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Exploring Multivariate GARCH DCC Model: Investigation into Spillover Effects among Global Financial Markets

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Abstract
This article examines the impacts of Eurozone crisis, COVID-19 and Russia-Ukraine war on stock market integration and risk contagion for five largest stock markets of developed countries (Hong Kong, USA, UK, Japan, and Canada) in the post financial crisis period. Weekly data from 2010 to 2023 has been tested by employing multivariate GARCH DCC model. We find existence of significant comovement between market returns of five countries during the sample period with a significant contagion effect between all during the Eurozone crisis. However, during the COVID period, existence of risk contagion has been established amongst USA, UK, Japan and Canada. Furthermore, our findings reveal the presence of 'flight to quality effects' among all five stock markets during Russia- Ukraine war and also when Hong-Kong stock market is paired with rest four during the COVID period. The results highlight the importance of policy coordination amongst the world's major developed economies.

Keywords
Stock Market Volatility; Risk Contagion; Financial Markets, Econometric Analysis
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1. Introduction

The progress of world economy can be identified by the number of countries that are progressive, industrialised, innovative and investing globally to reap benefits of portfolio diversification through optimal allocation of funds. The stock market performance of is one of the main indicators that determine the economic growth of a country. In particular, strong equity markets can place the country in the list of developed group. Trade openness motivates the extended business activities across borders and pave the way for the stock market (SMI) integration through trade policies and agreements, technological advancements and legal restrictions to name a few. Since stock markets are very much sensitive to the shocks or information connected to crises like political conflicts, financial scams, social degradation, civil & trade war and other natural disasters; these events impact comovement of stock indices and risk contagion. Regulatory bodies, global giants, investors and academia have long been inquisitive about the relationship between SMI and financial to make financial planning and investment decisions. The consequences of crises on SMI and risk are common to both emerging and developed economies in the world. However as proven historically, developed markets have a spillover impact on emerging markets. Though this unidirectional relationship has been examined by various studies with a mix of developed and emerging economy samples, understanding the integration of largest stock markets of the world amongst themselves is critical to dwell upon economic integration and volatility.

There are many evidences quoted in the previous researches for the impact of the crises on stock market returns. (Matar et al., 2021) highlighted the importance of co-movements in international investment strategies, and concluded about existence of long-term co-movements between several GCC stock markets with significant disparities during economic declines, affecting the potential for international portfolio diversification. (Gjika & Horváth, 2013) observed the stock market correlations are transformed, more volatile and increased among the Central European stock markets during the financial crisis. Central and Eastern European stock markets have a statistically significant positive effect on the degree of global and regional financial integration with the stock market size and stock market turnover (Dai & Tang, 2024; Deltuvaitė, 2017) found the severe swings in oil prices influenced the G7 equity markets in terms of systematic risk. They concluded that asymmetric effect of oil shocks had insignificant impact on supply however there was significant effect with demand side during notable economic crises. Global financial interdependencies have been proven in the study. “Several stock return determinants are shown to be affected by uncertainty regarding economic policies and geo political factors. This finding implies that higher exposure to certain risk factors makes bivariate cointegration relations more susceptible to segmentation” (Babaei et al., 2023). The state of France, Germany and USA stock markets directly impacts Indian economy in the short-run hence investors can reap benefits of international portfolio diversification only in the short-run as per (Samadder &

Bhunia, 2018). The vulnerability of co-movements influences other economies. Developed countries have stable market environment for large volume of trade activities and long –term investments across the world. Yet, political risks and fiscal policies makes the stock market more volatile.

The performance of select developed economies and the size of their markets and GDP showcases promising investment options. Table 1 captures the size and magnitude of these markets at the beginning of period and three crises' periods observed during the study period.

Table 1: Financial Overview of Sample Economies (2023 data unavailable)

Country	**Hong Kong**	**United Kingdom**	**United States**	**Japan**	**Canada**
Stock Index	**HKEX**	**FTSE**	**NYSE**	**TSE**	**TSX**
GDP (US$ Millions)					
2010	228638.7	2485482.6	15048964.4	5759071.8	1617343.4
2013	275696.9	2784853.5	16843191.0	5212328.2	1846597.4
2020	344943.1	2697806.6	21060473.6	5055587.1	1655684.7
2022	359838.6	3089072.7	25439700.0	4256410.8	2161483.4
Listed domestic companies					
2010	1396	4279	2105	2281	3654
2013	1553	4180	1857	3408	3810
2020	2353	4104	..	3754	3922
2022	2414	4642	..	3865	3534
Market capitalization of listed domestic companies (% of GDP)					
2010	1185.9	114.8	108.1	66.5	134.2
2013	1124.7	142.7	141.7	87.2	114.5
2020	1777.2	197.4	..	132.9	159.5
2022	1269.1	158.4	100.2	126.4	127.0
Stocks traded, total value (% of GDP)					
2010	650.6	239.4	129.3	74.1	86.9
2013	459.6	197.4	60.1	116.7	71.7
2020	889.8	195.1	..	125.4	118.0
2022	791.7	174.2	25.4	137.6	104.1
Stocks traded, turnover ratio of domestic shares (%)					
2010	54.9	208.4	119.6	111.6	64.7
2013	40.9	138.3	42.4	133.9	62.6
2020	50.1	..	..	94.3	74.0
2022	62.4	..	25.3	108.9	81.9

Source: World Development Indicators (https://databank.worldbank.org)

Assessing the size, volatility and dominance of stock markets within an economy can be effectively gauged through metrics such as market capitalization, liquidity, turnover ratio, and the number of listed companies. While growth in market size is akin to development, it's critical to acknowledge that trends presented by these metrics to be further strengthened with findings based on interdependence of markets, financial sector volatility and efficiency. It is pertinent to note that the GDP of Japanese economy has witnessed a decline over the study period and Hong Kong is the single economy where stock market capitalization is more than 10 times its GDP. Further, Figure 1(a-e) presents the weekly stock price indices and respective returns of developed countries over the study period.

Figure 1: Weekly stock price index of developed countries, January 2010-December 2023

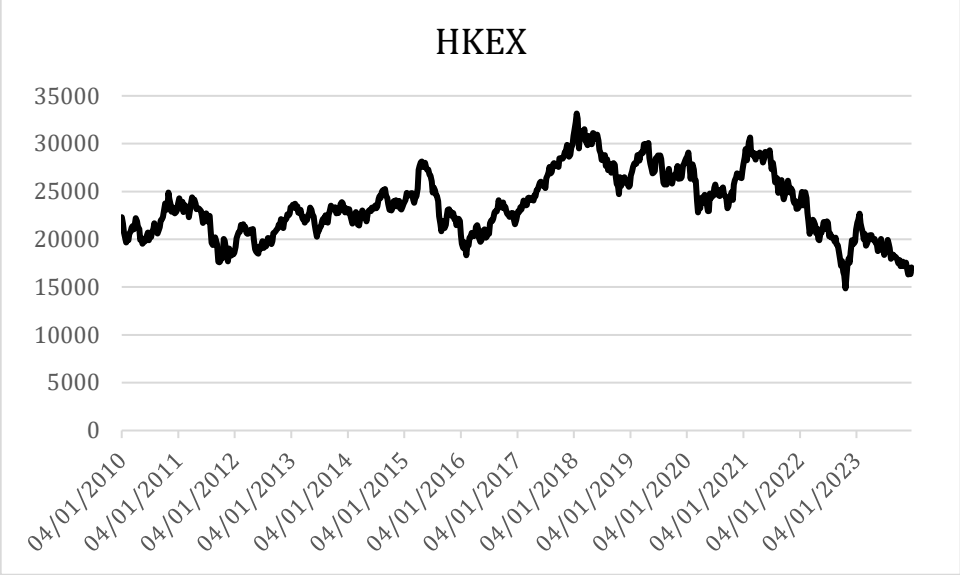

Figure 1 (a): Weekly stock price index of HKEX-Hong Kong, January 2010-December 2023

