
Mean	-0.011	0.0148	-0.00586	0.0173	0.00786	0.062
Std. Dev.	0.6033	0.7531	0.6898	0.8431	1.072	0.89
Pandemic						
Mean	0.0367	-0.0675	-0.0115	0.00909	-0.0218	0.0571
Std. Dev.	1.47	1.8377	2.2269	2.1118	2.616	2.5623

Table 3: Average Daily Returns (%)

Table 3 shows the mean daily returns of these markets. From 2017 till the pre-market meltdown, Malaysia and Thailand were the only markets that posted negative average daily returns, while the USA was the best performing market. For the pandemic period, Singapore, Thailand and the Philippines were amongst the markets in negative mean daily returns. Malaysia was the only market that posted a better return than the pre-pandemic period. Note that the standard deviations of all the markets during the pandemic are at least two times higher than pre-pandemic time, suggesting that the market volatility was indeed higher after the market meltdown and staged a robust V-shaped rebound.

Table 4: Correlation amongst all return series

	Malaysia	Singapore	Thailand	Indonesia	Philippines	USA
Pre-pandemic						
Malaysia	1					
Singapore	0.484***	1				
Thailand	0.384***	0.483***	1			
Indonesia	0.414***	0.360***	0.310***	1		
Philippines	0.441***	0.366***	0.317***	0.418***	1	
USA	0.352***	0.428***	0.308***	0.300***	0.329***	1
Pandemic						
Malaysia	1					
Singapore	0.701***	1				
Thailand	0.580***	0.703***	1			
Indonesia	0.590***	0.691***	0.551***	1		
Philippines	0.580***	0.637***	0.568***	0.693***	1	
USA	0.394***	0.423***	0.306***	0.476***	0.422***	1

*Notes: ***, **, * represent significance at 1%, 5%, and 10% levels respectively.*

The correlation between the returns series shows that all markets are positively correlated. For the pre-pandemic period, only Malaysia-Singapore and Singapore-Thailand have more significant correlations. Table 4 shows an apparent change in the co-movement relationship among all stock markets. The correlations during the pandemic period are higher than the pre-pandemic period, especially amongst the ASEAN markets.

Table 5: Unit root tests - Augmented Dickey-Fuller & KPSS

Country	Pre-pandemic		Pandemic	
	ADF	KPSS	ADF	KPSS
Malaysia	-25.3418***	0.0349	-12.9901***	0.0854
Singapore	-24.5984***	0.0615	-14.0006***	0.0718
Thailand	-24.7284***	0.0405	-5.7647***	0.1030
Indonesia	-25.5091***	0.0386	-4.7440***	0.0946
Philippines	-26.4058***	0.0718	-13.2806***	0.0743
USA	-26.5940***	0.0580	-7.1072***	0.1150

*Notes: ***, **, * represent significance at 1%, 5%, and 10% levels respectively. The test regression contains constant and trend.*

Table 5 shows the results for both the ADF & KPSS unit root tests. For the ADF test, all return series are statistically significant to reject the null hypothesis of containing a unit root. While in the KPSS test, all return series do not reject the null hypothesis of stationary. Next, we can then study the linkages of each ASEAN stock market to the US market using the stationary return series. The bivariate GARCH-diagonal BEKK model will be employed.

4.1 Pre-pandemic Period Analysis

Table 6: Mean equation of the GARCH-BEKK model pre-pandemic

	Malaysia	USA	Singapore	USA	Thailand	USA	Indonesia	USA	Philippines	USA
Mean	0.0001	0.0012***	0.0005**	0.0011***	0.0002	0.0010***	0.0005*	0.0011**	0.0006	0.0013*
MY_{t-1}	0.0115	0.1241***								
SG_{t-1}			-0.0442	0.1948***						
TH_{t-1}					0.0268	0.1127***				
ID_{t-1}							0.0041	0.0316		
PH_{t-1}									-0.0743*	-0.0201
USA_{t-1}	-0.0368	-0.1185**	0.0651**	-0.1669***	0.0004	-0.0993**	-0.0976**	-0.0923*	0.0078	-0.0770

*Notes: ***, **, * represent significance at 1%, 5%, and 10% levels respectively.*

Table 6 shows that none of the ASEAN markets except the Philippines have significant own-return linkages during the pre-pandemic period. On the other hand, cross-mean spillovers are significant for all ASEAN markets except the Philippines. The cross-mean effects are positive for Malaysia, Singapore and Thailand, while negative for Indonesia.

