

## **Volatility Modelling and Dynamic Linkages between Pakistani and Leading Foreign Stock Markets: A Multivariate GARCH Analysis**

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It is essential for financial institutions and academicians to understand volatility spillover and financial market returns. However, previous studies examined the effects of direct spillover only and ignored those of the newly emerging stock markets. Therefore, this study attempts to estimate the time-varying volatility of Pakistani and leading foreign stock markets. It also tries to explore the direct and indirect volatility spillover effect between Pakistani and eight leading foreign stock markets. Daily data were used from nine international equity markets (KSE 100, NIKKEI 225, HIS, S&P 500, NASDAQ 100, DOW JONES, GADXL, FTSE 350 and DFMGI) for the period between 2005 and 2016. The univariate GARCH and GJR models were employed for analysing volatility, and the multivariate GARCH Diagonal BEKK model was used to explore direct and indirect volatility spillover effects. In order to analyse the volatility spillover effect during and after the global financial crisis period, the data were categorised into two periods: between 2005 and 2009 and between 2010 and 2016. The Chow break-point test was also employed to identify structural breaks in return series due to global financial crises. Direct and indirect spillover effects were found between KSE100, S&P 500, NASDAQ 100, DOW JONES and DFMGI.

*Keywords:* Volatility, Spillover, Equity Market, Financial Crisis and GARCH

### **1. INTRODUCTION**

Globalisation has led to great changes in the global business including easy capital flow, the growth of technology, financial associations among the economies, and markets integration. However, the integration of markets extends the effects of financial crises, which means a crisis in one market affects other markets around the world. Therefore, financial institutes, portfolio managers, and market players should understand the volatility modelling and make an analysis of linkages among different financial markets. The global financial crisis stands as a perfect opportunity to quantify the magnitude of interdependence among the global financial markets. The objective of this study is to conduct an investigation to describe the direct and indirect spillover effects among the Pakistani and leading foreign financial markets.

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The severe financial crisis took place in the US in 2008 not only caused imbalances in the US economy but also affected the global economy. The main reasons for this crisis were imperfections in the international financial planning, an exceptionally relaxed monetary policy, accumulation of imbalances in the global balance of payment, and regulatory breakdowns at micro-prudential and macro-prudential levels [Kawai, *et al.* (2012)]. Generally, global financial crises begin in the US, and owing to the strong linkages between the US economy and global economies, the effects of these crises reach all integrated economies.

The effects of the 2008 global financial crisis directly transferred to the Pakistani economy through capital flow, exports, equity values and remittances [Amjad and Din (2010)]. The Pakistani economy at that time was also suffering from some domestic social and economic problems, such as energy shortage, political instability, the deficit in the current account, growing unemployment, bad governance and inefficient macroeconomic policies [Ghose and Khan (2017)]. Accordingly, the Pakistani economy encountered a shortfall in balance of payment, a reduction in exports volume and stagflation. Nazir, *et al.* (2012) stated that financial institutions in Pakistan, especially the commercial banks, were directly affected by the 2008 financial crisis, which also significantly compressed their market policies, working strategies, and financial arrangements. However, the Islamic banking system was less affected than the conventional banking system [Phulpoto, *et al.* (2012)].

Pakistan stock exchange (KSE 100 index) closed at its highest points 14,814.85 on 26 Dec. 2007 with accumulated market assets of Rs 457 trillion. The accumulated stock market capitalisation was only Rs.1.85 trillion (\$23 billion) with points 5,865.01 on 31 Dec. 2008. A more critical situation arose on 23 Jan. 2009, when the stock market index had only pointed 4,929.54 with a total market capitalisation of Rs 1.58 trillion [Amjad and Din (2010)]. It indicates the loss of approximately 65 percent from the highest point of 26 Dec. 2007. In 2006-07, the foreign direct investment in PSX listed companies was \$500 million, which was reduced due to the global financial crisis (for further detail see SBP, 2006-07 and 2008-09).

Dubai economy also suffered from the effects of the US mortgage crisis 2008 (hereafter global financial crisis) due to its investment linkages with the US economy and the international financial system [Onour (2010)]. The real estate was one of the most prominent sectors of Dubai in 2007-08. The real estate sector contributed more than 23 percent to the GDP of Dubai economy in 2007-08, which was badly affected by the global financial crisis. Dubai property sharply slumped due to the global recession; home prices were declined 50 percent from their peak in 2008. In the real estate sector, the government of Dubai hampered \$59 billion liabilities, and the total debt became \$80 billion in a few weeks [Gabbatt (2009)]. Dubai banking sector was stuck in this vicious circle of financial crisis, limited capital reserves and the regulation imposed on bank lending. The investment in the real estate sector was reduced due to the shortage of loaning from the banks.

The financial sector of Dubai contributed 11 percent to the GDP in 2008, while exports and other trade contributed 31 percent to the GDP. Because of the global financial crisis, the oil prices dropped significantly from \$140 to \$50 from June 2008 to March 2009 in the international market, which curtailed the volume of trade [Ellaboudy (2010)]. Dubai

financial market also impressively affected Dubai economic growth. Dubai financial market was also crashed by the global financial crisis as the portfolio investment declined from 42 percent to 18 percent in the crisis period, which resulted in a debt crisis (known as Dubai financial crisis 2009). In June 2008, the Dubai stock market fell down; 57 companies were listed on the Dubai financial market (DFM) with an accumulated market capitalisation of about \$360 billion in 2007 [Gabbatt (2009)]. Dubai financial market index (DFMGI) closing price was found \$5489.37 on Nov. 13, 2007, while on 31 Jan. 2008, Dubai financial market index (DFMGI) closing price was recorded \$5615.95. Also, on 21 Dec. 2008, (DFMGI) closing price was found only \$1793.26.