Source: Authors' own elaboration

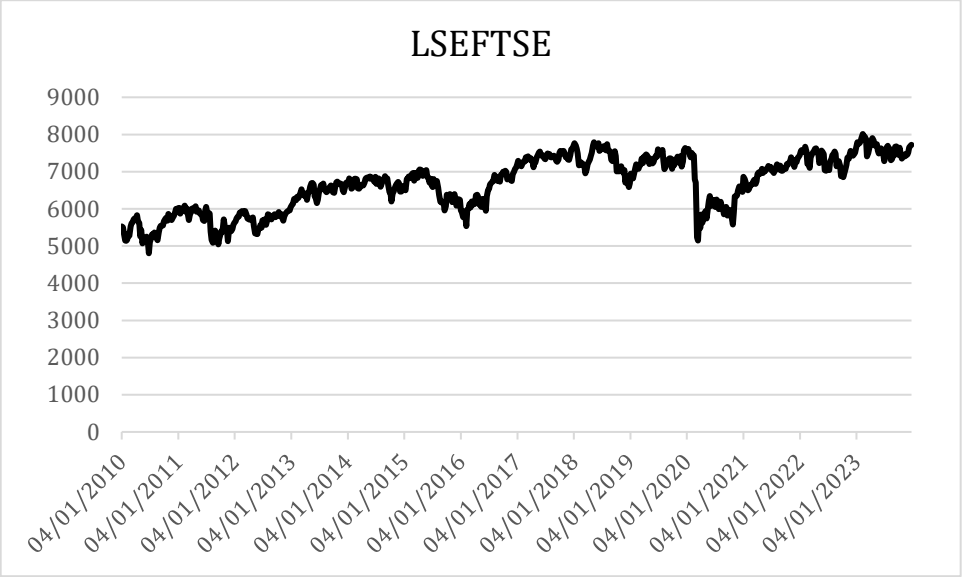

Figure 1 (b): Weekly stock price index of LSE- United Kingdom, January 2010-December 2023
Source: Authors' own elaboration

Figure 1 (c): Weekly stock price index of NYSE- USA, January 2010-December 2023
Source: Authors' own elaboration

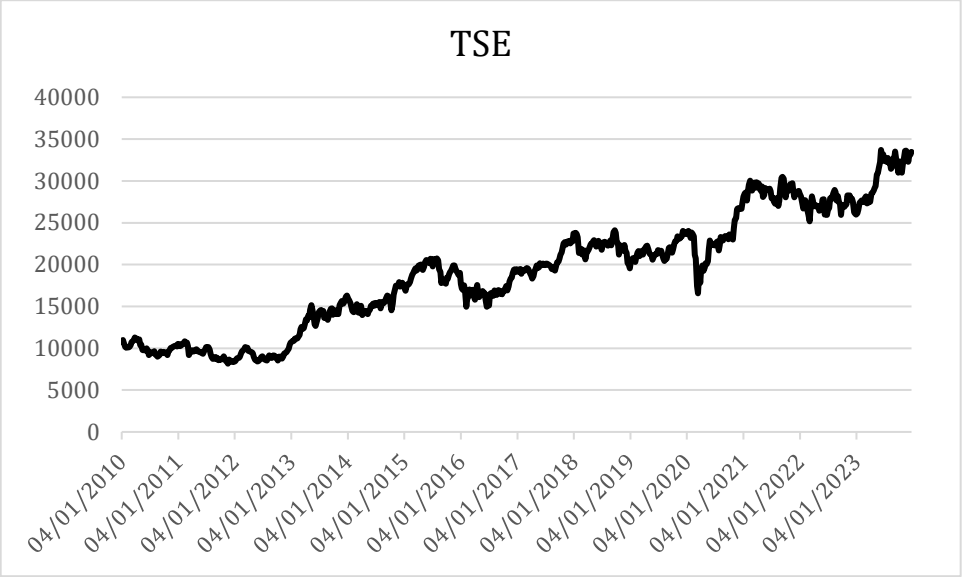

Figure 1 (d): Weekly stock price index of TSE- Japan, January 2010-December 2023
Source: Authors' own elaboration

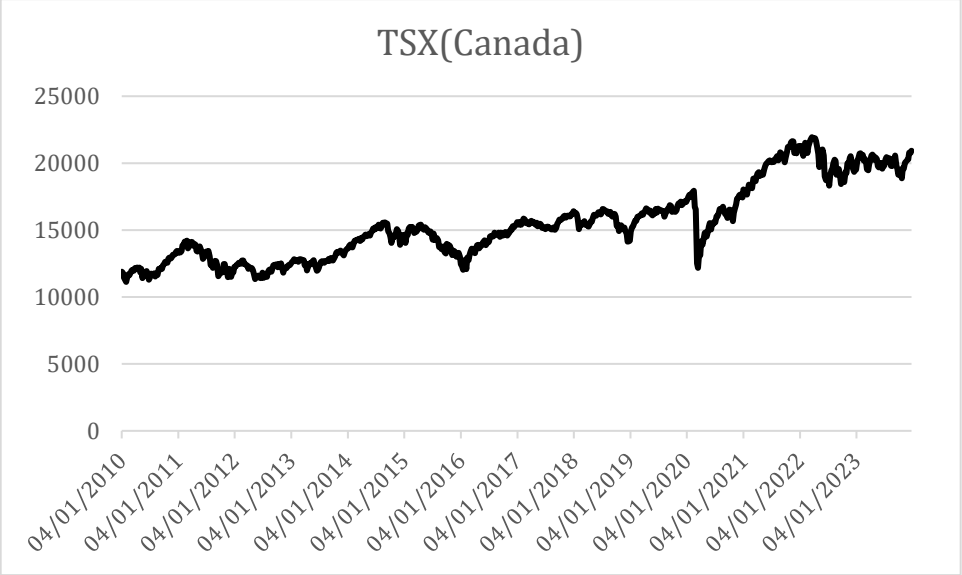

Figure 1 (e): Weekly stock price index of TSX- Canada, January 2010-December 2023
Source: Authors' own elaboration

In this context, this research focusses on exploring the influences of crises on SMI and risk contagion with special reference to developed countries. Further the study will explore the consequences of real time challenges on financial markets of developed countries. The present study focusses on risks of stock markets and portfolio management during crises period.

This paper is further presented as follows: Section 2 provides a review of literature on SMI in developing economies with few studies having specific focus on developed countries too. Further Section 3 details the research methodology followed by Section 4 that presents results in detail. The last section, Section 5 comprises of conclusions drawn from the paper.

2. Literature Review

The present study compares the SMI of developed countries during three major crises periods since Financial Crisis 2008 with non-crisis period. Although several research studies have been conducted on these crisis periods separalty but this paper is an attempt to draw long term conclusions combining impact of crises periods. It is important to know whether their results have been consistent or varied depending on the countries and the nature of crisis. Mostly, previous researches resulted with positive effects of the crises on stock markets in all parts of the European continent (Deltuvaitė, 2017; Gjika & Horváth, 2013; Horvath & Petrovski, 2013; Islami & Welfens, 2013; Naumoski et al., 2017; Syllignakis & Kouretas, 2010; Vidal-Llana et al., 2023; Vyrost et al., 2013). Few studies (Matar et al., 2021; Mohite & Bhandari, 2022) explored the results of long-term co-movements with respect GCC (Gulf Cooperation Council) countries stock markets.

Studies by (Ayyildiz & Iskenderoglu, 2024; Babaei et al., 2023; Chen & Chiang, 2022; Dai & Tang, 2024; Matar et al., 2021) have focused G7 countries-(Canada, France, Germany, Italy, Japan, UK and US) equity markets and analysed the impacts of trade war, oil, stock and housing prices, artificial neural network application, economic policy uncertainty and global geopolitical risks. Similarly, relationship of Indian stock markets with other developed nations during the crises, have been discussed by (Mukherjee & Mishra, 2007; Raj & Dhal, 2008; Samadder & Bhunia, 2018). These observations from the literature provided the background for the present study.

The study on relationship between South East European (SEE) stock markets with the developed stock markets investigated by (Naumoski et al., 2017) by employing Vector autoregressive model (VAR) concluded high correlation among the SEE markets and with the developed markets during crisis and no association existed in the pre- and post-crisis period. Similarly, (Horvath & Petrovski, 2013) found that Central Europe and South Eastern Europe equity markets had high integration with developed markets at the time of global financial crisis. (Gjika & Horváth, 2013) investigate the stock market comovements in three Central European countries by applying MGARCH and asymmetric dynamic conditional correlation (ADCC) models on daily data collected from 2001 to 2011. The paper highlighted strong correlations among Central European stock markets and found the same effect between Central Europe and the euro area during the financial crisis. (Vidal-Llana et al., 2023) applied vector autoregressive (VAR) system on the data of 645 ‘large-

cap' companies from 35 European countries. "They summarize the connectedness of individual companies in a network that international risk managers and investors can use to assess global financial market dependencies and to inform their risk management practices" (Vyrost et al., 2013) used the DCC MV-GARCH model and found no significant impact of monetary convergence on the relationship of Central and Eastern European (CEE) equity markets with the German market. However, the global financial crisis influenced considerable degree of co-movement of stock indices in CEE stock markets. (Islami & Welfens, 2013) examine the connection between nominal stock market index with nominal exchange rate and reveals that Eastern European stock markets have inadequate integration except the Hungarian stock indices. Using Gonzalo and Granger methodology (Syllignakis & Kouretas, 2010) analysed the long-term firmness of the relationships between Central & Eastern European markets and German &US markets. The result asserts the increased financial relationship of CEE and world markets exists at the beginning of EU compliance process. (Deltuvaitė, 2017) reveals short term risk effect by the introduction of the euro, size and stock market turnover . Further, the exchange rate removal have a significant positive impact on the degree of global and regional financial integration of Central and Eastern European Stock Markets.