Table 7: Variance-Covariance estimations of GARCH-BEKK model pre-pandemic

	Malaysia-USA	Singapore-USA	Thailand-USA	Indonesia-USA	Philippines-USA
c_{11}	0.000***	0.000***	0.000***	0.000***	0.000*
c_{22}	0.000***	0.000***	0.000***	0.000***	0.000***
c_{12}	0.000***	0.000***	0.000***	0.000***	0.000***
${\alpha_{11}}^2$	0.0403***	0.0143***	0.0010	0.0249***	0.0223***
${\alpha_{22}}^2$	0.2047***	0.1461***	0.1448***	0.1808***	0.1992***
$\alpha_{11}\alpha_{22}$	0.0909***	0.0456***	0.0123	0.0671***	0.0667***
${\beta_{11}}^2$	0.9513***	0.9730***	0.9956***	0.9645***	0.9724***
${\beta_{22}}^2$	0.7449***	0.7986***	0.8034***	0.7706***	0.7431***
$\beta_{11}\beta_{22}$	0.8418***	0.8815***	0.8944***	0.8621***	0.8501***

*Notes: ***, **, * represent significance at 1%, 5%, and 10% levels respectively.*

The conditional variance-covariance equations of Diagonal BEKK specification, as shown in Table 7, show a strong GARCH effect and a weaker ARCH effect. All coefficients of past shocks are lower than the coefficients of past volatility. Own-volatility spillovers are significant for all ASEAN-5 markets, with the coefficients all near to 1 (0.95-0.99). Own-past shocks are

also shown to be significant except for Thailand, which suggests that past innovations do not affect the volatility of the Thailand market. As such, the cross-shock effects are significant for all ASEAN markets except for Thailand.

As for the cross-volatility effects, there is significant evidence that all ASEAN-5 have volatility linkages with the US. The coefficients for all cross-volatility are high as well (0.84-0.89). Own-volatility spillovers are higher than cross-volatility effects for all ASEAN-5 markets, while cross-product innovations are higher than own-shocks. The very high cross-volatility effect suggests that these markets mainly influenced by past market volatility instead of past innovations.

4.2 Pandemic Period Analysis

Table 8: Mean equation of GARCH-BEKK during the pandemic

	Malaysia	USA	Singapore	USA	Thailand	USA	Indonesia	USA	Philippines	USA
Mean	0.0004	0.0015	0.0002	0.0021	-0.0001	0.0009	0.0025**	0.0017	0.0010	0.0016
MY_{t-1}	-0.0410	0.090								
SG_{t-1}			0.0552	0.3891***						
TH_{t-1}					-0.0841	0.615***				
ID_{t-1}							-0.0244	0.1857**		
PH_{t-1}									-0.1979**	0.0103
USA_{t-1}	0.0745*	-0.1490**	0.0181	-0.255***	-0.0670	-0.393***	-0.109***	-0.255***	0.0015	-0.0916

*Notes: ***, **, * represent significance at 1%, 5%, and 10% levels respectively.*

Table 8 shows that again, only the Philippines have significant return linkages during the pandemic period. The cross-mean spillovers were also found to be significant for all ASEAN markets except the Philippines. The linkages in the mean appeared to have strengthened during the pandemic.