Pakistan has a significant economic relationship with Dubai. Dubai is one of the emerging markets in the United Arab Emirates (UAE) where over 1.2 million Pakistani emigrants are providing their services. Their remittances significantly contribute to Pakistan's foreign reserve, which makes the UAE the second prominent source of remittances to Pakistan. For example, Pakistan expatriates provided \$2.52 billion remittances in 2013-14 with a share of 19.57 percent in total remittances. Similarly, the UAE has a major share in Pakistan exports and imports [PES (2010)].

In 2006-08, a lot of money moved from Pakistan and many other countries to Dubai where property and capital markets were flourishing. At that time, credit was available at low cost, and traders were operating the market to gain large dividends. These people did not know what would be the result of this easy money. During the UAE cityscape "7th annual property and real estate exhibition 2008" in Dubai, more than 100 Pakistani, out of 40,000 visitors from all over the world, invested over \$100 million in the booking of construction projects. Within the 10 to 11 months after Nov. 3, 2007, the outflow of capital from Pakistan economy to Dubai was estimated to be between \$30 billion and \$45 billion [Aziz (2008)]. A huge amount of new money arrived in Dubai and a large ratio of it wiped out when Dubai capital and the property market crashed.

The above discussion elaborates the financial linkages between Pakistan, US, and Dubai economies. In this study, the stock markets of those countries are considered, which are interlinked with the Pakistan economy and the global economic and financial system. Although Pakistan economy is not very much linked with the international financial system, it could be affected through indirect channels which have not been explored in any previous study especially in context of Pakistan, US, and Dubai stock markets.

The main objective of this study is to measure the degree of direct and indirect volatility spillover effects of other leading foreign stock markets on Pakistan stock exchange. To explore the spillover effects among leading stock markets in crisis and after the crisis period, data from the period between 2005 and 2016 is used. To see the magnitude of volatility spillover effect during and after the crisis, data was split into two parts, from 2005 to 2009 and post-crisis period ranging between 2010 and 2016. The findings of the study are helpful in device short run and long economic policies during and after crises.

## **2. LITERATURE REVIEW**

This section briefly discusses previous studies. Kawai, *et al.* (2012) found that global markets experienced a huge wave of financial crisis due to the United State sub-

prime mortgage crisis. This crisis affected not only the US domestic economy but also other economies of the world, which were integrated directly or indirectly with the US economy. Mishkin (2011) indicated that this crisis started from a small segment of the financial system, but in 2008-2009, it became a reason for the global financial crisis.

Jawed (2015) investigated co-movements between S&P 500 and KSE 100 and found a significant spillover effect from the S&P 500 to KSE 100. Ahmed, *et al.* (2018) explored the mean and volatility spillover effect between stock indices of five developed and seven developing stock markets and concluded that there is a spillover effect from NIKKIE 225 to KSE 100. Jebran, *et al.* (2017) explored the spillover effect amongst emerging markets of Asia. They found that there is a bi-directional volatility spillover effect among Pakistan, India, and Sri Lanka stock markets. Zia-ur-Rehman, *et al.* (2011) found that the global financial crisis's negative effect was transmitted to the Pakistan stock market. Aziz and Iqbal (2017) explored the spillover effect among the USA, India, Japan, and Pakistan stock markets. He found a volatility spillover effect between Pakistani, USA, and Japan stock markets. Jan and Jebran (2015) investigated the volatility spillover effect from USA, Germany, France, and UK stock markets to Pakistan stock market. They found a significant volatility spillover effect from G5 stock markets to KSE 100 in the global financial crisis. The volatility spillover effect was transmitted to Pakistan from international stock markets due to the regional connectivity [Wahid and Mumtaz (2018)]. Draz (2011) examined that Pakistan economy faced five financial crises (1958, 1974, 1979, 1997 and 2008); four out of them significantly affected the Pakistan economy. Li and Giles (2015) measured the spillover effect from US stock markets to Japan and other six Asian developing countries stock markets. They found a unidirectional return and volatility spillover from the US to other markets.

Iqbal and Sattar (2010) found that the global crisis was also a cause for dipping remittances, fewer exports, stock markets decay, the flight of capital, and local currencies depreciation. They also concluded that the global crisis critically affected foreign direct investment, exports, and portfolio investment. During the financial crisis, Pakistan needed financial inflows in different shapes from other countries to improve economic growth. Financial inflow to the developing countries decreased by approximately US\$300 billion. Investors shifted Portfolio investment and foreign direct investment to those countries that were not affected by the global financial crisis [Cali, *et al.* (2008)].

Kharchenko and Tzvetkov (2013) examined the volatility spillover effect between developing and developed market economies and found that there is a spillover effect between the USA and European stock markets. Angkinand, *et al.* (2009) investigated how the financial crisis in US markets impacted 17 developed economies, and they found that spillover effects from the US to other industrial countries were highest after the collapse of the U.S subprime mortgage market in 2007. Fraser and Oyefeso (2001) explained the significant dynamic links of United State stock markets with the UK and European stock markets.

Ghouse and Khan (2017) examined the spillover effect between Dubai financial market and S&P 500, DOW JONES, and NASDAQ indices. They found a significant bidirectional spillover effect between Dubai financial market and USA stock markets. Alsukker (2010) explored that the US mortgage crisis 2008 affected Dubai financial market, the banking system, economy, and Dubai's companies credit ratings. Onour

(2017) stated that the spillover effect of the US Mortgage crisis 2008 badly affected oil-producing countries including Dubai. The portfolio investment in the financial market of Dubai decreased by 42 percent. Due to this spillover effect, Dubai also faced an internal debt crisis in 2009. Hasan (2010) found that the financial crisis crushed the major sector of the economy. The Global financial crisis barely affected Dubai among all the other oil-producing countries leading to reducing the oil prices in the developed countries. Ellaboudy (2010) indicated that from mid-2008 to March 2009, oil prices dropped down from \$140 to \$50 at the international market.