(Chen & Chiang, 2022) examine a time-dependent relationship between stock and housing prices in G7 member countries by employing Granger causality model and establish unidirectional informational connection among Canada, Italy, Japan and the USA and a bi-directional relationship between France and Germany. By employing wavelet coherence analysis on weekly stock index prices, (Matar et al., 2021) investigate the co-movement between stock market returns of the GCC countries with US and deduce definite long-term co-movements between several GCC stock markets and the US stock markets. (Babaei et al., 2023) analysed a long term data covering a three decades with monthly indices, "variations in a number of financial risk factors, economic policy uncertainty (EPU) and world geopolitical risk (GPR), have a significant impact on cointegrating coefficients and globalisation has reduced market segmentation causes to our risk factors."(Babaei et al., 2023). A recent study by (Ayyildiz & Iskenderoglu, 2024)predicts of movement directions of stock market indices of developed countries (G7) through the several algorithms and prediction performance shown by "artificial neural networks were found to be the best algorithm for NYSE 100, FTSE 100, DAX 30 and FTSE MIB indices, while logistic regression was determined to be the best algorithm for the NIKKEI 225, CAC 40, and TSX indices"(Ayyildiz & Iskenderoglu, 2024). In G7 stock indices, (Dai & Tang, 2024) apply the DCC-GARCH methodology and find the oil supply shock has insignificant influence on aggregate and speculative demand shocks. Moreover, in the short run, speculative demand shocks create the high risk and in long term, systematic risk is formed by the aggregate demand shocks.

The short and long run association of Indian stock market with other developed economies and the portfolio opportunities evaluated by Samadder and Bhunia (2018), concludes all equity markets have steady association. Indian stock market is significantly related to USA in the long term and it also has association with Germany and France for short run. Similarly, another study done by (Raj & Dhal, 2008) finds that Indian stock market is highly correlated with the global markets like US and UK than with the regional stock markets and provides higher stock yields to the investors. Using VAR analysis, (Mukherjee & Mishra, 2007) examines both the degree of integration and the implication of some variables in the progress of international SMI with Indian stock markets and 22 other developed and emerging countries from the rest of the world. The result show that not only is the Indian stock market related to others in the study for same day but there is "increasing tendency in the degree of integration among the markets over a period of time, leading to a greater co-movements and therefore higher market efficiency at the international scenario" (Mukherjee & Mishra, 2007).

Further the impact of external shocks on stock markets have been debated in the literature. The conventional and Islamic Canadian stock markets relationship between inflation and stock return studied by (Neifar, 2020) with monthly data and X-MGARCH model and find Islamic (conventional) stock market has negative significant inflation on return volatility. During extended periods of crisis events, using a machine learning approach (Karim et al., 2024) investigates the potential for extreme risk spill overs across developed stock markets, and deduce that economic interconnectedness, size, book-to-market, investment portfolio and financial market volatility have significant impact on the magnitude of spill overs. (Hassan et al., 2024) investigated the reaction of the Nigerian market-level stock return and volatility to the related external shocks from oil, gas markets and carbon trading by employing GARCH model to conclude that the openness of the market has significant influence with the related external shocks occurred outside of Nigerian market.

Research Question:

- Are the largest five stock markets (market capitalisation based) from developed economies integrated?
- Is there a change in magnitude of SMI of these markets during select three crises periods?

3. Research Methodology

3.1 Data

The secondary data sourced from Yahoo Finance in the post financial crisis period from January 2010 to December 2023. Weekly data for HKEX, FTSE 100, NYSE, TSE, and S&P/TSX Composite Index has been downloaded for the same. As established by similar empirical literature, the stock prices have been converted into

logarithmic first differences. The descriptive statistics along with unconditional correlations of the five largest stock markets' returns has been presented Table 2. As displayed in the Table, TSE has the highest weekly returns, followed by NYSE with HKEX being the lowest. Additionally as indicated by the deviation, the TSE stock market returns has the maximum volatility and the TSX stock market return series has been least volatile amongst the sampled countries during the study period. All stock market returns exhibit negative skewness and are characterised with leptokurtic traits.

Table 2. Descriptive Statistics and Unconditional Correlations

	RHKEX	RLSE	RNYSE	RTSE	RTSX
Descriptive Statistics					
Mean	-0.036824	0.045895	0.113319	0.155156	0.077595
Std. Dev	2.666847	2.266488	2.332886	2.769058	2.102588
Skewness	-0.198230	-1.820129	-1.584305	-0.477785	-3.357979
Kurtosis	3.773822	23.91481	17.24042	7.280213	47.05446
Jarque- Bera	22.96294	13689.42	6464.704	584.2126	60321.69
Minimum	-9.972511	-24.70689	-22.45008	-17.42811	-28.02194
Maximum	10.48942	12.12538	10.76138	15.81710	9.408816
Unconditional Correlations					
RHKEX	1				
RLSE	0.53240716	1			
RNYSE	0.58976029	0.82455175	1		
RTSE	0.53972780	0.64138011	0.69622716	1	
RTSX	0.50532969	0.79188983	0.87954611	0.61229418	1

Note: RHKEX, RLSE, RNYSE, RTSE and RTSX denote the stock market returns of Hong Kong, United Kingdom, USA, Japan and Canada, respectively

Source: Authors' own elaboration

The unconditional correlation between all stock market returns is positive. Table 3 displays the outcomes of unit root test, indicating all the stock market returns are stationary at a significance level of 5 percent.

Table 3: Unit Root test results

Variable	**DF-GLS statistic**	**DF-GLSu statistic**
RHKEX	-15.686**	-27.157**
RLSE	-27.875**	-29.438**
RNYSE	-28.045**	-29.864**
RTSE	-21.902**	-27.039**

RTSX	-25.469**	-28.433**
Inference	Stationary for all	Stationary for all
Critical values		
10%	-2.58	-2.91
5%	-2.89	-3.17
1%	-3.47	-3.71
Note: RHKEX, RLSE, RNYSE, RTSE and RTSX denote the stock market returns of Hong Kong, United Kingdom, USA, Japan and Canada, respectively		
*,**, *** indicate 10%, 5% and 1% LoS respectively		

Source: Authors' own estimation

Table 3 furnishes the findings that the stock market returns of all five developed stock markets are stationary.

3.2 Econometric Methodology

Any time series analysis pre-requisites scrutinising the stationarity of the variables to begin with. This study adopts Dickey–Fuller Generalised Least Squares (DF–GLS) test for the same. Thereafter, we run multivariate GARCH - DCC specification to test for the presence of SMI in five major developed countries. Further, to analyze the contagion effects among the stock market returns of developed countries, conditional correlations derived from this estimated model are regressed on three dummy variables, created for the Eurozone crisis, the COVID-19 pandemic, and the Russia-Ukraine war.

3.2.1 Dynamic Condition Correlation GARCH (DCC-GARCH)

As advocated by (Bollerslev et al., 1988), economic time series are commonly featured by the interdependence in volatility. They introduced multivariate GARCH model (also called the "generalized multivariate GARCH model or VECH-GARCH model") that account for the inter-dependence in time varying volatility of economic time series. However, there are three basic limitations of this model. First, this model involves estimation of too many parameters that causes difficulty in the convergence of the model. Second, this model doesn't ensure a positive variance-covariance matrix. Lastly, the estimated conditional correlations in this model may not lie between -1 and +1. (Engle, 2002; Tse & Tsui, 2002) introduced the DCC-GARCH model that is not plagued by any of these three limitations of VECH-GARCH model. The estimation of DCC-GARCH model pertains maximization of log-likelihood function in two steps. The initial phase involves estimation of univariate GARCH models for all the economic time series.

