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# Is the COVID-19 pandemic more contagious for the Asian stock markets? A comparison with the Asian financial, the US subprime and the Eurozone debt crisis

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## ABSTRACT

The ongoing COVID-19 pandemic has sent shock waves across the global stock markets. Several financial crises in the past too have had a global impact with their reach extending beyond the country of origin. The current study compares the contagion effect of four such crises viz. the Asian financial crisis, the US subprime crisis, the Eurozone debt crisis, and the currently ongoing Covid-19 crisis on Asian stock markets to understand which of these has had the most severe impact. It finds that among all the four crises, the US subprime crisis has been the most contagious for the Asian stock markets. The study also highlights the difference between severities of a liquidity crisis versus a real crisis and identifies the markets that remained insulated from all these crises, a finding which will be useful for portfolio managers in devising their asset allocation.

## 1. Introduction

The catastrophic impact of a financial crisis is one of the most researched issues in financial markets worldwide. A typical consequence of a financial crisis is that it causes severe disruption in originating financial market and sets off volatility shock waves across other financial markets (Akhtaruzzaman, Boubaker, & Sensoy, 2021; Allen & Gale, 1999; Baig and Goldfajin 1998; Corbet, Hou, Yang, Lucey, & Oxley, 2021; Celik, 2012; Diebold & Yilmaz, 2012; Mohti, Dionisio, Vieira, & Ferreira, 2019). This type of transmission or comovement between financial markets across various geographies is commonly referred to as 'contagion'. The term contagion has several definitions and as of date, there is lack of unanimity on a common one. For the purpose of our study, we follow Forbes and Rigobon (2002) who define it as "a significant increase in cross-market linkages after a shock to one country (or group of countries)." To be more specific, contagion will occur only if two markets show a significant increase in correlation during the crisis period as compared to the pre-crisis period. However, if this correlation does not increase significantly, the comovement is termed as interdependence (Forbes & Rigobon, 2002).

The financial markets have witnessed several crises in the past, whose reverberations were felt across the globe. The last decade of the 20th century saw the unfolding of the Mexican crisis in 1994, the Asian financial crisis in 1997, and the Russian default in 1998. The onset of the 21st century brought the US subprime crisis in 2008, the Eurozone debt crisis in 2009, and the COVID-19 pandemic in early 2020 (Akhtaruzzaman et al., 2021).

A number of characteristics mark these financial crises, including unusual variation in asset prices and credit volume, significant

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disruptions in credit markets, liquidity and solvency problems of financial institutions, balance sheet issues of firms, sovereign debt crisis, and exceptional monetary authority intervention followed to tame the crisis (Classes and Kose, 2013). There are two schools of thought regarding how a financial crisis can spread across countries. The first believes that the presence of real and financial connections arising from macroeconomic fundamentals, such as changes in trade links, interest rates, exchange rates, and oil prices (Mohi et al., 2019) leads to the spread of a financial crisis across countries. The second suggests that a crisis can spread due to portfolio rebalancing strategies and investor reaction to unfavorable conditions in the crisis-originating country. Thus, internationally diversified investors may become wealth-constrained during a crisis and adopt portfolio rebalancing strategies to balance their loss in the crisis country by liquidating their positions in other countries, thereby, causing a downward market movement in these countries (Calvo, 2004; Kaminsky & Reinhart, 1998; Karolyi & Stulz, 1996; Kyle & Xiong, 2001; Rijckeghem & Mauro, 2001; Yuan, 2005).

In line with this, various studies have evaluated the presence of either real and financial connections, or stock market imperfections and investors' herding behavior in making a country vulnerable to a crisis that has originated in another country and hence causing contagion (Boyer, Kumagal, & Yuan, 2006; Kaminsky & Reinhart, 1998; King & Wadhvani, 1990; Kodres & Pritsker, 2002; Rijckeghem & Mauro, 2001).

Extending the previous research, the current study evaluates the contagion between the stock markets of thirteen Asian economies across the four major financial crises that took place from the 1990s till date. It specifically evaluates if the recent COVID-19 pandemic caused a stock market contagion. It also compares the pandemic's impact with the Asian financial crisis, the US subprime crisis, and the Eurozone debt crisis across various developed and emerging markets in Asia. This is the first study of its kind to investigate investor-induced stock market contagion during the four major crises and understand whether the COVID-19 pandemic, which started as a health crisis affecting the real market and later transformed into a financial crisis, is as severe in its spread as the previous financial crises. To assess this, we analyse the contagion effect in terms of the dynamic correlation of the markets resulting from information asymmetry and irrational behaviour of investors, i.e., their herding behavior, also referred to as 'pure contagion' (Morales & Andreosso-O'Callaghan, 2012). We find that among all the four crises, it is not the COVID-19 pandemic but the subprime crisis that has been the most pervasive and contagious in spreading across the majority of the Asian stock markets.

The study is important on several counts. First, it provides an insight into how various crises, with different causes of origin, resulted in a different degree of transmission of risks to markets outside the originating country. Second, it helps policymakers and regulators understand whether shocks due to real connections (viz. COVID-19) are more severe for investors than shocks due to direct financial connections (viz. Asian, US subprime, Eurozone debt crisis). The comparative analysis presented here of the shocks due to financial connections help understand the type of crisis that could require higher insulation of the domestic economy. Third, portfolio managers and other international investors can use the findings in determining their portfolio diversification strategy across Asian markets. A comprehensive analysis of these crises has never been done in the past, to the best of our knowledge.

The rest of the research is organized as follows. Section 2 provides a detailed review of the literature on financial contagion caused by the selected four crises; Section 3 presents the empirical framework; Section 4 discusses the empirical findings and analysis; and finally, Section 5 concludes with some suggestions for further research.

## 2. Review of literature

The extant literature provides little evidence to support the claims that macroeconomic fundamentals act as determinants of contagion (Boyer et al., 2006). These fundamentals may only result in interconnectedness, but not contagion between countries. Karolyi and Stulz (1996) and King, Sentana, and Wadhvani (1994) find no evidence of comovements of stock markets due to macroeconomic variables. Connolly and Wang (2003) find that economic fundamentals do not determine movement in international equity markets in the USA, the UK & Japan. Forbes and Rigobon (2002) also find partial explanations for stock market comovement via trade links. However, Kyle and Xiong (2001), Calvo (2004) and Boyer et al. (2006) find the presence of wealth-constrained investors in crisis countries. These investors are better informed than others and have expectations from the fundamentals of the crisis country. Hence, they re-evaluate their risk and rebalance their portfolios to cover their losses and invest in low-risk markets. This divestment and investment of funds from one market to another cause significant movements in both the crisis country and the home country. Uninformed investors soon follow the informed investors and sell in panic (Yuan, 2005), resulting in the spread of contagion via stock markets. In the following sections, we discuss the past literature related to contagion caused by the selected crisis.

### 2.1. The Asian financial crisis

The research on contagion became prominent during the late 1990s when the Asian crisis spread quickly across national boundaries. The crisis started post the devaluation of the Thai baht, on July 2, 1997, when regional markets across Asia came under growing strain, which was reflected in the subsequent unravelling of the regulated currencies of Indonesia and Malaysia. As the crisis became more severe, the entire region experienced extreme foreign exchange and stock market volatility, resulting in the collapse of the Korean Won. Authorities in these countries were pressurized into increasing the interest rates to avoid a run on their currencies and stock markets that had plummeted to new lows. As a consequence, Hong Kong and Taiwan were also impacted, placing pressure on their currencies and depressing local stock markets sharply. The first true global contagion then broke out with the crashing of the financial markets in the United States and Europe as well. Several researchers have examined the potential reasons for the occurrence and spread of this contagion across geographies (Allen & Gale, 1999; Baig and Goldfajn 1998; Chowdhary and Goyal, 2000; Chinn, 1997; Corsetti, Pesenti, & Roubini, 1999; Forbes & Rigobon, 2002; Goldstein, 1998; Jang & Sul, 2002; Kuper & Lestano, 2007). These studies suggest that the Asian crisis resulted in financial market instability, which caused market participants across various countries

to move together. This movement intensified the relationship among the financial markets during the crisis, resulting in contagion. [Chancharoenchai and Dibooglu \(2006\)](#) evaluated contagion effect of the Asian crisis in various Southeast Asian stock markets namely Thailand, Philippines, Indonesia, Malaysia, Korea and Taiwan. Their study observed that the crisis began in Thailand and spread through the markets of Southeast Asia. [Khan and Park \(2009\)](#) revisited the contagion in five Asian countries viz. Thailand, Malaysia, Indonesia, Korea, and Philippines, and attributed it to the herding behavior of investors in the Asian markets, based on the belief that if Thailand is facing trouble, other Asian markets will follow suit.

## 2.2. The US subprime crisis

The US subprime crisis can be attributed to the burst of the U.S. mortgage bubble in 2007. It was marked by the bankruptcy of Lehman Brothers, the country's biggest bankruptcy till date, and had global ramifications. Followed by this, the Eurozone sovereign debt crisis began after the government of Greece declared that its public deficit had hit 12.7 per cent of the domestic GDP, four times the permitted cap. Various academics interested in financial contagion have assessed these two crises because of their widespread effects.