All the studies reviewed in this section examined direct channels of the volatility of spillover effect from leading foreign stock markets. There is no single study exploring the indirect channel of volatility spillover effect between Pakistani and foreign leading stock markets. Also, the relation between Pakistan and Dubai stock markets has not been significantly explored. To fill these gaps at first, the magnitude of direct volatility spillover effect between Pakistani and foreign stock markets was re-estimated. Secondly, the indirect volatility spillover effect between Pakistani and foreign stock markets was estimated. Lastly, the volatility spillover effect between Pakistani and Dubai financial market was estimated.

### 3. ECONOMETRIC METHODOLOGY AND MODEL SPECIFICATION

To capture the time-varying conditional variance phenomenon, Engle (1982) proposed the Autoregressive Conditional Heteroscedastic (ARCH) model. Although the ARCH model is a considerable contribution to the econometric literature, it has some problems including long lag length and non-negativity restriction on parameters. To solve the first problem, Bollerslev (1986) introduced generalised autoregressive conditional heteroscedastic (GARCH) model, which improves the unique specification with the addition of the lag value of conditional variance, which acts as a smoothing term. The GARCH model cannot analyse asymmetric and leverage effects. For this, Glosten, Jagannathan, and Runkle (1993) proposed a GJR model. GJR model is a significant extension of the standard GARCH model. It contains an asymmetric term in conditional variance equation. To avoid any non-convergence problem in this study, an appropriate univariate GARCH type model such as GARCH (p, q) and GJR (p, q) is employed to estimate volatility models, and the multivariate DGARCH-BEKK is employed to explore volatility spillover effect.

The financial series at a level are trendy in nature [Ghouse and Khan (2017)]. It is impossible to estimate a robust model if the series is trendy. To deal with the trend, the log return is used.

$$R_t = \log_e(l_t/l_{t-1})$$

$l_t$  = Financial time series at level i.e. stock indices and exchange rates at the end of time  $t$ .

$l_{t-1}$  = First lag of financial time series.

#### 3.1. Modelling for Volatility

##### 3.1.1. GARCH (p, q) Model

Bollerslev (1986) proposed a generalised extension of ARCH (q) model Generalised autoregressive conditional heteroscedastic (GARCH) model.

The general description of the GARCH model is

**Conditional Mean Equation**

$$R_t = \alpha_0 + \beta X_t + \varepsilon_t \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (3.1)$$

Where  $\varepsilon_t = z_t \sigma_t$ ,  $z_t \sim N(0,1)$

**Conditional Variance Equation**

$$\sigma_t^2 = \theta_0 + \sum_{i=1}^q \theta_i \varepsilon_{t-1}^2 + \sum_{j=1}^p \varphi_j \sigma_{t-1}^2 \quad \dots \quad \dots \quad \dots \quad \dots \quad (3.2)$$

Where  $\theta_0 > 0$ ,  $\theta_i \geq 0$ ,  $\varphi_j \geq 0$

In the GARCH (p, q) model, the conditional variance depends upon the square of past values of process  $\varepsilon_t$  and lag of conditional variance  $\sigma_{t-1}^2$ . The condition of non-negativity of parameter also applied in this model.

**3.1.2. GJR (p, q) Model**

Glosten, *et al.* (1993) introduced (GJR) model in 1993. GJR model is a significant extension in a simple GARCH model. This model also captures the asymmetries in ARCH process. GJR model also accounts for the leverage effect in a financial series.

The general representation of the GJR model is:

**Conditional Mean Equation**

$$R_t = \alpha_0 + \beta X_t + \varepsilon_t \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (3.3)$$

Where  $\varepsilon_t = z_t \sigma_t$ ,  $z_t \sim N(0,1)$

**Conditional Variance Equation**

$$\sigma_t^2 = \theta_0 + \sum_{i=1}^q \theta_i \varepsilon_{t-i}^2 + \sum_{i=1}^q \delta_i \varepsilon_{t-i}^2 G_t + \sum_{j=1}^p \varphi_j \sigma_{t-j}^2 \quad \dots \quad \dots \quad (3.4)$$

Where  $\theta_0 > 0$ ,  $\theta_i \geq 0$ ,  $\varphi_i \geq 0$ ,  $0 \leq \delta_i \leq 1$  Range of parameter of leverage effect.  $G_t = 1$  when  $\varepsilon_{t-1} < 0$  and  $G_t = 0$  when  $\varepsilon_{t-1} \geq 0$ .

**3.2. Modelling for Volatility Spillover**

The multivariate GARCH diagonal BEKK has been used to measure the spillover effect between the markets. The Chow break-point test is used to test the breaks in return series, especially due to the financial crisis.

**3.2.1. Chow Break-Point Test**

The Chow break-point test is proposed by Chow (1960). Chow test is employed to identify the structural breaks due to the financial crisis, whether the coefficient of linear regressions are equal in different data sets. The Chow test is used to identify the structural breaks in return series due to the global financial crisis.

$$F = \frac{(RSS_{UR} - (RSS_{Res1} + RSS_{Res2}))/K}{(RSS_{Res1} + RSS_{Res2})/(N-2K)} \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (3.5)$$

$RSS_{URes}$  is the residual sum of square of whole data sets.  $RSS_{Res1}$  is the residual sum of square of the first part of data.  $RSS_{Res2}$  is the residual sum of square of second part of data  $N$  is the number of observations and  $K$  is the number of parameters.