Subsequently, the dynamic correlation matrix is drawn by utilising the standardized residuals estimated in the first step.

The generalized framework of DCC-GARCH model is given by:

$$r_t \,|I_{t-1} \sim N(0, D_t R_t D_t) \quad (1)$$

$$Q_t = (1 - \alpha - \beta)U + \alpha(v_{t-1}v_{t-1}') + \beta Q_{t-1} \quad (2)$$

$$R_t = \text{diag}(Q_{t-1})\, Q_t\, \text{diag}(Q_{t-1}) \quad (3)$$

Where r_t are returns, I_{t-1} stands for the past set of information, $D_t = \text{diag}(h_{11t}^{1/2}, \ldots, h_{NNt}^{1/2})$ is the N X N diagonal matrix containing standard deviation obtained from univariate GARCH models, and R_t is N × N conditional correlations matrix; Q_t is a symmetric positive semi-definite matrix of v_t; S is N × N unconditional variance matrix of v_t; $\varepsilon_{it} \sim N(0, R_t)$ are the standardized residuals obtained from GARCH models; scalers α and β satisfy the restriction that $\alpha \geq 0$, $\beta \leq 1$; and $\alpha + \beta \leq 1$.

3.2.2 Test for change in conditional correlations during and after Euro-debt crisis, Covid-19 and Russia -Ukraine War

The following model has been applied to test for the contagion effects among the five major developed countries during Eurozone crisis, during and after COVID-19, and after the onset of Russia-Ukraine war.

$$\widehat{\rho_{ij,t}} = \gamma_0 + \gamma_1 EZ + \gamma_2 COVID + \gamma_3 WAR + \varepsilon_t \quad (4)$$

Where "$\widehat{\rho_{ij,t}}$ is the pairwise correlation coefficient between market i and market j; i and j represent the stock markets of US, London, Hong Kong, Japan and Canada respectively." following (Dua & Tuteja, 2016)

$$EZ = \begin{cases} 1 \; if \; t \in 1/04/2010 - 24/12/2012 \\ 0 \; otherwise \end{cases}$$

$$COVID = \begin{cases} 1 \; if \; t \in 1/06/2020 - 01/05/2023 \\ 0 \; otherwise \end{cases}$$

$$WAR = \begin{cases} 1 \; if \; t \; \epsilon \; 28/02/2022 - \; 25/12/2023 \\ 0 \; otherwise \end{cases}$$

As envisaged by several empirical studies (such as (Dua & Tuteja, 2016, 2023; Kenourgios et al., 2016), the pairwise correlation coefficients between market i and market j are obtained from the estimated multivariate GARCH DCC model and OLS (with robust standard errors) is used to estimate equation 4.

A positive (negative) and significant coefficient, i=1, 2, and 3 signifies an increase (decrease) in the comovement between stock market returns of the US, UK, Hong Kong, Japan and Canada amid the Eurozone debt concern, during and post COVID-19, and after the onset of Russia Ukraine WAR respectively. Following (Dua & Tuteja, 2016, 2023), when the conditional correlations between the markets increase during the crisis periods vis-a-vis the non-crisis period, it is termed as 'contagion' whereas when they decrease during the crisis period vis-a-vis the non-crisis period, it is termed as 'flight to equality". A significant intercept coefficient in equation 4 indicates strong interdependence between the markets during a non-crisis period.

4. Results

Table 4 Results of MV-DCC GARCH Model

	RBR	RBSE	RJSA	RMOEX	RSHANGHAI
Mean	0.159976758**	0.176202832***	0.268502809***	0.293721729***	0.220017850***
Variance Equations					
Constant	0.241471226**	0.211036112***	0.238722102***	0.644377422**	0.398910362***
A	0.043827064***	0.055381011***	0.068664060***	0.101221267***	0.105039947***
B	0.926129242***	0.900889058 ***	0.883452791***	0.817264756***	0.791033234***
DCC(A)	0.015887765***				
DCC(B)	0.966760422 ***				
t-distribution	10.022760075 ***				
Note: RHKEX, RLSE, RNYSE, RTSE and RTSX denote the stock market returns of Hong Kong, United Kingdom, USA, Japan and Canada, respectively					
*,**, *** indicate 10%, 5% and 1% LoS respectively					

Source: Authors' own estimation

The estimates of multivariate GARCH DCC model are reported in Table 4. We utilize t-distribution for the estimation due to non-normal stock market returns. Table 4 shows that the estimated t-distribution shape is significant at 1 % significance level. The results of the mean equation reveal that the mean returns are positive for all five stock markets. The GARCH-DCC parameters, denoted by α and β are significant 1% level of significance. We find that the conditions of mean reverting process, i.e. $\alpha \geq 0$, $\beta \leq 1$; and $\alpha + \beta \leq 1$ are satisfied in the estimated model. This reveals existence of strong integration between the stock markets of five major developed countries during the sample period considered in this study. It can be seen from Table 4 that the ARCH and GARCH coefficients in the volatility equations of all five stock market returns are significant at 1% level of significance. Further, as the sum of ARCH and GARCH coefficients in all volatility equations is greater than 0.8, all five stock market returns reveal high persistence in volatility.

Figure 2: Volatility Estimates of BRICS Stock Exchanges

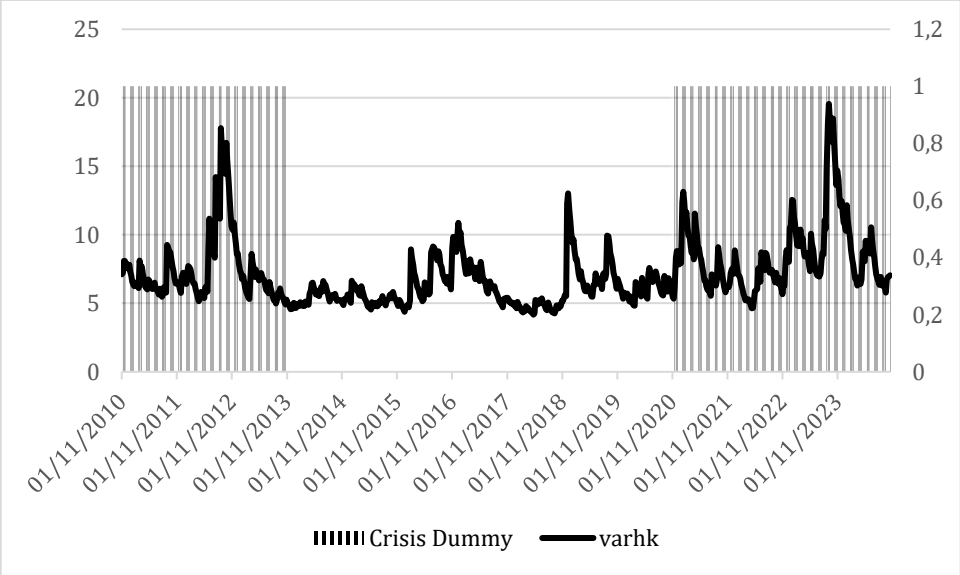

Figure 2 (a): Volatility Estimates of Hong Kong's Stock Exchange
Source: Authors' own elaboration

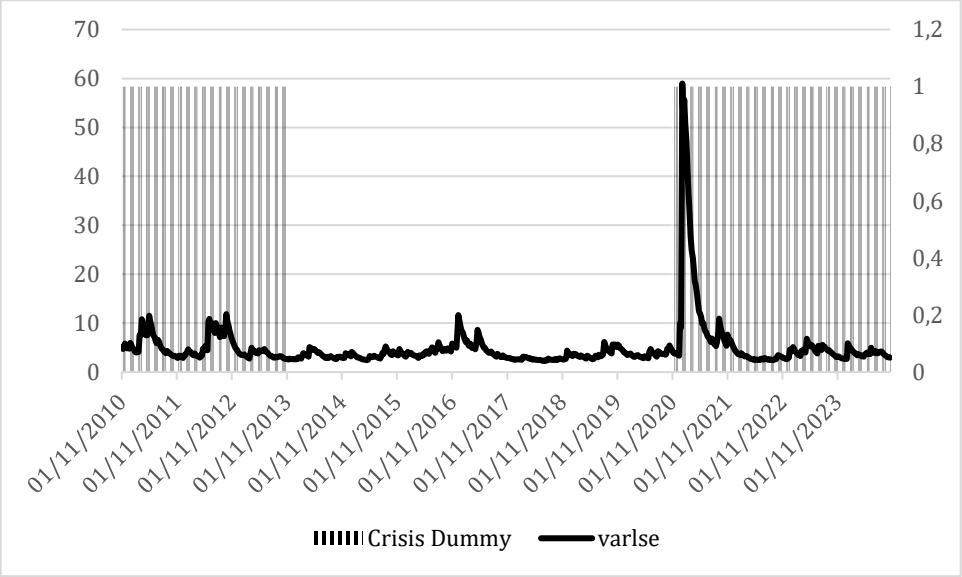

Figure 2 (b): Volatility Estimates of London's (UK) Stock Exchange
Source: Authors' own elaboration