Among the studies on contagion caused by the US subprime crisis, [Longstaff \(2010\)](#) established the financial contagion of 2008 and attributed its spread to liquidity and risk-premium channels across major countries of the world. [Bekaert, Ehrmann, Fratzscher, and Mehl \(2011\)](#) used an asset-pricing framework to find the existence of a very small but a statistically significant transmission of the subprime crisis to country-industry equity portfolios in 55 countries. In addition to the contagion effects from US markets, the study also found contagion effects from domestic equity markets to individual domestic equity portfolios. [Gallegati \(2012\)](#) used a wavelet-based approach to test whether contagion occurred during the US subprime crisis of 2007. The study found that all stock markets have been affected by the US subprime crisis and that Brazil and Japan are the only countries in which contagion is observed at all scales. Their results provide evidence of international contagion effects from the USA during the subprime crisis, and indicate that these contagion effects do not display their influence uniformly across scales, except for Japan and Brazil. [Chudik and Fratzscher \(2012\)](#) demonstrated that investors had a flight-to-safety behavior during US subprime crisis due to which financial capital moved from emerging market economies to bond markets in the USA and other advanced economies. [Neaime \(2012\)](#) studied the contagion related global and regional financial linkages between MENA stock markets and the more developed financial markets, as well as on the intra-regional financial linkages between MENA countries' financial markets. [Horta, Lagoa, and Martins \(2014\)](#) found that financial markets in Canada, Japan, as well as European markets viz. Belgium, France, Netherlands and UK displayed significant signs of contagion while those in Germany and the Portugal showed mere interdependence. [Dimitriou, Kenourgios, and Simos \(2013\)](#) found significant contagion among the BRIC markets with the USA during different phases of the subprime crisis, which they attributed to their common trade and financial characteristics. [Wang \(2014\)](#) evaluated the contagion impact on six major East Asian stock markets namely, China, Hong Kong, Taiwan, Singapore, South Korean and Japan, due to the subprime crisis and found a strong contagion among the USA, Japanese and South markets only. [Romero-Meza, Bonilla, Benedetti, and Serletis \(2015\)](#) studied the contagion caused by financial crises in Latin America. [Jin and An \(2016\)](#) found substantial contagion effects from the USA to the stock markets of the BRICS countries during the global financial crisis of 2007–2009; however, the degree to which financial markets respond to such shocks varies by market, depending on the level of integration with the global economy. [Kim, Kim, and Lee \(2015\)](#) found that the US subprime crisis had a major spillover impact on five Asian countries namely, Indonesia, Korea, Philippines, Thailand and Taiwan, and that this impact was stronger in the foreign exchange than the equity markets. [Mohti et al. \(2019\)](#) studied the impact of the US financial and the Eurozone debt crises on a set of 18 frontier stock markets. Using the USA and Greece as benchmark countries, they found a weak evidence of contagion during the Eurozone debt crisis to prove that the US subprime crisis created a greater turmoil on the frontier markets. [Kao, Zhao, Ku, and Nieh \(2019\)](#) studied asymmetry in contagion effects of US subprime crisis between the U.S. S&P 500 Index and 23 markets in Asia, Europe, and America. They found that the subprime crisis determined the degree of contagion, depending on the financial linkage to the U.S. market, which also demonstrated the differences in the causes and influence between the subprime crisis and other financial crises in emerging markets. [Tilfani, Ferreira, and Boukfaoui \(2021\)](#) measure the cross correlation between the USA and other eight stock markets (the remainder of the G7 plus China and Russia) to study the contagion effect during the US sub-prime crisis. They found a decrease in correlation levels of other stock markets with US stock market before the crisis and an increase during the crisis, pointing out to the presence of contagion effect.

## 2.3. Eurozone debt crisis

[Missio and Watzka \(2011\)](#) studied the contagion effect in Euro area through the correlation structure of Greek, Portuguese, Spanish, Italian, Dutch, Belgian and Austrian bond yield spreads over the German yield. The findings of their study point towards the presence of contagious effects spreading from Greece mainly to Portugal, Spain, Italy and Belgium. The study also found that the announcements of negative rating for Greece have generated contagious effects to Portugal and Spain. [Grammatikos and Vermeulen \(2012\)](#) examined the contagion effect of Eurozone debt crisis on fifteen EMU countries and found strong evidence of the same.

[Samitas and Tsakalos \(2013\)](#) studied eight European markets viz. the UK, France, Germany and the "PIIGS" (Portugal, Italy, Ireland, Greece and Spain) to decipher the Eurozone debt crisis. They found that the Greek crisis seems to have had less of an effect on the correlation between the Greek stock market and the seven indices studied. [Ahmad, Bhanumurthy, and Sehgal \(2014\)](#) assessed the contagion effects of Eurozone crisis on stock markets of seven Eurozone and six non-Eurozone countries. The study observed that among the Eurozone countries Austria, Belgium France and Germany and among the non-Eurozone Denmark, Sweden and UK were the most severely affected by the contagion shock. Thus the EU-based diversification strategies were not effective during Eurozone crisis.

Aizenman, Jinjarak, Lee, and Donghyun (2016) evaluated the impact of the eurozone debt crisis on the bond market and stock market of the developing countries and found mixed results regarding the presence and magnitude of financial contagion. They concluded that the eurozone debt crisis largely affected Europe. Samarakoon (2017) investigated the contagion effect of the Eurozone debt crisis on the fifty-two stock markets around the world and found that the Asian stock markets display no signs of contagion from the Eurozone crisis. Kosmidou, Kousenidis, Ladas, and Negkakis (2018) further studied the Eurozone debt crisis and show that policy announcements from the EU, ECB, and IMF had an effect on the transmission of banking sector shocks to the stock market during this crisis. Furthermore, they found that national governments' policy responses seemed to play an important role in the spread of the crisis. Anastasopoulos (2018) evaluated the contagion effect of Greek debt crisis on the stock markets of European countries. The study found that the crisis was contagious, although the contagion effects were not persistent.

#### 2.4. The COVID-19 pandemic

The World Health Organization declared COVID-19 to be a pandemic on March 11, 2020. Initially, the bulk of COVID-19 confirmed cases and deaths came from China and the G7 countries (WHO, 2020a). However, the virus soon spread across the globe, jolting global financial markets. Literature on the financial impacts of the COVID-19 is mushrooming day by day. Baker et al. (2020) found voluntary social distancing and government restrictions on commercial activity to be the main driving force behind the impact of Covid-19 on the US stock market. Al-Awadhi, Al-Saifi, Al-Awadhi, and Alhamadi (2020) studied the Chinese stock market, and confirmed that both the daily growth in the total confirmed cases and total cases of death caused by COVID-19 had significant negative effects on stock returns across all companies. Papadamou, Fassas, Kenourgios, and Dimitriou (2020) used Google-based anxiety measures and found a rising risk-aversion during COVID-19 pandemic in thirteen major stock markets, across Europe, Asia, USA and Australia regions, thus resulting in contagion effect. Sharif, Aloui, and Yarovaya (2020) related the spread of COVID-19, oil price volatility shock, the stock market, geopolitical risk, and economic policy uncertainty in the USA within a time-frequency framework. Zaremba, Kizys, Aharon, and Demir (2020) demonstrated that non-pharmaceutical interventions during Covid-19 significantly increased equity market volatility across 67 countries around the world. Ashraf (2020) examined stock market reaction to the COVID-19 pandemic using regularly reported COVID-19 cases and deaths, as well as stock market returns data from 64 countries. The study found that the negative market reaction was strongest during the early days of reported cases and this reaction differed over time depending on the stage of the outbreak. Banerjee (2021) looked into the possibility of financial contagion between China and its major trading partners during the pandemic. The study showed substantial financial contagion in most developed and emerging markets with significant trading relationships with China. Malik, Sharma, and Kaur (2021) measured the contagion during COVID-19 via volatility spillovers between BRIC countries and the USA. They found that as compared to Russia and India, the USA, China, and Brazil had the highest own volatility spillovers while Russia was the least vulnerable to external shocks. The United States and Russia had the greatest and most long-term spillover impact. Akzahrutuzzman et al. (2021) explored how financial contagion occurred between China and G7 countries during COVID-19 based on financial and non-financial firms. Their findings revealed that correlations between the stock returns of these firms across G7 have increased significantly and this increase is much higher for financial firms during the period of COVID-19 outbreak, demonstrating the critical position they play in financial contagion transmittance. Okorie and Linb (2020) investigated the fractal contagion effect of the COVID-19 crisis on the stock markets of 32 countries. The results confirmed the existence of a significant contagion impact in the stock markets; however, the impact is short-lived. These effects can be seen in both stock markets and volatility. Fu, Chengkum and Xinyang (2021) found the impact of the COVID-19 pandemic on the stock markets of 15 countries selected from Asia, Europe, Latin America, and North America. Using external dependence tests of contagion, the study found that contagion effects were widespread to global equity markets in four regions. Latin America and North America are highly exposed to contagion risks, followed by Europe, with Asia being least vulnerable. Out of these, Latin America with severe epidemic had a stronger contagion effect. Iwanicz-Drozdowska, Rogowicz, Kurowski, and Smaga (2021) investigated the impact of a wide range of economic as well as non-economic events on stock market spillover effects across 16 major developed and emerging countries over the 2000–2020 period. They found the COVID-19 pandemic to be the most widespread sources of non-economic contagion and prudential measure taken by governments to be the most influential source of economic contagion.

The COVID-19 crisis is a recent and ongoing phenomenon, which offers the scope for further understanding its contagion effect. The review of literature discussed above shows that existing research on contagion in Asian countries has mostly focused on the Asian financial and the US subprime crises, with a few studies on the Eurozone debt crisis. However, we did not find a comparative analysis of the severity of all the past crises, especially in relation to the COVID-19 pandemic. Such an analysis is required in order to identify which crisis can serve as an ideal laboratory for studying the best combination of the Asian stock markets for a portfolio diversification strategy, given their relationships during these crises.

Our study fills this gap by covering the episodes of four financial crises, including the COVID-19 pandemic, to understand whether this pandemic has been the most contagious for the Asian stock markets among all the crises. Additionally, this comparison gives a better insight into whether the policy responses from regulators across countries, towards any crisis, have been useful in preventing contagion during subsequent crises, enabling international diversification to be useful when it is needed the most.