**3.2.2. Multivariate GARCH Diagonal BEKK**

Baba, Engle, Kraft, and Kroner (1990) proposed the BEKK model to guarantee the positive definiteness of the variance-covariance matrix  $H_t$ . the BEKK model is also known as a restricted version of the VEC model. When  $A$  and  $G$  matrices become diagonal then the BEKK model is converted into Diagonal BEKK which is introduced by Bollerslev, Engle, and Wooldridge (1988).

$$R_t = \sum_{i=1}^k \vartheta_i R_{t-i} + \varepsilon_t \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (3.6)$$

Where  $R'_t = [r_1 \quad r_2 \quad \dots \quad r_n]$  and  $\varepsilon'_t = [\varepsilon_1 \quad \varepsilon_2 \quad \dots \quad \varepsilon_n]$

**The Diagonal BEKK (p,q,k) Model**

$$H_t = \delta \delta' + \sum_{i=1}^q \sum_{k=1}^k A'_{ki} \varepsilon_{t-i} \varepsilon'_{t-i} A_{ki} + \sum_{i=1}^p \sum_{k=1}^k G'_{ki} H_{t-i} G_{ki} \quad \dots \quad \dots \quad (3.7)$$

Where  $H_t = \begin{bmatrix} h_{11,t} & \dots & h_{k1,t} \\ \vdots & \ddots & \vdots \\ h_{k1,t} & \dots & h_{kk,t} \end{bmatrix}$  and  $\delta = \begin{bmatrix} \delta_{11} & \dots & 0 \\ \vdots & \ddots & \vdots \\ \delta_{k1} & \dots & \delta_{kk} \end{bmatrix}$

$Diagonal A = [a_{k1}, \dots, a_{kk}]$ , and  $Diagonal G = [g_{k1}, \dots, g_{kk}]$

Where  $H, A, \delta$  and  $G$  are parameter matrices.  $\delta$  is a lower triangular matrix. The constant term decomposition of into a multiplication of two triangular matrices, is to ensure the variance covariance matrix  $H$  positive definiteness. The GARCH Diagonal BEKK model is used here instead of GARCH-BEKK because of the large parameter, the GARCH-BEKK, has a convergence problem.<sup>1</sup>

**3.3. Description of Data and Sources**

The daily data of stock market indices have been used for the period between 2005 and 2016. The leading stock markets are taken from Asia, Europe, America, and Gulf regions. The American markets are S&P 500, DOW JONES (DJI), and NASDAQ 100. Leading markets from Europe are London (FTSE 350) and German (GDAXI) stock exchange. The prominent markets from Asia are Pakistan (PSX 100), Japan (NIKKEI 225) and Hong Kong (HIS) stock markets. The Dubai financial market (DFM) is taken from Gulf countries.

**4. ESTIMATIONS AND ANALYSIS**

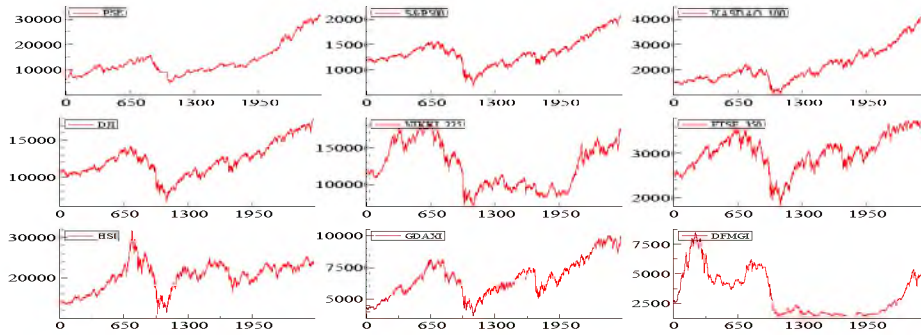
This section describes results and discussion of results.

**4.1. Graphical Analysis**

Figure 1 indicates that all the series have an upward trend and a sharp decline around 2008 due to the global financial crisis. Then again, there is a continuous upward trend with some fluctuations. It shows that the series is trendy and seems non-stationary at level.

<sup>1</sup>Khan, S.A (2012). <https://asadzaman.net/my-students/>

**Fig. 1. Graph of Series at Level**



A single return series (PSX 100) is used for further data visualisation, and other return series could be visualised in the same manner. Figure 2 given below is representing a return series of PSX 100 index. In financial econometrics, the spread is characterised as volatility. Figure two shows that the spread does not remain the same throughout the series, which is known as Heteroscedasticity. The circles in Figure 2 are indicating low and high volatility. According to The Efficient Market Hypothesis (EMH), returns are unpredictable and show mean reversion behaviour.” We can easily distinguish between low volatility clustering and high volatility clustering period. The greater depreciation from a constant level (mean of return series) indicates high volatility clustering, and less depreciation illustrates low volatility clustering. If all effects are combined, they indicate the ARCH (Auto-Regressive Conditional Heteroscedasticity) effect.

**Fig. 2. Graph of Given Return Series**

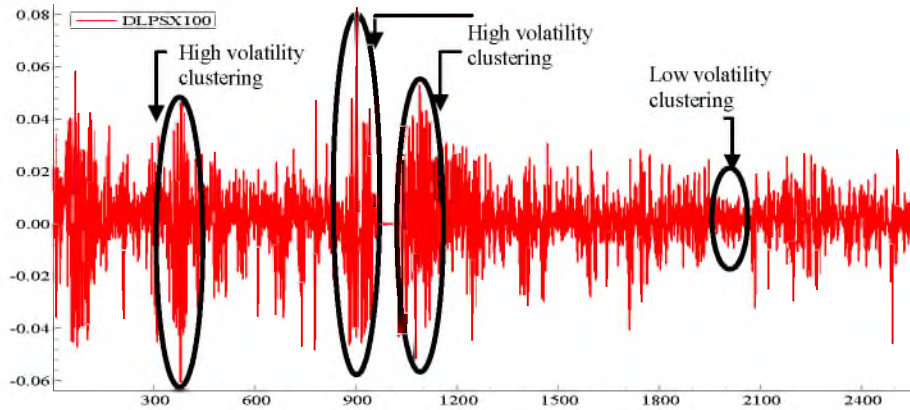
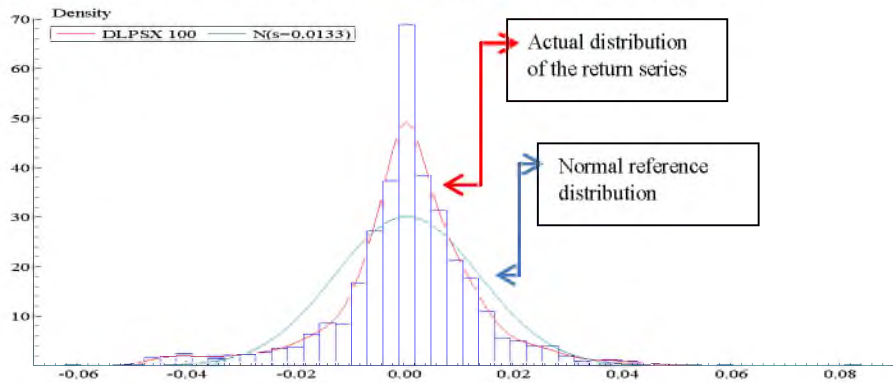