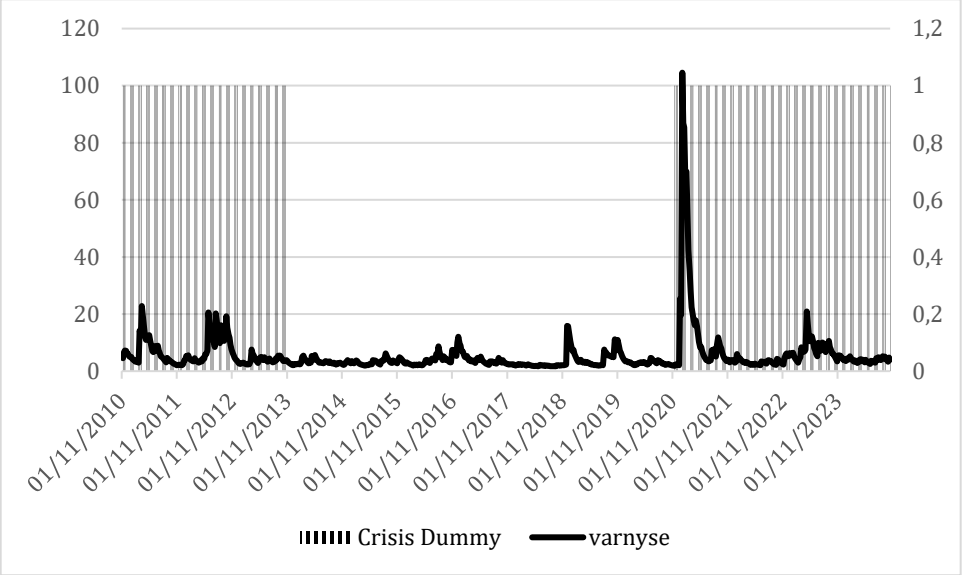

Figure 2 (c): Volatility Estimates of New York (USA) Stock Exchange
Source: Authors' own elaboration

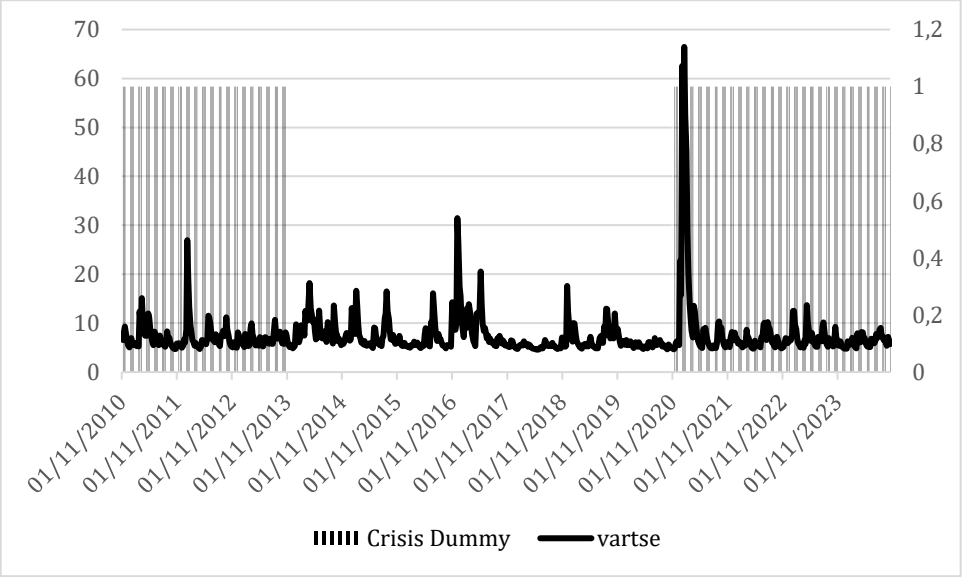

Figure 2 (d): Volatility Estimates of Japan's Stock Exchange
Source: Authors' own elaboration

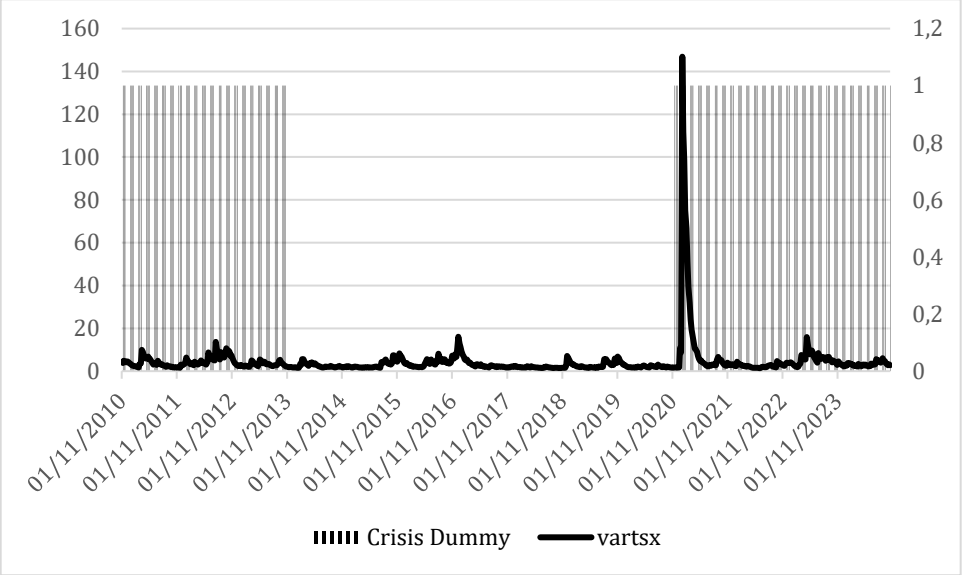

Figure 2 (e): Volatility Estimates of Canada's Stock Exchange
Source: Authors' own elaboration

Figure 3: Conditional Correlations

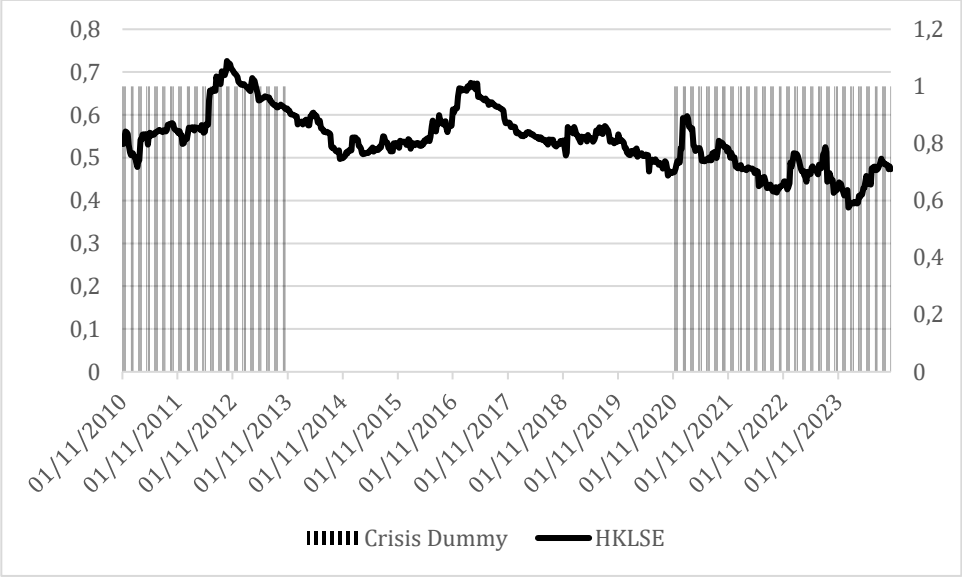

Figure 3 (a): Conditional Correlations between Hong Kong and UK
Source: Authors' own elaboration