### 3. Empirical framework

#### 3.1. Data

We investigate the contagion effect for emerging as well as developed stock markets of Asia during the Asian financial crisis, the US

**Table 1**  
Sample Asian markets and the epicenter of each crisis.

Markets	Countries
Emerging Markets	China, Indonesia, India, Malaysia, Philippines, South Korea, Taiwan, Thailand
Developed markets	Australia, Hong Kong, Japan, New Zealand, Singapore
Epicenter of Asian crisis	Thailand
Epicenter of Subprime crisis	United States of America (USA)
Epicenter of European debt crisis	Greece
Epicenter of COVID-19 crisis	China

**Table 2**  
Indices selected for the sample markets.

Country	Index
China	Shanghai Composite Index
India	Nifty 50
Indonesia	Jakarta Stock Exchange Composite Index (JCI)
Malaysia	FTSE Bursa Malaysia KLCI index
Philippines	Philippines Stock Exchange PSEi Index
South Korea	The Korea Composite Stock Price Index (KOSPI)
Taiwan	Taiwan Capitalization Weighted Stock Index (TCWI)
Thailand	The Stock Exchange of Thailand (SET)
Australia	S&P/ASX 50
Hong Kong	Hang Seng Index
Japan	Nikkei Index
New Zealand	NZX 50
Singapore	Straits Times Index (STI)

**Table 3**  
Timeline and cut points for calm and crisis periods.

Crisis	Calm period (Data points)	Crisis period	Supporting literature
Asian Crisis	January 1, 1995–31st December 1996 (521 data points)	July 2, 1997-May 18, 1998 (228 data points)	<a href="#">Baig and Goldfajin (1998)</a>
US Subprime crisis	January 4, 2005-July 31, 2007 (670 data points)	August 1, 2007- December 7, 2009 (613 data points)	<a href="#">Horta et al., (2014, 2016)</a> , <a href="#">Mohti et al. (2019)</a>
European crisis	January 4, 2005- July 31, 2007 (670 data points)	December 8, 2009-April 27, 2012 (707 data points)	<a href="#">Mohti et al. (2019)</a>
COVID-19 crisis	January 1, 2018-December 31, 2019 (520 data points)	January 1, 2020- April 30,2021 (347 data points)	Based on our own analysis taking US subprime and European crisis periods as benchmarks

subprime crisis, the Eurozone debt crisis, and the ongoing COVID-19 pandemic. Accordingly, we compute Dynamic Correlation Coefficients (DCC) coefficients between the crisis-originating country (i.e. the epicenter of the crisis) and each individual Asian market. We consider thirteen Asian countries (as classified under emerging and developed markets by Morgan and Stanley Capital International – MSCI). [Table 1](#) shows the emerging and developed Asian markets taken for the study, and the country taken as epicenter of each crisis.

Further, [Table 2](#) gives the details of indices selected for each of the sample market. We select the prominent index for each country to ensure that our results are not affected by illiquidity. The data includes daily closing prices of prominent indices of the selected countries. These prices are gathered from the Bloomberg database. The data for NZX 50 index (New Zealand) and Straits Times Index (Singapore) was not available for the period of 1995–1996. Hence, only eleven countries are considered for testing contagion during the Asian crisis.

[Table 3](#) gives the timeline and the cut points followed for the calm (tranquil) period, and also the crisis period, based on previous studies ([Baig & Goldfajin \(1998\)](#), [Horta et al. \(2014\)](#), [Horta, Lagoa, and Martins \(2016\)](#), [Mohti et al. \(2019\)](#)). For COVID-19 crisis, we select the calm and crisis periods based on our own analysis taking US subprime and European crisis periods as benchmarks. We calculate the returns of stock indices as  $L_n(P_t/P_{(t-1)})$  where  $P_t$  is the price level of the index at time  $t$ .

### 3.2. Methodology

We use [Engle \(2002\)](#) DCC-GARCH model to test the presence of contagion during the four crises. Dynamic conditional correlation

(DCC) allows the detection of time variance in conditional correlations, which can occur due to active investor reaction to news and innovations in the market. This helps in understanding the contagion effect in the market due to the investors' herding behavior.

A number of studies (Embrechts, McNeil, & Straumann, 2002; Huang & Lin, 2004; Rodríguez, 2007) have used copula approach as an alternative to correlation in the modeling of financial risks. Fitting copulas with different tail behavior makes it possible to test whether times of increased dependence can also be characterized by changes in one or both tails of the distribution. In contrast to linear correlation, a copula captures the complete dependence structure inherent in a random vector (Embrechts et al., 2002; Huang & Lin, 2004). However, in order to capture shifts in the dependence structure, the copula that describes it, must be time varying. Patton (2006a, 2006b) pioneered the study of time-varying copulas. On the other hand, DCC GARCH is a new class of multivariate model given by Engle in 2002 that has lower mean absolute error in comparison with any other mean reverting model. DCC GARCH provides contagion effect in two aspects i.e. contagion effect of the news (shock) as well as volatility persistence. It is one of the novel multivariate analysis methodology to model a contagion effect (Dungey, Fry, Gonzalez-Hermisillo, & Martin, 2005). DCC-GARCH also helps to solve the problems of increased dimensionality in multivariate GARCH and constant correlation in the Constant Conditional Correlation (CCC) model (Bollerslev, 1990; Engle, Ito, & Lin, 1990). Besides, it calculates the uniform residuals' correlation coefficients and thus, accounts for heteroscedasticity directly. Additionally, the technique adjusts the variance, so it is free of volatility bias (Chiang, Jeon, & Li, 2007). In contrast to the volatility-adjusted cross-market correlation coefficient of Forbes and Rigobon (2002), DCC-GARCH constantly changes the correlation for time-varying volatility. So, DCC is a superior estimator of correlation (Cho & Parhizgari, 2009). This method has a clear computational advantage over multivariate GARCH models as the number of parameters to be estimated are independent of the series to be correlated. This enables the estimation of very large correlation matrices.

The DCC-GARCH measure has been used in various empirical studies. Banerjee (2021); Bekaert, Harvey, and Ng (2005), Boyer et al. (2006); Celik (2012); Chiang et al. (2007), Corsetti, Pericoli, and Sbracia (2005); Jeon and Moffett (2010), Syllignakis & Kourteas (2011) and Mighri (2013) have used the measure to examine contagion behavior in financial markets during the crises cycles.

### 3.2.1. DCC-GARCH model

There are two steps in the estimation of the DCC-GARCH model. The first step estimates the univariate GARCH model and the second, the conditional correlations that vary across time. The multivariate DCC-GARCH model can be defined as:

$$X_t = \mu_t + H_t^{1/2} \varepsilon_t \tag{1}$$

$$\begin{cases} H_t = D_t R_t D_t \\ R_t = (\text{diag}(Q_t))^{-1/2} Q_t (\text{diag}(Q_t))^{-1/2} \\ D_t = \text{diag}(\sqrt{h_{11,t}}, \sqrt{h_{22,t}}, \dots, \sqrt{h_{NN,t}}) \end{cases} \tag{2}$$

Here,  $X_t = (X_{1t}, X_{2t}, \dots, X_{Nt})$  is the vector of past observations.  $H_t$  is the multivariate conditional variance and  $\mu_t = (\mu_{1t}, \mu_{2t}, \dots, \mu_{Nt})$  is the vector of conditional returns.  $\varepsilon_t = (\varepsilon_{1t}, \varepsilon_{2t}, \dots, \varepsilon_{Nt})$  is the vector of standardized residuals and  $R_t$  is an  $N \times N$  symmetric dynamic correlations matrix.  $D_t$  is a diagonal matrix of conditional standard deviation for return series obtained from estimating the univariate GARCH model with  $\sqrt{h_{NN,t}}$  on the  $i^{\text{th}}$  diagonal and  $i = 1, 2, \dots, n$ .

The model defines DCC specification as follows:

$$\begin{aligned} X_t &= (1 - \psi - \xi) \bar{Q} + \xi Q_{t-1} + \psi \delta_{i,t-1} \delta_{j,t-1} \\ R_t &= Q_t^{*-1} Q_t Q_t^{*-1} \end{aligned} \tag{3}$$

Here,  $(Q_t) = |q_{ij}|$  is  $(N \times N)$  time-varying covariance matrix of residuals.  $(\delta^{it} = \varepsilon_t / \sqrt{h_{it}})$ ,  $\bar{Q}$  is the unconditional correlations of  $\delta_{it}$ ,  $\delta_{jt}$ , and  $\psi$  and  $\xi$  are non-negative scalar parameters that satisfy the condition  $\psi + \xi < 1$ .  $Q_t^* = [q_{ii,t}^*] = \sqrt{q_{ii,t}}$ . Here,  $\sqrt{q_{ii,t}}$  is a diagonal matrix with the square root of the  $i^{\text{th}}$  diagonal element of  $Q_t$  on its  $i^{\text{th}}$  diagonal position. Therefore, for a pair of markets  $i$  and  $j$ , their conditional correlation at time  $t$  can be defined as:

$$\rho_{ij,t} = \frac{(1 - \psi - \xi) \bar{q}_{ij} + \psi \delta_{i,t-1} \delta_{j,t-1} + \xi \bar{q}_{ij,t-1}}{[(1 - \psi - \xi) \bar{q}_{ii} + \psi \delta_{i,t-1}^2 + \xi \bar{q}_{ii,t-1}]^{1/2} [(1 - \psi - \xi) \bar{q}_{jj} + \psi \delta_{j,t-1}^2 + \xi \bar{q}_{jj,t-1}]^{1/2}} \tag{4}$$

Where  $q_{ij}$  is the element on the  $i^{\text{th}}$  line and  $j^{\text{th}}$  column of the matrix  $Q_t$ . The quasi-maximum likelihood method (QMLE) (Bollerslev, Ray, & Kenneth, 1992) is used to calculate the parameters. The log-likelihood of the estimators, under the Gaussian assumption is stated below:

$$L(\theta) = -\frac{1}{2} \sum_{t=1}^T [(n \log(2\pi) + \log|D_t|^2 + \varepsilon_t' D_t^{-1} D_t^{-1} \varepsilon_t) + (\log|R_t| + \delta_t' R_t^{-1} \delta_t - \delta_t' \delta_t)] \tag{5}$$

Where  $n$ ,  $T$  and  $\theta$  are the number of equations, the number of observations, and the vector of parameters to be derived, respectively.