Figure 3, illustrates the distribution of the return series of PSX 100 index. In this graph, the blue line shows the normal reference distribution of return series. The red line indicates the actual distribution of the return series. Histograms describe the outliers (extreme values) in return series.



**Fig. 3. Graphs Distribution of the Return Series**



The distribution of return series has heavy tails and is leptokurtic, which shows that the distribution of return series is non-normal. This is due to the different response of market players who have the same information from the same market.

Figure 4, given below, presents ACF (Auto-correlation function) and PACF (Partial Auto-correlation function) of return series of PSX 100 index. The green straight lines in this graph show a 95 percent confidence interval. If any bar of ACF and PACF is outside these lines, it means at that lag the values are autocorrelated. It significantly varies from zero. The ARMA (p, q) process specifies through the significant lags of ACF and PACF. The ACF specifies the MA (q) process. PACF specifies the AR (p) process. In order to identify the ARMA process, prominent lags of ACF and PACF are focused upon. In this graph 1st lags of ACF is significantly prominent and 1st lag of PACF is also significant and prominent.

**Fig. 4. Graphs of ACF and PACF of Return Series**



#### 4.2. Summary Statistics

The results in Table 1 show the initial statistics of return series of stock markets indices. The statistics unveil some indications about the behaviour of stock markets. The distributions of return are non-normal, heavy tails and leptokurtic. The mean of all

returning series is about zero, which implies that return series have a mean reversion behaviour. The standard deviation of return series describes the dispersion from the mean value, which shows that if the return series has a greater standard deviation, it has more deviations from the mean value. The skewness deals with the asymmetry of the distribution. The distributions of PSX 100, S&P 500, NASDAQ 100, DJI, NIKKEI 225, FTSE 350 and DFMGI return series are negatively skewed, which means that the return of these stock markets is less than average return. The distributions of HIS and GDAXI are positively skewed, which implies that the returns of these markets are more than average returns. The Jarque-Bera (J.B) test with a null hypothesis of a normal distribution is employed. Jarque-Bera statistics of all returning series are significant, which means the distribution of all returning series is non-normal.

Table 1

*Summary of Statistics*

Series	Mean	Standard deviation	Skewness	Jarque Bera	Excess Kurtosis	Q-stat (5)	Q2-stat (5)	ARCH 1-2	KPSS
KSE 100	0.0006	0.0133	-0.3054	1096.1 (0.000)	3.1075 (0.000)	76.12 (0.000)	1167.51 (0.000)	266.88 (0.000)	0.2073
S&P 500	0.0002	0.0427	-0.0409	17088 (0.000)	11.448 (0.000)	45.484 (0.000)	1131.31 (0.000)	266.72 (0.010)	0.1965
NASDAQ 100	0.0003	0.0736	-0.0587	7685.9 (0.000)	8.6282 (0.000)	24.928 (0.000)	765.777 (0.000)	156.96 (0.000)	0.2005
DJI	0.0001	0.0716	-0.0851	3168 (0.000)	11.499 (0.000)	45.037 (0.000)	1123.85 (0.000)	283.89 (0.006)	0.1548
NIKKEI 225	0.0001	0.0653	-0.0737	9597.9 (0.000)	8.885 (0.000)	10.564 (0.000)	1396.71 (0.000)	489.45 (0.000)	0.1994
HIS	0.0002	0.0856	0.1459	18971 (0.000)	10.12 (0.000)	8.387 (0.000)	1361.38 (0.000)	361.66 (0.004)	0.0525
FTSE 350	0.0001	0.0018	-0.2879	7088.8 (0.000)	8.2401 (0.000)	39.367 (0.000)	1130 (0.000)	147.29 (0.009)	0.0569
GDAXI	0.0003	0.0637	0.5297	5010.5 (0.000)	7.1719 (0.000)	16.783 (0.000)	686.71 (0.000)	111.39 (0.000)	0.07411
DFMGI	0.0001	0.0883	-0.7778	19612 (0.002)	11.135 (0.000)	32.381 (0.000)	166.23 (0.000)	44.647 (0.000)	0.4874

Null Hypotheses (All Null Hypotheses are for nth order).

KPSS H0: Return series is level stationary, Asymptotic significant values 1 percent (0.739), 5 percent (0.463), 10 percent (0.347). Q-stat (return series) there is no serial autocorrelation. Q2-stat (square return series) H0: there is no serial autocorrelation. Jarque-Bera H0: distribution of series is normal. LM-ARCH H0: there is no ARCH effect. Use these Asymptotic Significance values of t-stat 1 percent (0.01), 5 percent (0.05), 10 percent (0.1) and compare these critical values with P-values (Probability values). P-values are in the parenthesis.

The Excess kurtosis in Table 1 of all returns series is significant, which means that return series distributions are leptokurtic and indicates that the probability of large values is more than normal return values. Q-stat of return series is significant, which shows that there is serial autocorrelation in return series. Q-stat of squared return series is significant, which shows that there is serial autocorrelation in square return series. LM-

ARCH test validates that there is ARCH effect in return series. KPSS is a unit root test with a null hypothesis of stationary series. KPSS test results of all variable show that the return series is level stationery.