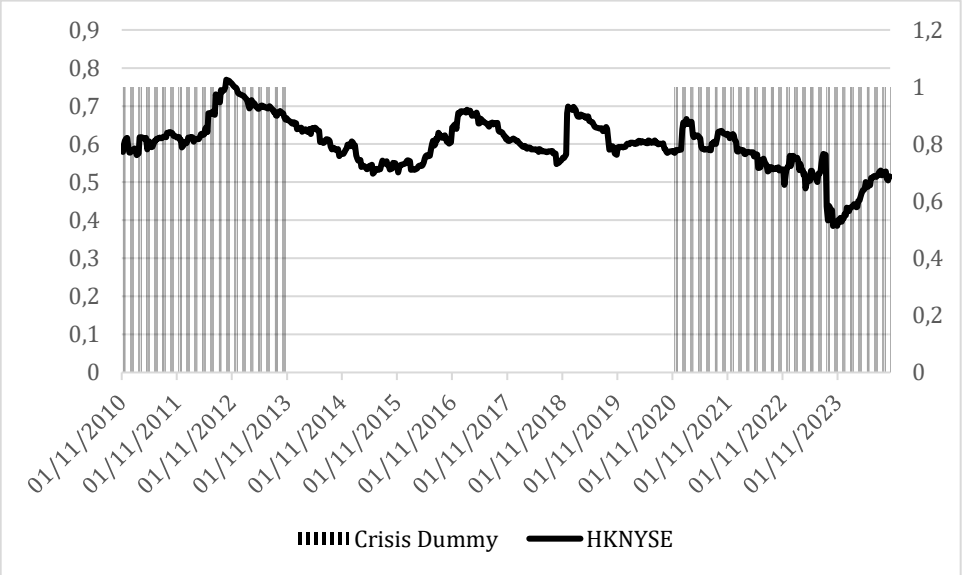

Figure 3 (b): Conditional Correlations between Hong Kong and USA
Source: Authors' own elaboration

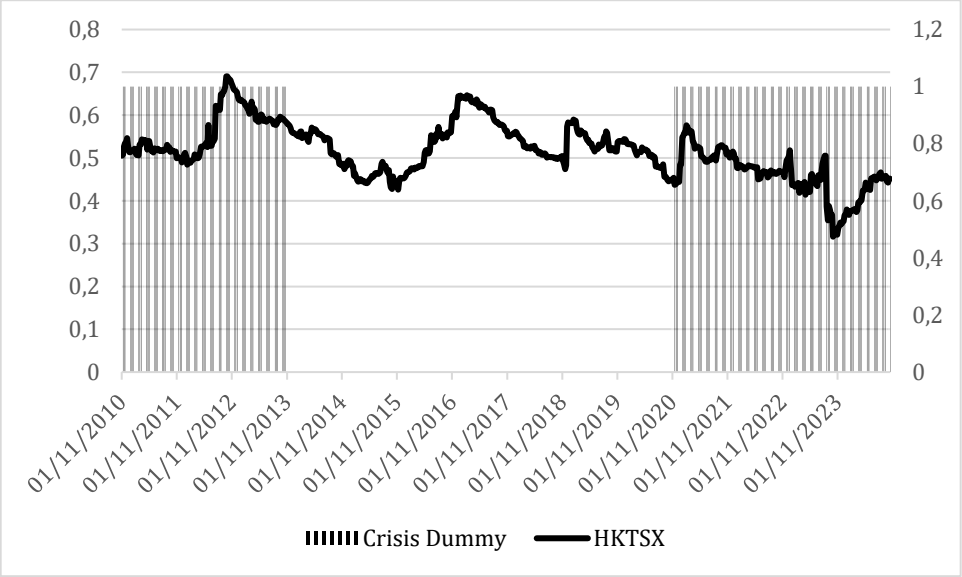

Figure 3 (c): Conditional Correlations between Hong Kong and Canada
Source: Authors' own elaboration

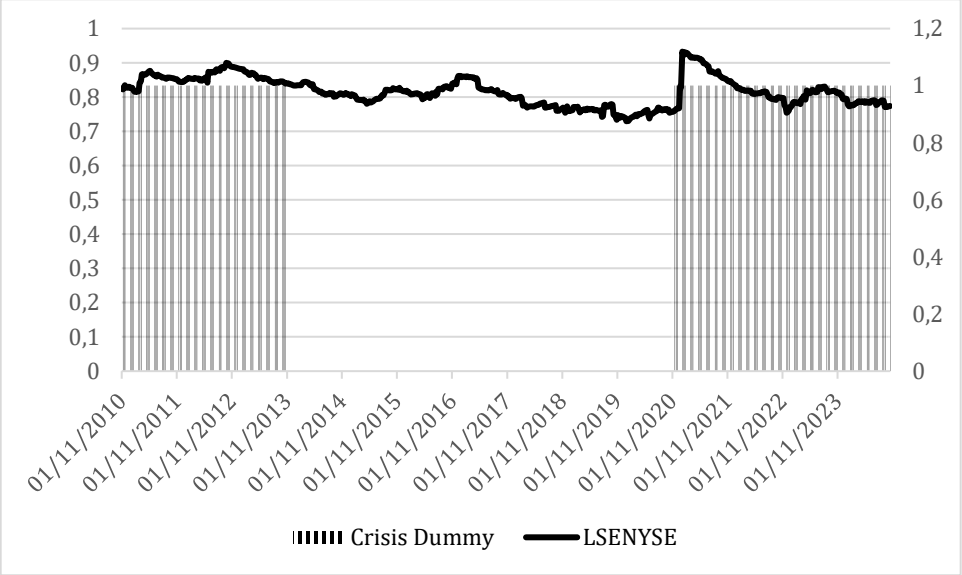

Figure 3 (d): Conditional Correlations between UK and USA
Source: Authors' own elaboration

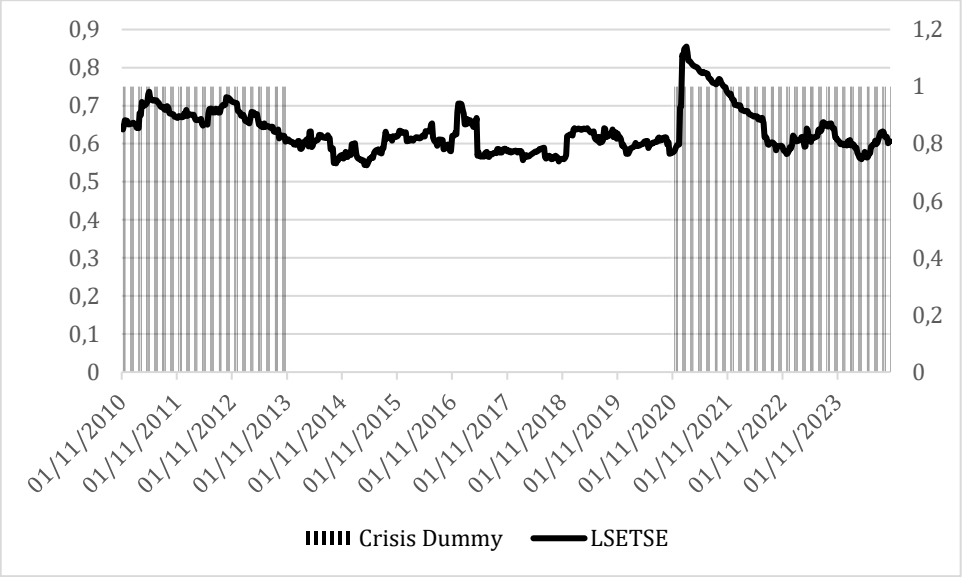

Figure 3 (e): Conditional Correlations between UK and Japan
Source: Authors' own elaboration