We use t-tests to find if there is any evidence of contagion. For this, we examine whether DCC coefficients increase significantly during the crisis period as compared to the pre-crisis times. These statistics are for one-sided t-tests (Forbes & Rigobon, 2002). Following Forbes and Rigobon (2002) and Celik (2012), we define the null hypothesis as:

**Table 4**  
Descriptive statistics of stock returns during Asian crisis.

Countries	Pre-crisis period								Crisis period							
	Mean	Max	Min	SD	Skewness	Kurtosis	Jarque Bera+	Obs	Mean	Min	Max	SD	Skewness	Kurtosis	Jarque Bera+	Obs
China	0.0007	0.2699	-0.1791	0.0278	1.3130	24.0146	9736.368	521	0.0006	0.0633	-0.0704	0.0155	-0.7319	7.4819	211.188	228
India	-0.0005	0.0546	-0.0399	0.0134	0.4482	4.4923	65.787	521	-0.0004	0.0696	-0.0820	0.0156	-0.2180	6.9325	148.717	228
Indonesia	0.0006	0.0565	-0.0424	0.0091	0.2242	7.5277	449.381	521	-0.0028	0.1313	-0.1273	0.0306	0.1787	6.4322	113.125	228
Malaysia	0.0005	0.0504	-0.0404	0.0100	0.4652	6.7543	324.767	521	-0.0030	0.2082	-0.1174	0.0314	1.6344	13.0833	1067.400	228
Philippines	0.0002	0.0342	-0.0585	0.0110	-0.3556	5.6987	169.087	521	-0.0012	0.0967	-0.0974	0.0233	0.2457	6.7563	136.334	228
South Korea	-0.0009	0.0438	-0.0395	0.0114	0.1928	3.8348	18.355	521	-0.0034	0.0971	-0.1160	0.0319	0.1799	4.2717	16.594	228
Taiwan	0.0000	0.0540	-0.0698	0.0139	-0.2953	5.6610	161.285	521	-0.0004	0.0555	-0.0681	0.0165	-0.3721	5.1761	50.250	228
Thailand*	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Australia	0.0005	0.0195	-0.0211	0.0050	-0.3372	4.0752	34.974	521	0.0009	0.0276	-0.0274	0.0087	-0.2650	3.7759	8.387	228
Hong Kong	0.0010	0.0545	-0.0759	0.0115	-0.4845	8.2154	610.845	521	-0.0021	0.1725	-0.1473	0.0307	0.4473	10.9481	607.736	228
Japan	0.0000	0.0608	-0.0576	0.0120	0.1008	5.8940	182.701	521	-0.0012	0.0766	-0.0543	0.0175	0.1471	5.1735	45.702	228
New Zealand* *	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Singapore* *	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

\*Crisis originating country

+All the values are significant at 1%

\* \*Data not available



**Table 5**  
Descriptive statistics of stock returns during the Subprime crisis.

Countries	Pre-crisis period								Crisis period							
	Mean	Max	Min	SD	Skewness	Kurtosis	Jarque Bera+	Obs	Mean	Min	Max	SD	Skewness	Kurtosis	Jarque Bera+	Obs
China	0.0019	0.0789	-0.0926	0.0159	-0.6652	7.8079	694.74	670	-0.0004	0.0903	-0.0804	0.0232	-0.1351	4.5135	60.37326	613
India	0.0011	0.0611	-0.0701	0.0137	-0.6427	6.0131	299.58	670	0.0003	0.1633	-0.1301	0.0236	0.1430	8.3659	737.51	613
Indonesia	0.0012	0.0532	-0.0652	0.0117	-0.7746	7.3960	606.48	670	0.0002	0.0762	-0.1095	0.0199	-0.5073	7.6253	572.71	613
Malaysia	0.0006	0.0260	-0.0475	0.0064	-0.9622	10.4440	1650.34	670	-0.0001	0.0426	-0.0998	0.0111	-1.2145	14.4135	3477.98	613
Philippines	0.0009	0.0470	-0.0825	0.0123	-0.5943	7.1947	530.65	670	-0.0002	0.0937	-0.1309	0.0177	-0.6926	10.4369	1461.63	613
South Korea	0.0012	0.0345	-0.0418	0.0107	-0.4397	4.0406	51.82	670	-0.0002	0.1128	-0.1117	0.0200	-0.4617	8.1936	710.72	613
Taiwan	0.0006	0.0297	-0.0435	0.0091	-0.7493	6.1747	344.06	670	-0.0002	0.0652	-0.0674	0.0181	-0.1840	4.3096	47.26	613
Thailand	0.0003	0.1058	-0.1606	0.0120	-2.6890	59.3742	89,527.83	670	-0.0003	0.0755	-0.1109	0.0178	-0.6794	8.3392	775.28	613
Australia	0.0008	0.0497	-0.0611	0.0099	-0.6931	6.9108	480.62	670	-0.0003	0.0881	-0.0871	0.0181	-0.0770	7.0303	415.49	613
Hong Kong	0.0007	0.0266	-0.0408	0.0087	-0.4667	4.6450	99.87	670	0.0000	0.1341	-0.1358	0.0259	0.1359	6.8329	377.12	613
Japan	0.0006	0.0352	-0.0423	0.0101	-0.3127	4.4644	70.79	670	-0.0008	0.1323	-0.1211	0.0223	-0.3205	8.7154	844.83	613
New Zealand	0.0014	0.0848	-0.0706	0.0163	0.5754	7.5866	624.24	670	-0.0002	0.1207	-0.0741	0.0170	0.7769	9.4012	1108.23	613
Singapore	0.0008	0.0300	-0.0391	0.0085	-0.6979	5.5407	234.59	670	-0.0003	0.0753	-0.0870	0.0188	-0.0147	5.3044	135.65	613

+All the values are significant at 1%

**Table 6**  
Descriptive statistics of stock returns during the Eurozone crisis.

Countries	Pre-crisis period							Euro crisis period								
	Mean	Max	Min	SD	Skewness	Kurtosis	Jarque Bera+	Obs	Mean	Min	Max	SD	Skewness	Kurtosis	Jarque Bera+	Obs
China	0.0019	0.0789	-0.0926	0.0159	-0.6652	7.8079	694.74	670	-0.0004	0.0468	-0.0698	0.0137	-0.5458	5.5166	221.67	707
India	0.0011	0.0611	-0.0701	0.0137	-0.6427	6.0131	299.58	670	0.0002	0.0355	-0.0429	0.0117	-0.0139	3.5357	8.48	707
Indonesia	0.0012	0.0532	-0.0652	0.0117	-0.7746	7.3960	606.48	670	0.0008	0.0701	-0.0930	0.0125	-0.7887	10.1928	1597.35	707
Malaysia	0.0006	0.0260	-0.0475	0.0064	-0.9622	10.4440	1650.34	670	0.0004	0.0240	-0.0253	0.0058	-0.3876	4.9089	125.05	707
Philippines	0.0009	0.0470	-0.0825	0.0123	-0.5943	7.1947	530.65	670	0.0009	0.0498	-0.0527	0.0106	-0.1474	5.6524	209.81	707
South Korea	0.0012	0.0345	-0.0418	0.0107	-0.4397	4.0406	51.82	670	0.0003	0.0490	-0.0642	0.0125	-0.5472	6.0682	312.61	707
Taiwan	0.0006	0.0297	-0.0435	0.0091	-0.7493	6.1747	344.06	670	0.0001	0.0446	-0.0574	0.0115	-0.4956	5.0815	156.58	707
Thailand	0.0003	0.1058	-0.1606	0.0120	-2.6890	59.3742	89,527.83	670	0.0009	0.0575	-0.0581	0.0122	-0.3025	6.3952	350.36	707
Australia	0.0008	0.0497	-0.0611	0.0099	-0.6931	6.9108	480.62	670	0.0003	0.0503	-0.0459	0.0113	-0.2159	4.7105	91.68	707
Hong Kong	0.0007	0.0266	-0.0408	0.0087	-0.4667	4.6450	99.87	670	0.0000	0.0552	-0.0583	0.0134	-0.3105	4.9678	125.43	707
Japan	0.0006	0.0352	-0.0423	0.0101	-0.3127	4.4644	70.79	670	-0.0001	0.0552	-0.1115	0.0132	-0.9469	10.8997	1943.99	707
New Zealand	0.0014	0.0848	-0.0706	0.0163	0.5754	7.5866	624.24	670	0.0005	0.0683	-0.0913	0.0177	0.2093	5.7131	222.01	707
Singapore	0.0008	0.0300	-0.0391	0.0085	-0.6979	5.5407	234.59	670	0.0002	0.0329	-0.0377	0.0096	-0.3595	4.3197	66.53	707

+All the values are significant at 1%

**Table 7**  
Descriptive statistics of stock returns during the Covid-19 crisis.

Countries	Pre-crisis period								Crisis period							
	Mean	Max	Min	SD	Skewness	Kurtosis	Jarque Bera <sup>+</sup>	Obs	Mean	Min	Max	SD	Skewness	Kurtosis	Jarque Bera <sup>+</sup>	Obs
China*	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
India	0.0003	0.0518	-0.0270	0.0081	0.4850	6.8400	340.53	520	0.0005	0.0840	-0.1390	0.0182	-1.6880	16.6858	2864.57	347
Indonesia	0.0000	0.0263	-0.0383	0.0085	-0.4849	4.6670	80.74	520	-0.0001	0.0970	-0.0681	0.0150	0.0987	10.2850	765.67	347
Malaysia	-0.0002	0.0154	-0.0324	0.0058	-0.7617	5.8241	223.51	520	0.0000	0.0663	-0.0540	0.0110	-0.1536	9.4139	594.44	347
Philippines	-0.0002	0.0342	-0.0300	0.0100	0.1156	3.2777	2.83	520	-0.0006	0.0717	-0.1432	0.0186	-1.8929	17.0388	3047.99	347
South Korea	-0.0002	0.0347	-0.0454	0.0083	-0.7115	5.6519	196.61	520	0.0010	0.0825	-0.0877	0.0164	-0.2284	8.4955	438.39	347
Taiwan	0.0002	0.0286	-0.0652	0.0082	-1.4221	13.4638	2552.48	520	0.0011	0.0617	-0.0601	0.0124	-0.6606	8.5099	462.84	347
Thailand	-0.0002	0.0227	-0.0242	0.0066	-0.2294	4.2088	36.29	520	0.0000	0.0765	-0.1143	0.0165	-1.7779	16.7265	2898.62	347
Australia	0.0000	0.0218	-0.0310	0.0072	-0.4070	4.6783	75.39	520	-0.0002	0.0849	-0.1108	0.0161	-1.0904	12.9615	1503.50	347
Hong Kong	-0.0002	0.0413	-0.0525	0.0110	-0.3185	4.5790	62.82	520	0.0001	0.0493	-0.0572	0.0140	-0.4418	4.9307	65.18	347
Japan	0.0001	0.0381	-0.0514	0.0103	-0.7673	6.6397	338.04	520	0.0006	0.0773	-0.0627	0.0148	0.1361	7.6757	316.25	347
New Zealand	0.0004	0.0479	-0.0457	0.0123	-0.1027	4.2199	33.16	520	0.0012	0.0715	-0.0905	0.0183	-0.4216	7.0059	242.30	347
Singapore	-0.0001	0.0231	-0.0304	0.0073	-0.2791	4.1509	35.45	520	0.0000	0.0589	-0.0764	0.0132	-0.6267	10.7046	880.96	347