**4.3. Volatility Modelling**

A lot of empirical work on volatility modelling exists in financial literature. However, the predictability and modelling of volatility are still challenging for researchers. Many researchers in their studies employed GARCH family models for volatility modelling and forecasting. Akhtar and Khan (2016) used GARCH models for volatility modelling of KSE 100 index. Lim and Sek (2013) employed a symmetric and asymmetric GARCH model for volatility modelling of Malaysia. Ghouse and Khan (2017) used GARCH models to capture the dynamic symmetric and asymmetric effects in return series of leading financial markets.

The results in Table 2 describe the volatility modelling statistics of return series, and Table 3 contains the results of the residual analysis. the equation structure of one series (PSX 100) is provided for convenience in reading table results.

The GJR model is employed for PSX 100 volatility modelling. The estimated conditional mean Equation (4.3) is derived from Equation (3.9) and the estimated conditional dispersion Equation (4.4) is derived from Equation (3.10). The P-values are in parenthesis.

$$R_t = 0.0008 + 0.8900R_{t-1} - 0.9000\varepsilon_{t-1} \quad \dots \quad \dots \quad \dots \quad \dots \quad (4.1)$$

(0.0000)    (0.0000)    (0.0000)

$$\sigma_t^2 = 0.0056 + 0.1460\varepsilon_{t-2}^2 + 0.3234\varepsilon_{t-1}^2 G_t + 0.8031\sigma_{t-1}^2 \quad \dots \quad \dots \quad (4.2)$$

(0.9010)    (0.0000)    (0.0000)    (0.0000)

In the first equation, AR (1) term  $R_{t-1}$  is statistically significant which means that the current return depends upon 1st lag. The MA (1) term  $\varepsilon_{t-1}$  is also different from zero, which shows the relationship between past and current variations, while the constant term is also significant. The second equation describes that the PSX 100 series has an asymmetric effect, because the GJR term  $\varepsilon_{t-1}^2 G_t$  is significant which indicates the existence of a leverage effect. The leverage effect directs that the current return is negatively correlated with future volatility, while the ARCH  $\varepsilon_{t-2}^2$  and GARCH terms  $\sigma_{t-1}^2$  are also significant at 1 percent level of significance.

Similarly, the returns series of NIKKEI 225 also have asymmetric effects. All other series S&P 500, DOW JONES (DJI), NASDAQ 100, FTSE 350, GDAXI, HIS and DFMGI are having symmetric effects. Most of the parameters are statistically significant at 5 percent level of significance. ARCH and GARCH terms are also significant in the models, meaning that the return series are subject to ARCH effect.

The persistence of shock in return series is very important factor for forecasting different effects persisting in return series and their decay time. If it becomes close to 1, it means the persistence of ARCH and GARCH effect takes a long time to decay. If it is not close to 1 or less than 1, it shows that the persistence of ARCH and GARCH effect takes a short time to decay. As shown in Table 2, the persistence of shock estimators value is close to 1, which means that the persistence of ARCH and GARCH effects takes a long time to decay from all the series.

Table 2

*Volatility Modeling of Stock Markets*

	PSX-100	NIKKEI-225	HIS	S&P 500	NASDAQ 100	DOW JONES	FTSE 350	GDAXI	DFMGI
	ARMA(1,1)	ARMA(0,0)	ARMA(0,0)	ARMA(1,1)	ARMA(0,0)	ARMA(2,1)	ARMA(0,0)	ARMA(1,1)	ARMA(1,1)
	GJR (1,1)	GJR (1,1)	GARCH (3,2)	GARCH (1,2)	GARCH (1,1)	GARCH (1,1)	GARCH (1,1)	GARCH (1,1)	GARCH (1,1)
<b>Conditional Mean Equation</b>									
Constant	0.0009	0.0006	0.0006	0.0008	0.0011	0.0008	0.0006	0.0010	0.0005
$\alpha_0$	(0.7538)	(0.0093)	(0.0013)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.2032)
AR(1)	1.0000	—	—	0.7395	—	-0.9511	—	0.9396	0.8848
$\beta_1$	(0.0000)	—	—	(0.0000)	—	(0.0000)	—	(0.0000)	(0.0000)
AR(2)	—	—	—	—	—	-0.0560	—	—	—
$\beta_2$	—	—	—	—	—	(0.0039)	—	—	—
MA(1)	-0.9000	—	—	-0.7992	—	0.8958	—	-0.9551	-0.8330
$\beta_3$	(0.0000)	—	—	(0.0000)	—	(0.0000)	—	(0.0000)	(0.0000)
<b>Conditional Variance Equation</b>									
Constant	0.0000	0.0475	0.0070	0.0219	0.0232	0.0130	0.0139	0.0218	0.0313
$\theta_0$	(1.0000)	(0.0007)	(0.0830)	(0.0000)	(0.0000)	(0.0005)	(0.0025)	(0.0025)	(0.0633)
ARCH(1)	0.1460	0.0273	—	—	0.0890	0.1112	0.1145	0.0988	0.0630
$\theta_1$	(0.0003)	(0.0240)	—	—	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
ARCH(2)	—	—	0.0523	0.1433	—	—	—	—	—
$\theta_2$	—	—	(0.0000)	(0.0000)	—	—	—	—	—
GARCH(1)	0.8032	0.8839	2.0078	0.8481	0.8991	0.8841	0.8790	0.8943	0.9311
$\varphi_1$	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
GARCH(2)	—	—	1.7205	—	—	—	—	—	—
$\varphi_2$	—	—	(0.0000)	—	—	—	—	—	—
GARCH(3)	—	—	0.6600	—	—	—	—	—	—
$\varphi_3$	—	—	(0.0000)	—	—	—	—	—	—
GJR(1)	0.3234	0.1287	—	—	—	—	—	—	—
$\delta_1$	(0.0000)	(0.0000)	—	—	—	—	—	—	—
Persistence of shock	0.9109	0.9755	0.9996	0.9915	0.9883	0.9954	0.9935	0.9932	0.9941

Null Hypotheses (All Null Hypotheses are for n<sup>th</sup> order).