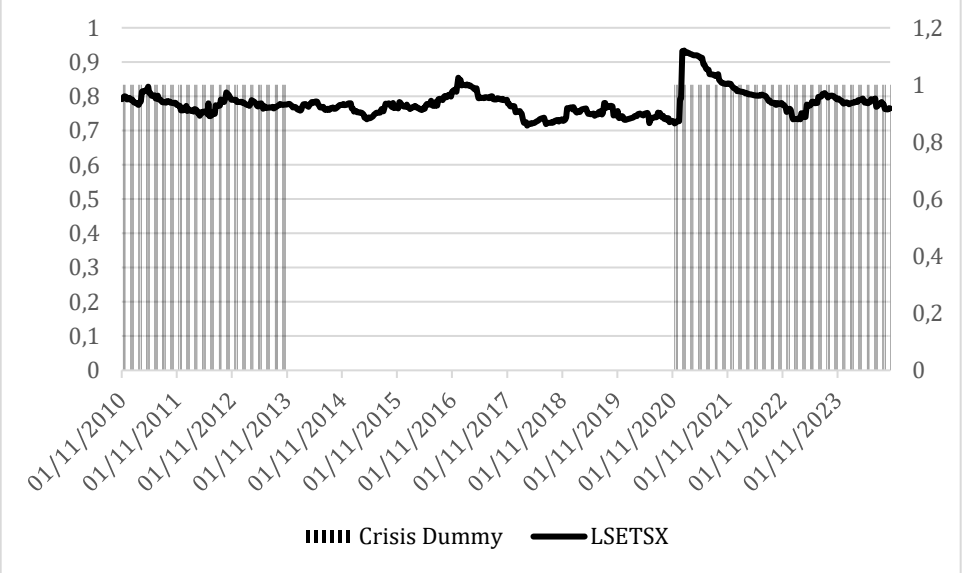

Figure 3 (f): Conditional Correlations between UK and Canada
Source: Authors' own elaboration

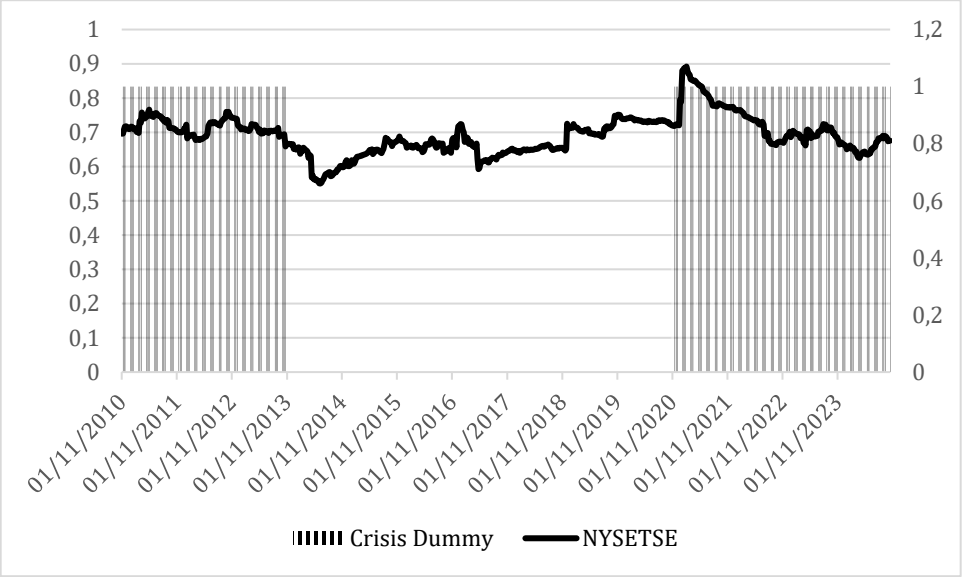

Figure 3 (g): Conditional Correlations between USA and Japan
Source: Authors' own elaboration

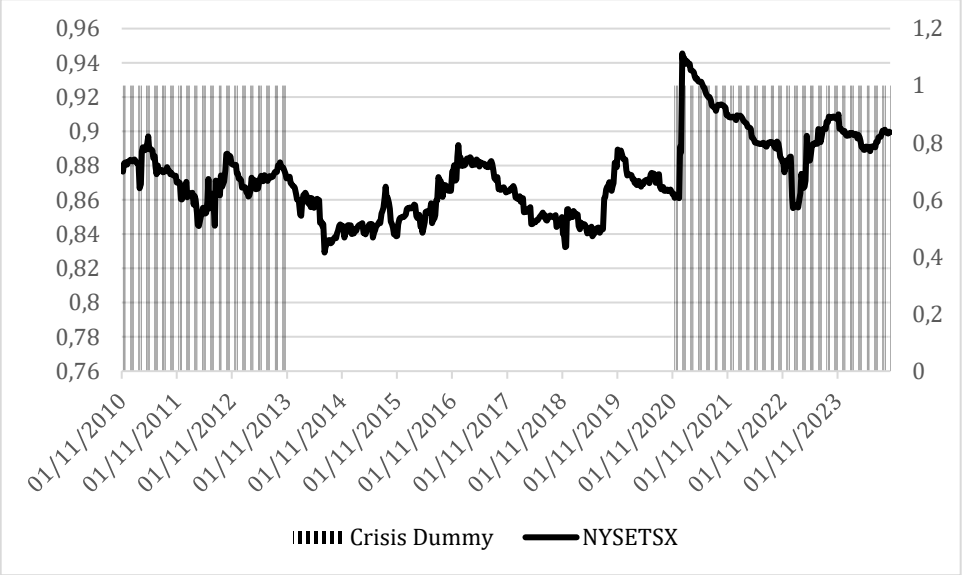

Figure 3 (h): Conditional Correlations between USA and Canada
Source: Authors' own elaboration

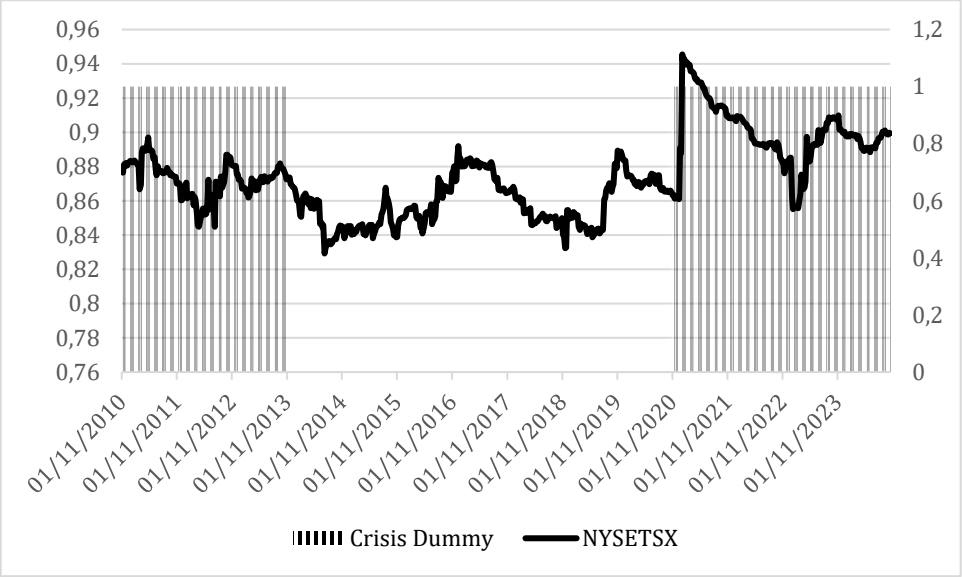

Figure 3 (i): Conditional Correlations between USA and Canada
Source: Authors' own elaboration

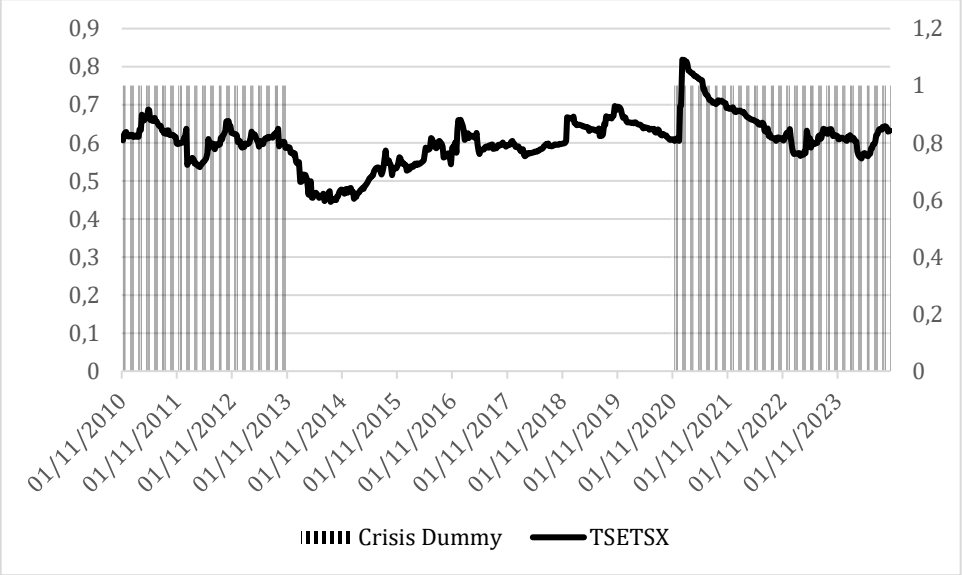

Figure 3 (j): Conditional Correlations between Japan and Canada
Source: Authors' own elaboration