\*Crisis originating country

\*All the values are significant at 1%

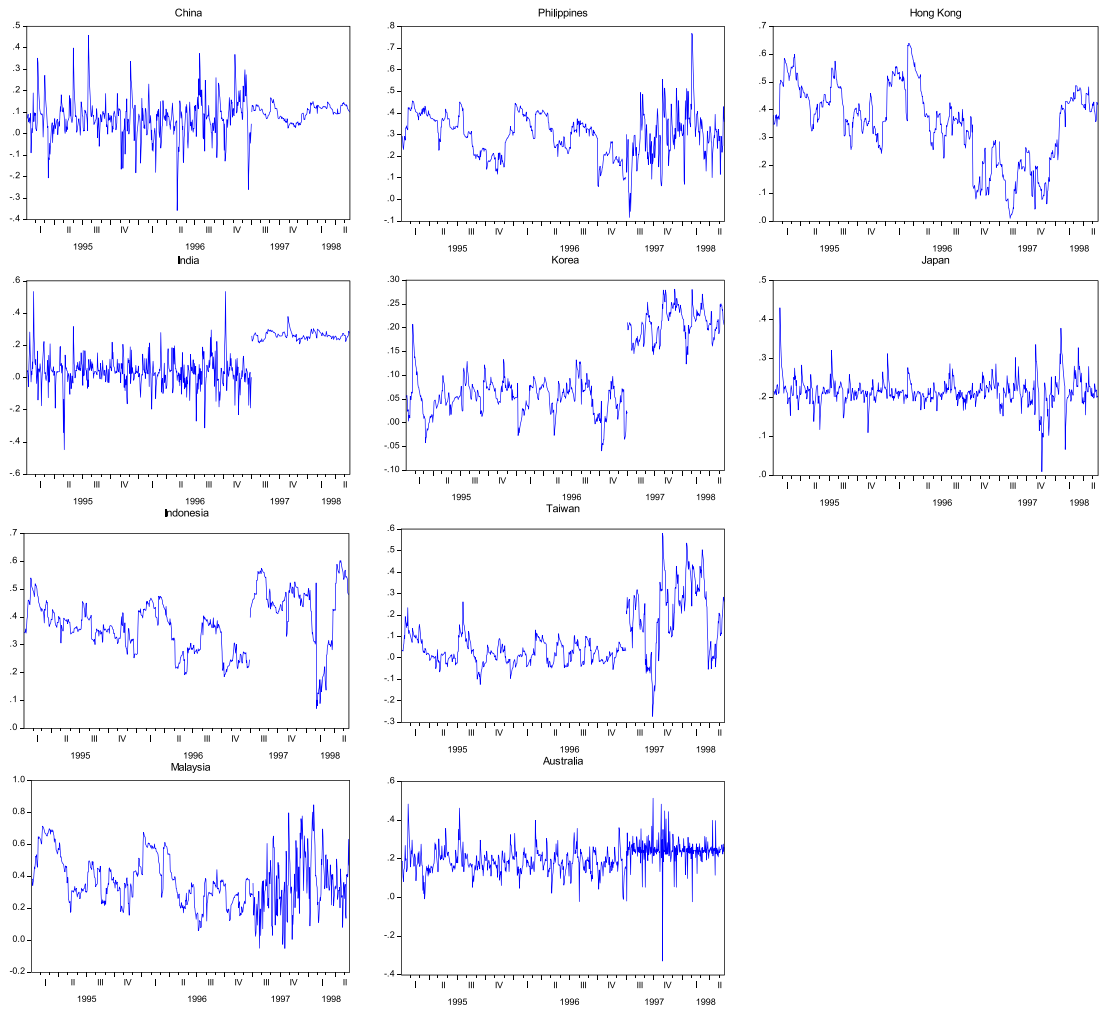


Fig. 1. DCC-GARCH model estimates during Asian crisis.

$$H_0 = \mu_{\rho}^{crisis} > \mu_{\rho}^{pre-crisis}$$

$$H_1 = \mu_{\rho}^{crisis} \leq \mu_{\rho}^{pre-crisis}$$

(6)

Where  $\mu_{\rho}^{crisis}$  and  $\mu_{\rho}^{pre-crisis}$  are the dynamic conditional correlation coefficients means of the sample during the crisis and pre-crisis period.

Given the sample sizes of  $n^{crisis}$ ,  $n^{pre-crisis}$ , population variances of  $\sigma^2_{pre-crisis}$  and  $\sigma^2_{post-crisis}$  and dynamic conditional correlation coefficients estimated via DCC as  $\bar{\rho}_{ij}^{pre-crisis}$  and  $\bar{\rho}_{ij}^{crisis}$ , the t-statistic is calculated as:

$$t = \frac{(\bar{\rho}_{ij}^{crisis} - \bar{\rho}_{ij}^{pre-crisis}) - (\mu_{\rho}^{crisis} - \mu_{\rho}^{pre-crisis})}{\sqrt{\frac{s^2_{crisis}}{n^{crisis}} - \frac{s^2_{pre-crisis}}{n^{pre-crisis}}}}$$

(7)

Here,  $s^2_{crisis} = \frac{1}{n^{crisis} - 1} \sum_{t=1}^{n^{crisis}} (\rho_{ij}^{crisis} - \bar{\rho}_{ij}^{crisis})^2$ ,

$$s^2_{pre-crisis} = \frac{1}{n^{pre-crisis} - 1} \sum_{t=1}^{n^{pre-crisis}} (\rho_{ij}^{pre-crisis} - \bar{\rho}_{ij}^{pre-crisis})^2$$

The degree of freedom  $\nu$  is estimated as follows:

$$\nu = \frac{\left( \frac{s^2_{crisis}}{n^{crisis}} + \frac{s^2_{pre-crisis}}{n^{pre-crisis}} \right)^2}{\frac{s^2_{crisis}/n^{crisis}}{(n^{crisis} - 1)} + \frac{s^2_{pre-crisis}/n^{pre-crisis}}{(n^{pre-crisis} - 1)}}$$

(8)

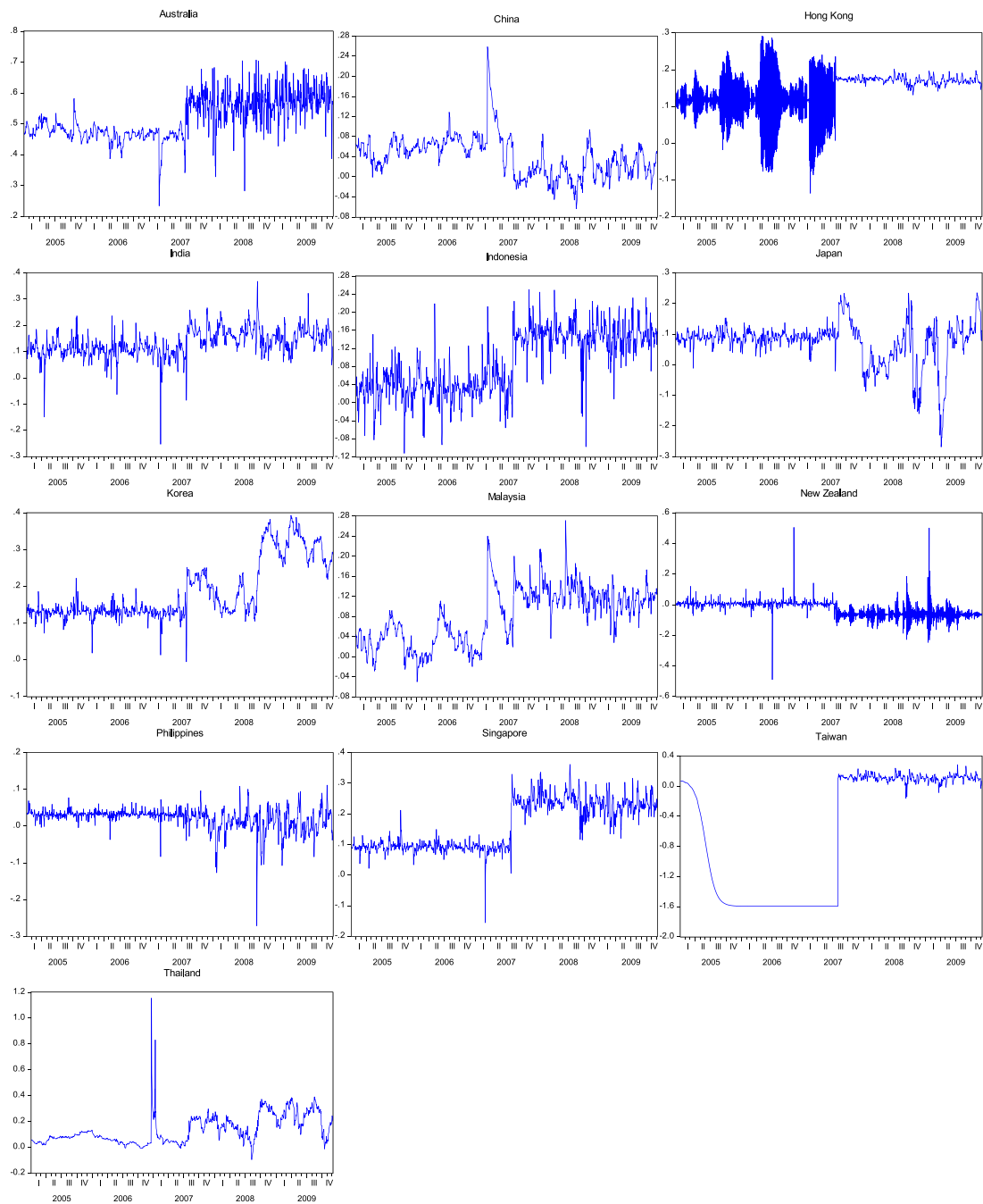


Fig. 2. DCC-GARCH model estimates during Subprime crisis.