AR (p) H0:  $\beta_i = 0$  No AR Process, MA (q) H0:  $\beta_i = 0$  No MA Process, ARCH H0:  $\beta_i = 0$  No ARCH effect, GARCH H0:  $\varphi_i = 0$  No GARCH effect, Leverage effect H0:  $\delta_i = 0$  No leverage effect. P-values are in the parenthesis.

Table 3

*Residual Analysis*

Series	Parameter	LM-ARCH LM-ARCH						
		Jarque Bera	Q-Stat (5)	Q-Stat (10)	Q <sup>2</sup> -Stat (5)	Q <sup>2</sup> -Stat (10)	(1-2)	(1-5)
PSX-100		7.0272	0.0019	0.0024	0.0020	0.0039	0.0004	0.0004
	ARMA(1,1) GJR (1,1)	(0.0000)	(0.9999)	(1.0000)	(0.9999)	(1.0000)	(0.9999)	(1.0000)
NIKKEI-225		509.46	2.0605	6.0220	0.6678	5.1253	0.2047	0.1380
	ARMA(0,0) GJR (1,1)	(0.0000)	(0.8407)	(0.8134)	(0.8807)	(0.7440)	(0.8149)	(0.9835)
HIS		128.04	1.7793	5.1972	5.2051	13.983	0.3964	0.5536
	ARMA(0,0) GARCH (3,2)	(0.0000)	(0.8787)	(0.8776)	(0.3913)	(0.5267)	(0.6727)	(0.7356)
S&P 500		524.96	4.5842	7.4715	1.2465	9.7895	0.2319	0.2597
	ARMA(1,1) GARCH (1,2)	(0.0000)	(0.2049)	(0.4867)	(0.5361)	(0.2008)	(0.7930)	(0.9350)
NASDAQ 100		213.74	2.8643	5.1957	5.8315	14.408	2.7272	1.1573
	ARMA(0,0) GARCH (1,1)	(0.0000)	(0.2387)	(0.6360)	(0.1201)	(0.0717)	(0.0656)	(0.3279)
DOW JONES		438.61	5.2781	8.9697	8.5410	17.475	3.8500	1.6483
	ARMA(2,1) GARCH (1,1)	(0.0000)	(0.0714)	(0.2548)	(0.0360)	(0.0255)	(0.0214)	(0.1438)
FTSE 350		134.01	3.5698	5.2425	3.7790	5.0251	0.6032	0.7742
	ARMA(0,0) GARCH (1,1)	(0.0000)	(0.6128)	(0.8743)	(0.2863)	(0.7548)	(0.5471)	(0.5682)
GDAXI		309.27	4.5445	7.4357	6.9227	8.9998	0.8606	1.4246
	ARMA(1,1) GARCH (1,1)	(0.0000)	(0.2083)	(0.4904)	(0.0744)	(0.3423)	(0.4230)	(0.2121)
DFMGI		12835	6.7335	12.502	3.4343	8.3277	0.2255	0.6888
	ARMA(1,1) GARCH (1,1)	(0.0000)	(0.0808)	(0.1301)	(0.3293)	(0.4021)	(0.7981)	(0.6319)

Null Hypotheses (All Null Hypotheses are for n<sup>th</sup> order).

Q-stat (return series) there is no serial autocorrelation. Q<sup>2</sup>-stat (square return series) H0: there is no serial autocorrelation. Jarque-Bera H0: distribution of series is normal. LM-ARCH H0: there is no ARCH effect. P-values are in the parenthesis.

Tables 3, illustrates the post-estimation results (Residual analysis). The Jarque-Bera test (Normality test) results show nonnormal distributions of residuals. The Q-stat are insignificant up to 10th lags, accept the null hypothesis that there is no serial autocorrelation in the standardised residuals. If the Q-stat on squared standardised residuals is insignificant up to 10th lags accept the null hypothesis of no serial autocorrelation in squared standardised residuals. LM-ARCH test is also insignificant up to 5th lags accept the null hypothesis of no ARCH effect remains in series residuals.

#### 4.4. Identification of Structural Break

The Chow break-point test was employed to identify the structural break in the return series due to the global financial crisis. As shown below, all the breaks are significant which indicates that the global financial crisis affected all the series to some extent.

Table 4  
*Chow Test Statistics*

Series	Chow Statistic	Probability value
KSE 100	67.021	0.0013
S&P 500	45.044	0.0123
NASDAQ 100	25.918	0.0356
DJI	41.371	0.0292
NIKKEI 225	18.564	0.0474
HIS	29.873	0.0291
FTSE 350	30.367	0.0108
GDXI	61.831	0.0075
DFMGI	34.3072	0.0258

Ho: there is no structural break.

H1: there is a structural break.

#### 4.5. Volatility Spillover Effect

The multivariate GARCH Diagonal BEKK model was employed to trace out the dynamic linkages between Pakistani and leading foreign stock markets. A simple multivariate equation is shown. There are heavy complicated calculations behind these results [for further details see Khan (2012)].<sup>2</sup> The whole data set for these estimations from 2005 to 2016 are used.