Figure 2 (a-e) and 3 (a-j) show the time varying volatility plots and conditional correlations plots of HKEX, FTSE 100, NYSE, TSE, and S&P/TSX Composite Index returns estimated from MARCH-DCC model. Table 5 shows the average volatility and average conditional correlations of all five stock market returns during four subperiods denoted by the Eurozone crisis period, non-crisis period,

COVID period, and Russia-Ukraine war period. Figure 2(a-d) and Table 5 show that among all five stock returns, TSE stock returns and HKEX returns had been highly volatile during the entire sample period. It may be seen from Table 5 and Figure 2 that the volatility of HKEX, FTSE 100, NYSE, and S&P/TSX Composite Index was remarkably higher during the crisis periods vis-a-vis the non-crisis periods. We find that while during the EZ crisis, only the UK and Canada showed a substantial jump in volatility, all stock market returns except TSE depicted a substantial increase in volatility during the COVID period and the Russia- Ukraine war.

Table 5. Summary

Variable	EZ crisis	Non-crisis	COVID	WAR
Mean Volatility				
Hong Kong	7.55	6.11	8.65	9.69
United Kingdom	5.24	3.75	7.27	4.09
United States	6.32	3.53	8.94	5.76
Japan	7.04	7.22	8.4	6.68
Canada	4.14	2.91	7.64	4.46
Mean correlation estimates				
Hong Kong & UK	0.604	0.555	0.477	0.456
Hong Kong & USA	0.658	0.606	0.55	0.488
Hong Kong & Japan	0.587	0.539	0.538	0.461
Hong Kong & Canada	0.561	0.528	0.463	0.419
UK & USA	0.858	0.796	0.827	0.796
UK & Japan	0.674	0.6	0.671	0.609
UK & Canada	0.779	0.765	0.81	0.778
USA & Japan	0.716	0.664	0.735	0.677
USA & Canada	0.873	0.859	0.9	0.892
Japan & Canada	0.611	0.577	0.657	0.604

Note: EZ stands for Euro Zone crisis, COVID stands for Covid-19 and WAR stands for Russia-Ukraine Conflict

Source: Authors' own estimation

Table 5 indicates a marginal uptick in the mean conditional correlations between five stock market returns during the Eurozone crisis. Further, Figure 3 (a-j) shows that while an outbreak of the pandemic in January 2020 led to a sudden spike in almost all TVCCs, they fell gradually, particularly depicting a major fall since the tension escalation between Russia and Ukraine from February 2022. The mean

correlation estimates in Table 5 reveal that during the COVID and Russia-Ukraine war periods, while the mean conditional correlations of HKEX with the remaining four stock market returns fell, there was a small increase in mostly all other mean conditional correlations vis-a-vis non-crisis periods.

Table 6 Effect on Conditional Correlations assessed on GARCH DCC among stock markets during the phases of Euro Debt, COVID 19 and Russia-Ukraine War (using OLS with robust standard errors)

	Euro Debt (D1)	**Covid (D2)**	**War (D3)**	**Intercept**	**Inference**
Hong Kong & UK	0.0522895***	−0.0532485***	−0.0613166**	0.551789***	EZ-Contagion WAR-Flight to Quality COVID- 1. Flight to Quality for HK and USA, HK and UK, and HK and Canada 2. Contagion for other pairs
Hong Kong & USA	0.0518277***	−0.0178297*	−0.106282***	0.605883***	
Hong Kong & Japan	0.0474010***	0.0348973***	−0.101288***	0.539559***	
Hong Kong & Canada	0.0334487**	−0.0331444***	−0.0877353***	0.527890***	
UK & USA	0.0611289***	0.0387755***	−0.0260278***	0.797150***	
UK & Japan	0.0696238***	0.0839362***	−0.0491501***	0.604082***	
UK & Canada	0.0110340**	0.0502223***	−0.0221621*	0.767755***	
USA & Japan	0.0485474***	0.0830662***	−0.0439530***	0.667242***	
USA & Canada	0.0116265***	0.0361793***	0.00761924	0.861034***	
Japan & Canada	0.0287477***	0.0867581***	−0.0337739**	0.582034***	

Note: RHKEX, RLSE, RNYSE, RTSE and RTSX denote the stock market returns of Hong Kong, United Kingdom, USA, Japan and Canada, respectively

*,**, *** indicate 10%, 5% and 1% LoS respectively

Source: Authors' own estimation

The distinct patterns observed in the TVCCs during three crisis periods are statistically tested using OLS. The OLS estimates of equation 4 are given in Table 6. We find that the intercept coefficient for all conditional correlation equations is positive and significant at 1%. This implies that during stable periods, there is a strong correlation among the stock markets of developed nations. Table 6 shows the lowest correlation of 0.527890 between Hong Kong (HK) and Canada and the highest correlation of 0.861034 between the USA and Canada. It may be seen from Table 6 that the EZ coefficient is significantly positive at 1% for all TVCCs implying a substantial jump in these TVCCs during the EZ crisis. Further, while the coefficient of COVID is negative and significant for HK & UK, HK & USA,

and HK & Canada stock market correlations, it is positive and significant for all other TVCCs. This indicates that while the pandemic caused a decline in the conditional correlations between Hong Kong and UK, Hong Kong and USA, and HK and Canada stock market returns, it led to a major increase in the remaining TVCCs. Based on the findings listed in Table 6, it is apparent that the coefficient of WAR is negatively significant at the conventional LoS for all TVCCs except USA & Canada's stock market returns. Thus, Russia- Ukraine conflict led to a significant decrease in most of the TVCCs.

5. Conclusion

This article examines the SMI of five major developed countries, viz., Hong Kong, USA, UK, Japan, and Canada, particularly analysing the risk contagion among these stock markets during three crisis periods, namely Eurozone crisis, COVID-19 and the ongoing Russia- Ukraine conflict. The findings of the study are based on weekly data for HKEX, FTSE 100, NYSE TSE, and S&P/TSX Composite Index returns from 11.01.2010 to 25.12.2023 and multivariate GARCH DCC model. To examine the risk contagion amongst five stock market returns, the TVCCs obtained from the estimated MGARCH DCC model are regressed on three dummy variables corresponding to three crisis periods.

Our results suggest the presence of significant comovement amidst returns of Hong Kong, USA, UK, Japan, and Canada during the sample period. The results of this study provide evidence in support of significant contagion effects amongst the largest stock markets globally during the Eurozone crisis. However, this spillover impact narrows down to the markets of USA, UK, Japan, and Canada during the COVID period with an exception of Hong Kong. The results further lend support to 'flight to quality' effects between the HK and USA, HK and UK, HK and Canada during the COVID period. These results can be extended further by deep diving into reasons for such an exception. This may be due to the political turmoil in Hong Kong, beginning with the enactment of the 'National Security Law' by China in 2020. Furthermore, our findings reveal the presence of 'flight to quality effects' among all five stock markets during the ongoing Russia- Ukraine war.

The risk contagion found between the markets of Hong Kong, USA, UK, Japan, and Canada whilst the EZ crisis and COVID-19 strengthens market efficiency perspective on one hand and hints at limited portfolio diversification benefits for risk diversification due to connectedness of markets. However, the presence of 'flight to quality' effects among the HK and USA, HK and UK, HK and Canada during the COVID period and between all the five countries during the heightened geo-political tensions of Russia and Ukraine alter the previous results by favouring portfolio diversification among the stocks of these countries. Trade wars, financial crisis periods and regional conflicts are sensitive areas of concerns for all economies and the results of this study share useful insights into the response of the

largest stock markets to select concerns during the study period especially in the period post financial crisis 2008. All the economies across the globe witnessed overhauling of financial systems and hedging of funds to avoids future shocks and minimise transmission effects post 2008. The correlation estimates found between all five stock market returns are helpful in optimal portfolio management. Further, the outcomes of this research emphasise on the importance of policy coordination between the world's major developed economies.

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