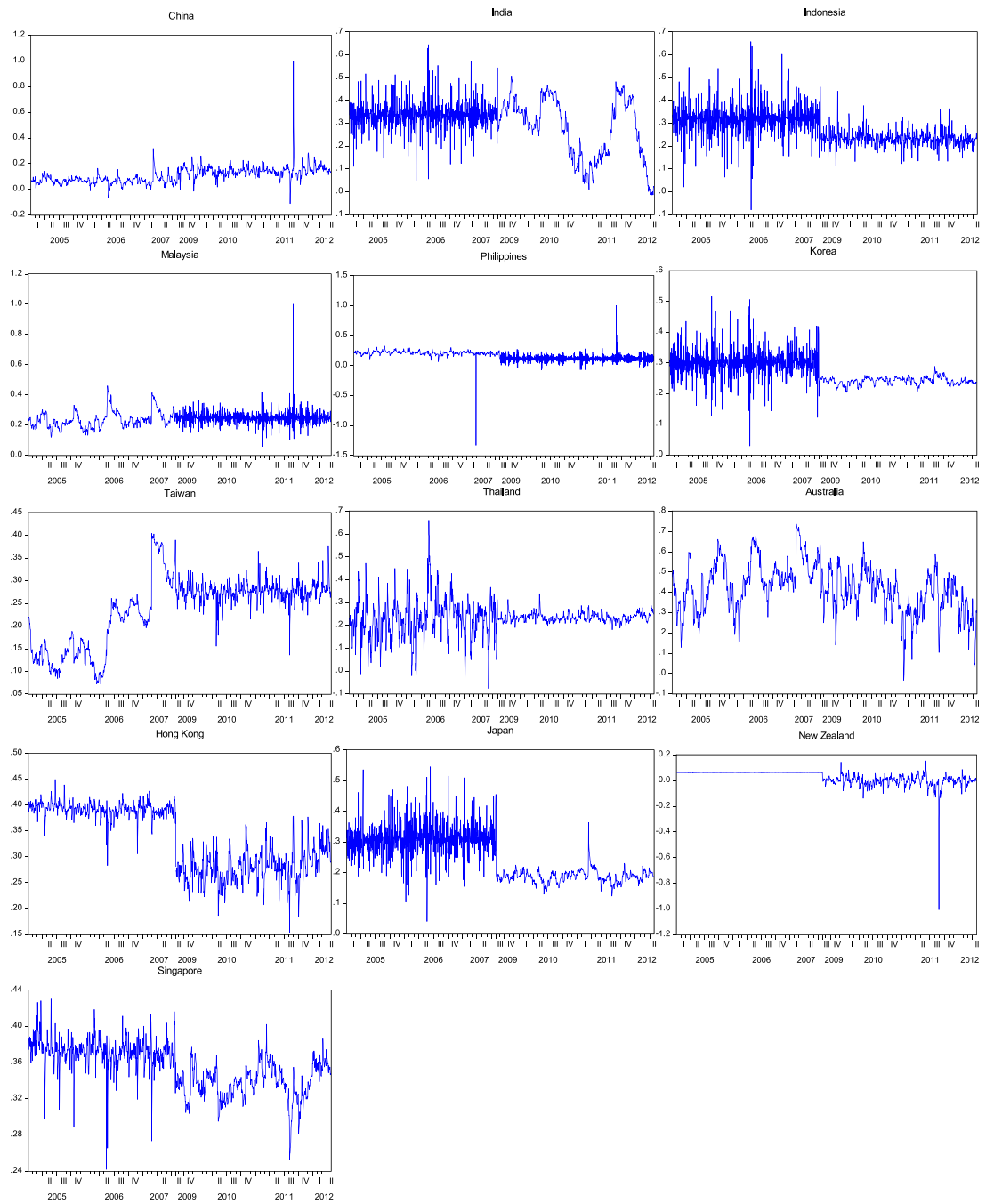


Fig. 3. DCC-GARCH model estimates during Eurozone crisis.

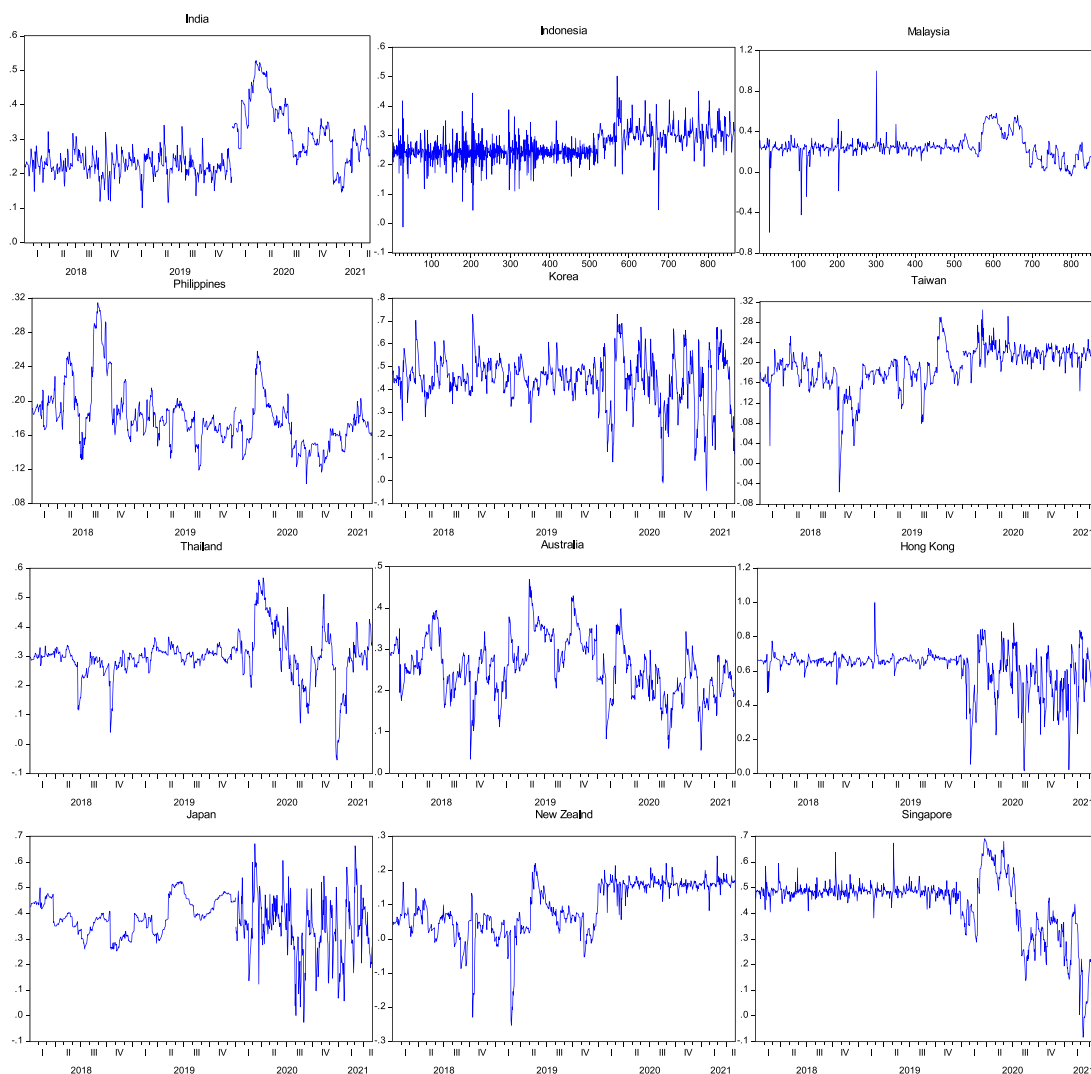


Fig. 4. DCC-GARCH model estimates during Covid-19 crisis.

**Table 8**  
Comparative analysis of unconditional correlation and DCC for the Asian crisis.

Countries	Unconditional correlation			Dynamic Conditional Correlation		
	Pre-crisis	Crisis	% difference	Pre-crisis	Crisis	% difference
China	- 0.0264	- 0.0047	- 82.18%	0.0705	- 0.0465	- 165.97%
India	0.0353	0.2458	596.70%	0.0353	0.2625	643.70%
Indonesia	0.3429	0.4263	24.33%	0.3516	0.4341	23.46%
Malaysia	0.4117	0.3616	- 12.17%	0.3789	0.3532	- 6.79%
Philippines	0.3230	0.3619	12.03%	0.3012	0.2959	- 1.76%
South Korea	0.0266	0.2290	760.16%	0.0544	0.2109	287.95%
Taiwan	0.0328	0.2337	613.43%	0.0276	0.2068	650.48%
Thailand	NA	NA	NA	NA	NA	NA
Australia	0.1789	0.2358	31.77%	0.1856	0.2439	31.42%
Hong Kong	0.3819	0.2984	- 21.88%	0.3898	0.2643	- 32.20%
Japan	0.2243	0.1713	- 23.64%	0.2168	0.2129	- 1.79%
New Zealand	NA	NA	NA	NA	NA	NA
Singapore	NA	NA	NA	NA	NA	NA

**Table 9**

Dynamic conditional correlation coefficient and contagion effect test during the Asian crisis.

	Mean	Variance	t-statistic	Contagion
Pre-crisis DCC Thailand_China	0.07	0.09	- 18.81	
Crisis DCC Thailand_China	0.04	0.07		
Pre-crisis DCC Thailand_India	0.03	0.09	52.22***	Y
Crisis DCC Thailand_India	0.26	0.02		
Pre-crisis DCC Thailand_Indonesia	0.35	0.07	9.50***	Y
Crisis DCC Thailand_Indonesia	0.43	0.12		
Pre-crisis DCC Thailand_Malaysia	0.37	0.14	- 1.90	
Crisis DCC Thailand_Malaysia	0.35	0.17		
Pre-crisis DCC Thailand_Philippines	0.30	0.08	- 0.58	
Crisis DCC Thailand_Philippines	0.29	0.12		
Pre-crisis DCC Thailand_South Korea	0.05	0.03	58.99***	Y
Crisis DCC Thailand_South Korea	0.21	0.05		
Pre-crisis DCC Thailand_Taiwan	0.02	0.05	15.962***	Y
Crisis DCC Thailand_Taiwan	0.20	0.16		
Pre-crisis DCC Thailand_Australia	0.18	0.06	10.38***	Y
Crisis DCC Thailand_Australia	0.24	0.07		
Pre-crisis DCC Thailand_Hong Kong	0.38	0.06	- 11.51	
Crisis DCC Thailand_Hong Kong	0.26	0.07		
Pre-crisis DCC Thailand_Japan	0.22	0.02	- 1.19	
Crisis DCC Thailand_Japan	0.21	0.04		
Pre-crisis DCC Thailand_New Zealand	NA	NA		
Crisis DCC Thailand_New Zealand	NA	NA		
Pre-crisis DCC Thailand_Singapore	NA	NA		
Crisis DCC Thailand_Singapore	NA	NA		

\*\*\* significant at 1%

**Table 10**

Comparative analysis of unconditional correlation and DCC for the Subprime crisis.