<sup>2</sup>Khan, S. A. (2012). <https://asadzaman.net/my-students/>

$$\begin{aligned}
 H_{t,PSX} = & 0.4557 + 0.461S\&P + 0.1061NAS + 0.6745DJ + 0.0834NIKK + 0.0310HIS \\
 & (0.0010) (0.0051) (0.0076) (0.00342) (0.0914) (0.0875) \\
 & + 0.1546FTSE + 0.2107GDXI + 0.6745DFM + 0.8131H_{t-1} \dots \dots (4.3) \\
 & (0.9010) (0.0001) (0.0000) (0.0516)
 \end{aligned}$$

It is clear that the coefficients of the S&P 500, NASDAQ 100, DOW JONES and DFMGI are statistically significant at 1 percent level of significance. The coefficients of HIS, NIKKEI 225 and FTSE 350 are statistically significant at 10 percent level of significance. It shows that there is a huge volatility spillover effect from S&P 500, NASDAQ 100, DOW JONES and DFMGI to PSX 100. It also indicates that there is a very weak volatility spillover effect from HIS, NIKKEI 225 and FTSE 350 to PSX 100; thus, they can be neglected to some extent. The coefficients of GDXI are statistically insignificant.

The data are divided into two parts; the first part contains the crisis period, and the second part consists of the post-crisis period. The MGARCH model has been employed on both data sets. The results are indicating that there is a strong linkage among these markets in both periods. Equation (4.4) shows the results of the first part of the data set. The results show a significant volatility spillover effect from S&P 500, NASDAQ 100, DOW JONES and DFMGI to PSX 100 in the crisis period. Equation (4.5) illustrates the results of the second part of the data set. The results indicate a significant volatility spillover effect from S&P 500, NASDAQ 100, DOW JONES and DFMGI to PSX 100 in the post-crisis period.

$$\begin{aligned}
 H_{t,PSX} = & 0.0081 + 0.2806S\&P + 0.1427NAS + 0.0156DJ + 0.6410DFM + 0.52331H_{t-1} (4.4) \\
 & (0.0000) (0.0061) (0.0078) (0.0410) (0.0001) (0.0000)
 \end{aligned}$$

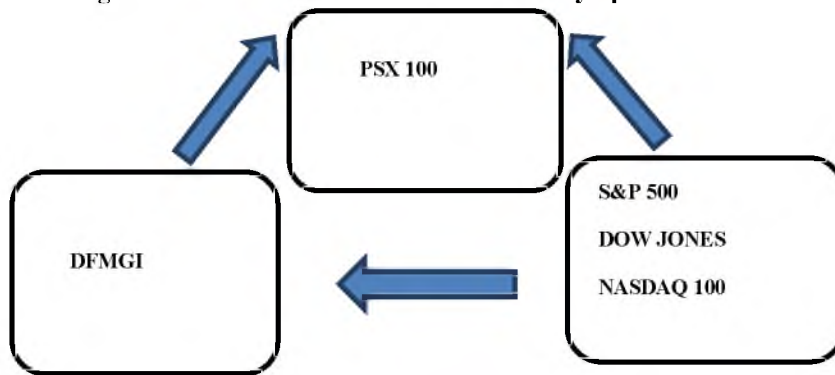
$$\begin{aligned}
 H_{t,PSX} = & 0.010 + 0.3401S\&P + 0.5497NAS + 0.4301DJ + 0.3494DFM + 0.7652H_{t-1} (4.5) \\
 & (0.0050) (0.0081) (0.0009) (0.0001) (0.0000) (0.0000)
 \end{aligned}$$

Likewise, the MGARCH DBEKK model was employed for DFMGI for both periods. Volatility spillover effects were found from S&P 500, NASDAQ 100 and DOW JONES to DFMGI. Equation (4.6) shows the results of the first part of the data set. The results show a significant volatility spillover effect from the S&P 500, NASDAQ 100 and DOW JONES to DFMGI in the crisis period. Equation (4.7) illustrates the results of the second part of data set. The results indicate a significant volatility spillover effect from S&P 500, NASDAQ 100 and DOW JONES to DFMGI in post-crisis period.

$$\begin{aligned}
 H_{t,DFM} = & 0.0093 + 0.2622S\&P + 0.1570NAS + 0.1134DJ + 0.0410PSX + 0.98671H_{t-1} (4.6) \\
 & (0.0059) (0.0101) (0.0280) (0.0019) (0.09001) (0.0008)
 \end{aligned}$$

$$\begin{aligned}
 H_{t,DFM} = & 0.0597 + 0.5681S\&P + 0.1034NAS + 0.1289DJ + 0.6745PSX + 0.5734H_{t-1} (4.7) \\
 & (0.9010) (0.0001) (0.0000) (0.0001) (0.8003) (0.0000)
 \end{aligned}$$

While PSX 100 remains insignificant in both equations, which shows that there is no volatility spillover effect from PSX 100 to DFMGI. In the first equation, PSX 100 is significant at 10 percent level of significance. The results are explaining direct and indirect volatility spillover effects from S&P 500, NASDAQ 100, DOW JONES and DFMGI to PSX 100. Figure 5 explains the direct and indirect paths.

**Fig. 5. Direct and Indirect Paths of Volatility Spillover Effects**

## 5. CONCLUSION

This study discusses the time-varying volatility and explores the spillover effects among equity markets. Since the past decade, the Dubai market has become very attractive for Pakistani investors, especially in the real estate sector. Pakistani are amongst top investors in the real estate sector considering Dubai as a safe haven for investment. This phenomenon is examined in the present study. This study provides important conclusions for financial institutions, market players, and portfolio managers enabling them to detect the nature of markets and level of linkages among the financial markets. Dubai is the nearest top market for Pakistani market players to be utilised as hedging and portfolio management. Based on the findings of this study, investors may minimise their risk. The portfolio managers can use these results in their diversified portfolios investment, which is badly affected by stock market prices. The stability of stock market prices is very important for foreign direct investment and domestic investment, which improves macroeconomic stability and positively affects economic growth. This study may have a significant impact on the trading behaviour of the PSX 100 that is beneficial for the retail investors, institutional investors (both local and foreigner) and mutual funds managers. The explored integration between Pakistani and Dubai markets may also be utilised by foreign investors who are interested in the Pakistani energy sector.

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