Table 9: Variance-Covariance estimations of GARCH-BEKK during the pandemic

	Malaysia-USA	Singapore-USA	Thailand-USA	Indonesia-USA	Philippines-USA
c_{11}	0.000*	0.000**	0.000***	0.000***	0.000**
c_{12}	0.000	0.000	0.000	0.000	0.000
c_{22}	0.000**	0.000**	0.000**	0.000**	0.000
${\alpha_{11}}^2$	0.1891***	0.3385***	0.0672***	0.4189***	0.2053***
${\alpha_{22}}^2$	0.1288***	0.0811***	0.2185***	0.1682***	0.3017***
$\alpha_{11}\alpha_{22}$	0.1561***	0.1657***	0.1212***	0.2654***	0.2489***
${\beta_{11}}^2$	0.6887***	0.6840***	0.8898***	0.5008***	0.7341***
${\beta_{22}}^2$	0.8293***	0.8690***	0.7190***	0.7997***	0.7148***
$\beta_{11}\beta_{22}$	0.7557***	0.7710***	0.7999***	0.6328***	0.7244***

*Notes: ***, **, * represent significance at 1%, 5%, and 10% levels respectively.*

From Table 9, it is shown that the ARCH effect picked up during the pandemic period. Own- and cross-shocks for all ASEAN-5 markets increased significantly compared to the pre-pandemic period, with Thailand's own-shock coefficient at 0.067, whereas others at the range of 0.189-0.419. Cross-shocks effects are lower than own-shocks, with the exception in Thailand and the Philippines. The increase in the effect of the past shocks implies an unexpected change in the economy's structure that affects the model exogenously.

Instead of the pickup in ARCH effects, the volatility spillover (GARCH) effects are lower than the pre-pandemic period. Own-volatility spillover for Thailand is 0.89, while others at the range of 0.50-0.73. The cross-volatility spillover effects are generally higher than the own-volatility for ASEAN markets except for Thailand and the Philippines. This observation suggests the cross-volatility transmission is more prevalent during pandemic time than pre-pandemic.

CHAPTER 5: CONCLUSION

5.1 Summary of Key Findings

This study contributes to the literature by examining the linkages in volatility spillovers between the stock markets in the ASEAN-5 countries with the US stock markets using daily key indices data spanning from 1 January 2017 to 31 December 2020, focusing on the period before the Covid-19 pandemic and during the pandemic. Bivariate GARCH-BEKK model is employed to study the market interdependence, and the spillover effects can be examined from 2 sources, namely past shocks and past volatility.

During the pre-pandemic period, responses to past shocks are evident for all ASEAN-5 markets except Thailand, which suggest that past innovations do not affect the volatility of the Thailand market. The past volatility effects are a lot stronger than past shock in all ASEAN-5 stock markets. Specifically, own-volatility spillover is stronger than cross-volatility spillover, suggesting that while all the ASEAN-5 markets are integrated with the US market, domestic conditions' fluctuations are better explained by domestic conditions rather than global influences.

In contrast to the pre-pandemic period, past shock effects for all ASEAN-5 markets increased significantly during the pandemic, implying an unexpected change in the economy's structure that affects the model exogenously. The past volatility effects are lower than that of the pre-pandemic period. Interestingly, however, the cross-volatility spillover is generally higher than the own-volatility for ASEAN markets except for Thailand and the Philippines. This finding suggests the cross-volatility transmission is more prevalent during the pandemic.

5.2 Limitations and Suggestions for Future Research

While this paper studies the interdependence of each ASEAN-5 with the US stock market, it does not explore the interdependence among the ASEAN-5 markets themselves. A multivariate GARCH with more than two variables would be very difficult to convey meaningful messages theoretically, as there will be too many parameters to be estimated. However, it is worth exploring the interdependence amongst the ASEAN markets themselves to find out how integrated these markets are prior to and during the pandemic. Furthermore, the study could also be extended by utilising the asymmetric GARCH model to capture the asymmetric characteristics of volatility.

Other than that, it would be interesting to expand the study to include more recent data. The year 2021 recorded some record high daily Covid-19 cases in most countries (refer to Figure 1), with multiple new virus variants discovered. However, the rollout of the vaccines has been rapid, and people worldwide are in the progress of being inoculated. Economic re-opening coupled with a very low-interest-rate environment has prompted the stock markets to recover swiftly despite a sharp meltdown in March 2020. The US stock market reached an all-time high recently in May 2021, but ASEAN markets broadly lagged. The dynamic relationship between these markets is worth exploring with the most recent data.

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