Countries	Unconditional correlation			Dynamic Conditional Correlation		
	Pre-crisis	Crisis	% difference	Pre-crisis	Crisis	% difference
China	0.0868	0.2871	230.8%	0.0660	0.0127	- 80.8%
India	0.1126	0.3154	180.1%	0.1043	0.1627	55.9%
Indonesia	0.0222	0.1461	558.9%	0.0363	0.1487	309.3%
Malaysia	0.0799	0.1178	47.4%	0.0438	0.1224	179.7%
Philippines	0.0261	0.0244	- 6.6%	0.0321	0.0106	- 67.1%
South Korea	0.1339	0.2221	65.8%	0.1299	0.2475	90.6%
Taiwan	0.0730	0.1183	62.1%	- 1.0248	0.1097	- 110.7%
Thailand	0.0512	0.0352	- 31.3%	0.0680	0.2053	201.9%
Australia	0.4480	0.5597	24.9%	0.4680	0.5648	20.7%
Hong Kong	0.1269	0.2632	107.4%	0.1142	0.1712	49.9%
Japan	0.0938	0.1090	16.2%	0.0890	0.0580	- 34.8%
New Zealand	0.0173	- 0.0758	- 537.2%	0.0066	- 0.0623	- 1045.7%
Singapore	0.1145	0.2816	145.8%	0.0912	0.2364	159.3%

T-test results indicate the presence of contagion if the t-statistic is more than the critical value. However, if it is less than or equal to the critical value, no contagion has occurred.

#### 4. Empirical analysis

Tables 4–7 present the descriptive statistics of the stock market during the pre-crisis and the crisis periods for the Asian, US subprime, Eurozone debt, and COVID-19 crises. For the Asian crisis, the mean pre-crisis returns of indices are positive for all countries except India and South Korea. However, there are no negative mean returns for the pre-crisis period during the US subprime and Eurozone debt crises. During the COVID-19 pre-crisis period, the majority of the countries except India, Taiwan, Japan and New Zealand show negative mean returns.

For the crisis period, the mean return of the indices during the Asian crisis turned negative for all countries except China and Australia. Similarly, during the US subprime crisis, except for India and Indonesia, all the other countries had negative mean returns. The mean returns of all indices remained positive during the Eurozone debt crisis except for China, which experienced a negative mean return. A surprising finding here is that the mean returns of all the countries in the sample except India and Philippines turned positive during the COVID-19 crisis period. The mean stock market returns in the pre-crisis period are higher than those in the crisis period for all the countries during the Asian, US subprime and Eurozone debt crises. However, the reverse holds for the COVID-19 crisis where the returns of crisis periods are higher than the pre-crisis period for all countries except Indonesia and Singapore. This is the first indication



**Table 11**

Dynamic conditional correlation coefficient and contagion effect test during the Subprime crisis.

	Mean	Variance	t-statistic	Contagion
Pre-crisis DCC USA_China	0.07	0.03	- 31.84	
Crisis DCC USA_China	0.01	0.03		
Pre-crisis DCC USA_India	0.10	0.04	26.41***	Y
Crisis DCC USA_India	0.16	0.04		
Pre-crisis DCC USA_Indonesia	0.04	0.03	56.43***	Y
Crisis DCC USA_Indonesia	0.15	0.03		
Pre-crisis DCC USA_Malaysia	0.04	0.05	36.28***	Y
Crisis DCC USA_Malaysia	0.12	0.03		
Pre-crisis DCC USA_Philippines	0.03	0.01	- 14.05	
Crisis DCC USA_Philippines	0.01	0.04		
Pre-crisis DCC USA_South Korea	0.13	0.01	36.45***	Y
Crisis DCC USA_South Korea	0.24	0.07		
Pre-crisis DCC USA_Taiwan	- 1.02	0.30	95.24***	Y
Crisis DCC USA_Taiwan	0.10	0.05		
Pre-crisis DCC USA_Thailand	0.07	0.08	28.80***	Y
Crisis DCC USA_Thailand	0.21	0.09		
Pre-crisis DCC USA_Australia	0.46	0.03	40.73***	Y
Crisis DCC USA_Australia	0.56	0.05		
Pre-crisis DCC USA_Hong Kong	0.11	0.07	18.39***	Y
Crisis DCC USA_Hong Kong	0.17	0.01		
Pre-crisis DCC USA_Japan	0.05	0.10	7.70***	Y
Crisis DCC USA_Japan	0.09	0.02		
Pre-crisis DCC USA_New Zealand	0.00	0.03	- 27.47	
Crisis DCC USA_New Zealand	- 0.06	0.05		
Pre-crisis DCC USA_Singapore	0.09	0.01	94.67***	Y
Crisis DCC USA_Singapore	0.23	0.03		

\*\*\* significant at 1%

**Table 12**

Comparative analysis of the unconditional correlation and DCC for the Eurozone crisis.

Countries	Unconditional correlation			Dynamic Conditional Correlation		
	Pre-crisis	Crisis	% difference	Pre-crisis	Crisis	% difference
China	0.0550	0.1464	166.1%	0.0687	0.1448	110.8%
India	0.4235	0.2701	- 36.2%	0.3350	0.2742	- 18.1%
Indonesia	0.3537	0.2630	- 25.6%	0.3201	0.2321	- 27.5%
Malaysia	0.2814	0.2565	- 8.9%	0.2371	0.2494	5.2%
Philippines	0.2251	0.1208	- 46.4%	0.2110	0.1203	- 43.0%
South Korea	0.3300	0.2590	- 21.5%	0.3017	0.2412	- 20.0%
Taiwan	0.3144	0.2122	- 32.5%	0.2894	0.2069	- 28.5%
Thailand	0.2339	0.2427	3.8%	0.2267	0.2347	3.5%
Australia	0.5431	0.4015	- 26.1%	0.4625	0.3789	- 18.1%
Hong Kong	0.4192	0.2821	- 32.7%	0.3919	0.2811	- 28.3%
Japan	0.3328	0.1979	- 40.5%	0.3097	0.1876	- 39.4%
New Zealand	0.0786	0.0157	- 80.0%	0.0626	- 0.0053	- 108.4%
Singapore	0.4072	0.3512	- 13.8%	0.3716	0.3380	- 9.0%

that COVID-19 has had less impact on stock markets as compared to the Asian, US subprime and Eurozone debt crisis.

A higher than the acceptable level of kurtosis is another notable statistic of stock returns that is observed for all the countries during all crises periods. This signifies the likelihood of large positive or negative shocks being present in these markets and that the stock return series may not have a normal distribution (Chiang et al., 2007). These values of kurtosis are exceptionally high for China (24.04) during the pre-crisis period in case of the Asian crisis; and Thailand (59.37) during the pre-crisis period in case of the US subprime and Eurozone debt crises. Such extreme values are not observed during the COVID-19 pre-crisis period. The level of kurtosis still remain higher than the acceptable levels during the crisis period for all the crises but no extreme values are found in any stock market during this time. The stock market returns of all the crises follow a leptokurtic distribution, which is a common feature in case of financial data. Furthermore, the results of the Jarque Bera test show that stock market returns do not follow a normal distribution during any pre-crisis and crisis periods. The pre-crisis standard deviation of stock market returns is lower than the crisis-period standard deviation for all the crises.

The DCC-GARCH model estimates have been depicted in Figs. 1-4.

Tables 8-15 provide the unconditional correlations and dynamic conditional correlations between the crisis originating market and the rest of the markets in the sample as well as the results of t-test. In the case of Asian crisis (Table 8), where the crisis originated from Thailand, the unconditional correlations increase between the pre-crisis and crisis periods for all countries except for China, Malaysia,

**Table 13**

Dynamic conditional correlation coefficient and contagion effect test during the Eurozone crisis.

	Mean	Variance	t-statistic	Contagion
Pre-crisis DCC Greece_China	0.07	0.03	32.62***	Y
Crisis DCC Greece_China	0.14	0.05		
Pre-crisis DCC Greece_India	0.33	0.06	- 10.90	
Crisis DCC Greece_India	0.27	0.13		
Pre-crisis DCC Greece_Indonesia	0.32	0.06	- 30.81	
Crisis DCC Greece_Indonesia	0.23	0.03		
Pre-crisis DCC Greece_Malaysia	0.23	0.05	4.36***	Y
Crisis DCC Greece_Malaysia	0.24	0.04		
Pre-crisis DCC Greece_Philippines	0.21	0.07	- 24.41	
Crisis DCC Greece_Philippines	0.12	0.07		
Pre-crisis DCC Greece_South Korea	0.30	0.04	- 31.94	
Crisis DCC Greece_South Korea	0.24	0.01		
Pre-crisis DCC Greece_Taiwan	0.28	0.003	- 71.02	
Crisis DCC Greece_Taiwan	0.20	0.03		
Pre-crisis DCC Greece_Thailand	0.22	0.09	2.23**	Y
Crisis DCC Greece_Thailand	0.23	0.02		
Pre-crisis DCC Greece_Australia	0.46	0.11	- 13.75	
Crisis DCC Greece_Australia	0.37	0.10		
Pre-crisis DCC Greece_Hong Kong	0.28	0.03	86.34***	Y
Crisis DCC Greece_Hong Kong	0.39	0.01		
Pre-crisis DCC Greece_Japan	0.30	0.05	- 54.90	
Crisis DCC Greece_Japan	0.18	0.02		
Pre-crisis DCC Greece_New Zealand	0.06	0.00	- 33.27	
Crisis DCC Greece_New Zealand	-0.01	0.05		
Pre-crisis DCC Greece_Singapore	0.37	0.02	- 34.63	
Crisis DCC Greece_Singapore	0.33	0.02		

\*\* significant at 5%

\*\*\* significant at 1%

**Table 14**

Comparative analysis of the unconditional correlation and DCC for the Covid-19 crisis.

Countries	Unconditional correlation			Dynamic Conditional Correlation		
	Pre-crisis	Crisis	% difference	Pre-crisis	Crisis	% difference
China	NA	NA	NA	NA	NA	NA
India	0.2028	0.3757	85.3%	0.2237	0.3286	46.9%
Indonesia	0.2362	0.3084	30.6%	0.2424	0.3048	25.8%
Malaysia	0.2415	0.3360	39.1%	0.2394	0.2466	3.0%
Philippines	0.1817	0.2130	17.2%	0.1898	0.1667	- 12.1%
South Korea	0.4734	0.4503	- 4.9%	0.4606	0.4170	- 9.5%
Taiwan	0.4796	0.4564	- 4.8%	0.1725	0.2196	27.3%
Thailand	0.2807	0.3718	32.5%	0.2907	0.3093	6.4%
Australia	0.2945	0.2921	- 0.8%	0.2840	0.2199	- 22.6%
Hong Kong	0.4093	0.5854	43.0%	0.6614	0.5514	- 16.6%
Japan	0.4088	0.3783	- 7.5%	0.3904	0.3439	- 11.9%
New Zealand	0.0287	0.1744	508.1%	0.0462	0.1604	247.2%
Singapore	0.4699	0.4348	- 7.5%	0.4854	0.3714	- 23.5%

Hong Kong and Japan. Similarly, DCC coefficients also increase for all the countries except for the four countries mentioned in case of unconditional correlation along with Philippines. India, South Korea and Taiwan appear to be affected the most by impacts of the Asian crisis as depicted by the change in the DCC mean values of 643.70%, 287.95% and 650.48%, respectively.

The results of the t-test (Table 9) indicate that there is a significant increase in the correlation coefficient for India, Indonesia, South Korea, Taiwan and Australia during the crisis period as compared to the pre-crisis period. Hence, we reject the null hypothesis indicating the presence of contagion from Thailand to these five countries. For the rest of the countries, viz. China, Malaysia, Philippines, Hong Kong and Japan, we cannot reject the null hypothesis i.e. the mean of DCC coefficients of the crisis are greater than or equal to the pre-crisis eras. This indicates the absence of the contagion effect from Thailand towards these countries during the Asian crisis.

In the case of the US subprime crisis, the unconditional correlations (between the USA and other countries) increase between the pre-crisis and crisis periods for all countries except Philippines, Thailand and New Zealand (Table 10). The DCC coefficients increase between the pre-crisis and crisis periods for all countries except China, Philippines, Taiwan, Japan and New Zealand. Indonesia, Thailand, Malaysia and Singapore appear to be the most affected by the US subprime crisis showing an increase in DCC mean values of 309.30%, 201.9%, 179.70% and 159.3%, respectively. The t-test results (Table 11) show that out of the thirteen sample countries there

**Table 15**

Dynamic conditional correlation coefficient and contagion effect test during the Covid-19 crisis.

	Mean	Variance	t-statistic	Contagion
Pre-crisis DCC China_India	0.22	0.03	21.06***	Y
Crisis DCC China_India	0.32	0.08		
Pre-crisis DCC China_Indonesia	0.24	0.04	21.35***	Y
Crisis DCC China_Indonesia	0.3	0.04		
Pre-crisis DCC China_Malaysia	0.23	0.07	0.74	
Crisis DCC China_Malaysia	0.24	0.17		
Pre-crisis DCC China_Philippines	0.19	0.04	- 10.80	
Crisis DCC China_Philippines	0.17	0.03		
Pre-crisis DCC China_South Korea	0.46	0.06	- 5.02	
Crisis DCC China_South Korea	0.41	0.16		
Pre-crisis DCC China_Taiwan	0.17	0.04	22.69***	Y
Crisis DCC China_Taiwan	0.22	0.02		
Pre-crisis DCC China_Thailand	0.29	0.04	2.90***	Y
Crisis DCC China_Thailand	0.30	0.11		
Pre-crisis DCC China_Australia	0.28	0.06	- 15.07	
Crisis DCC China_Australia	0.21	0.05		
Pre-crisis DCC China_Hong Kong	0.66	0.03	- 12.67	
Crisis DCC China_Hong Kong	0.55	0.15		
Pre-crisis DCC China_Japan	0.39	0.06	- 6.58	
Crisis DCC China_Japan	0.34	0.119		
Pre-crisis DCC China_New Zealand	0.05	0.06	39.41***	Y
Crisis DCC China_New Zealand	0.16	0.02		
Pre-crisis DCC China_Singapore	0.48	0.02	- 12.91	
Crisis DCC China_Singapore	0.37	0.16		

\*\*\* significant at 1%

is a significant increase in the correlation coefficient for ten countries viz. India, Indonesia, Malaysia, South Korea, Taiwan, Thailand, Australia, Hong Kong, Japan and Singapore indicating that they suffered from contagion due to the US subprime crisis. The remaining three countries namely, China, Philippines and New Zealand do not show any signs of contagion. These results indicate that the contagion caused by the US subprime crisis spread wider than the Asian crisis.

Further, the results of the Eurozone debt crisis show a decline in unconditional correlation coefficients between Greece and all the other countries with the exception of China and Thailand. Similar trend is observed for DCC coefficients which decline for all the countries except China, Thailand and Malaysia (Table 12). The impact of the crisis appears to be the highest for China as observed from the increase of its DCC coefficient by 110.8%. The results of the t-test (Table 13) show that only in the case of China, Malaysia, Thailand and Hong Kong, we can reject the null hypothesis indicating the occurrence of contagion from Greece to these four countries. For all the remaining countries, we cannot reject the null hypothesis indicating the absence of contagion or negative contagion in the remaining nine countries. This shows that the contagion caused by the Eurozone debt crisis spread less than the Asian crisis and the US subprime crisis.

Lastly, in the case of the COVID-19 crisis, the unconditional correlations (between China and other countries) increase for India, Indonesia, Malaysia, Philippines, Thailand, Hong Kong and New Zealand (Table 14). The DCC coefficients increase for India, Indonesia, Malaysia, Taiwan, Thailand and New Zealand. The impact of this crisis seems to be the highest for New Zealand as shown by 247.2% increase in its DCC coefficient. Further, the results of the t-test (Table 15) indicate a significant increase in DCC coefficients for India, Indonesia, Taiwan, Thailand and New Zealand suggesting the spread of contagion from China during the COVID-19 crisis. For all the remaining seven countries, we cannot reject the null hypothesis denoting the non-occurrence of the contagion.

A comparison of all the four crises provides evidence that the US subprime crisis was the most virulent in terms of its spread in the Asian countries. This was followed by the Asian crisis and the COVID-19 crisis. The Eurozone debt crisis, on the other hand, had the least contagious effect on the Asian countries.

## 5. Conclusion

Stock market comovements between countries can be the result of interdependence or contagion. Any comovement caused due to asset trading, bilateral trade or technological factors is interdependence (Forbes & Rigobon, 2002); on the other hand, the comovement due to flight-to-quality and liquidity (Longstaff, 2004) or investor sentiments regarding possible impact on their country's fundamentals is contagion. This type of contagion is also known as a herding contagion (Khan & Park, 2009). The current paper brings out and compares the presence of herding contagion in stock markets during four major financial crises viz. Asian crisis, the US subprime crisis, the Eurozone debt crisis and the COVID-19 pandemic. Our study finds that contagion was the most acute during the US subprime crisis among all.

All the four crises under study spread due to flight-to-quality. At the time of the Asian crisis, there was little role played by Thailand in bilateral trade and competition with other Asian countries. The devaluation of the Thai Baht was perceived as a wake-up call by investors in other Asian countries and they expected similar economic weakness in their countries as well. Due to this expected economic and financial market instability, market participants moved together across a range of countries, transmitting the shocks and

resulting in contagion (Baig & Goldfajn, 1998). Similarly, during the subprime crisis, the shocks in the asset-backed securities (ABS) markets acted as a predictor for the decline in equity markets (Khan & Park, 2009). The crisis that primarily occurred due to exposure of banks to packaged subprime loans led to bank failures in the USA and Europe, ultimately resulting in reductions in values of stocks across the globe. The Eurozone crisis was the result of the balance-of-payments crisis and it worsened due to the inability of EU nations to devalue their currency. In response to this crisis, several stock markets across the world declined. The COVID-19 pandemic put the world in a virtual lockdown leading to a projection of unparalleled geo-economic challenges by financial economists. This resulted in a high implied volatility in equity markets due to flight-to-safety by investors.

The conclusion we draw from our results is that the subprime crisis has been the most contagious for the Asian stock markets, directly affecting multiple channels of financing and liquidity (Allen & Gale, 1999; Brunnermeier & Pedersen, 2009), and thereby, converting a liquidity contagion to a stock market contagion. Additionally, the impact of this crisis was more severe than the Asian crisis as there was a greater degree of integration of Asian stock markets with the global stock markets, especially the USA in 2007, as compared to the era of 1997 (Cyn-Young, 2013). As a result, the flight-to-quality could have become more intense during the US subprime crisis as compared to the Asian crisis. The Eurozone debt crisis had the weakest impact on the Asian stock markets, spreading only in those regions which were under a significant economic influence of the euro (Mohti et al., 2019). In fact, the results imply a negative contagion and stock market decoupling during this crisis (Samarakoon, 2017). The COVID-19 crisis originated as a health crisis and affected the real sector in terms of demand and supply mismatch. The pandemic came in waves across different countries and economic activity kept rising in each country as it eased its lockdown conditions. Hence, it did not get priced into the stock markets. Companies learnt to operate under lockdown and were able to manage profitability by cutting down costs. Hence, the impact of COVID-19 pandemic was less contagious for stock markets compared to the longer impact of the liquidity crisis caused by subprime.

The contagion study in the current paper has several implications for both policymakers and investors. The recurrence of contagion shows that policymakers need to strengthen the fundamentals, such as reduction of information asymmetry if they want markets to rebound from repeated external shocks. If markets are depreciating as a result of panic, the first priority of policymakers should be to calm market sentiments. Learnings from past mistakes and experiences must be used to improve the design of institutions, policies, and market laws, thus reducing the frequency and severity of financial crises. A comparative view of contagions can give policymakers and regulators an insight into devising multifarious approaches to prevent events of varied economic causes and protect their home economies. These findings may also be useful to foreign investors to understand which stock markets can be used as prospective destinations for diversification, given that they have been least affected during any of the four crises. International investors can understand how their portfolio allocation and rebalancing actions can spread the crisis to other markets, which makes following a herding approach risky. Overall, the paper offers a new perspective on varying degrees of stock market linkages in the form of contagion across crises of different economic significance. The research on COVID-19 is still new and evolving, and more studies on the contagious effects of COVID-19 are warranted given that the crisis is still ongoing. It is only when the pandemic converts into an epidemic and data for longer periods is available, we can conclude about its severity versus other crises. The current study can also be extended to non-Asian markets. This would enable a comparative analysis of markets worldwide, which would further strengthen our findings.

## Data Availability

Data will be made available on request.

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