“Return and volatility spillover between India, UK, USA and European stock markets: The Brexit impact”

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RETURN AND VOLATILITY SPILLOVER BETWEEN INDIA, UK, USA AND EUROPEAN STOCK MARKETS: THE BREXIT IMPACT

Abstract

The 2016 Brexit referendum created potential turmoil in financial markets. The purpose of this study is to examine the impact of the Brexit referendum on the return and volatility spillover between the EU, the UK, and the USA stock markets and the Indian stock market during the pre- and post-Brexit referendum period. The VAR and bivariate GARCH BEKK models were employed. The study results suggest that before the Brexit referendum, Indian stock market returns made no significant return spillover on the other markets. On the contrary, following the referendum, Indian stock returns significantly spilled over to France, Germany, the UK, and the USA stock market returns. The study results also identified a substantial increase in the bidirectional volatility spillover between India-France, India-UK, and India-USA during the post-Brexit referendum period. Therefore, the investors' opportunity to invest simultaneously in India, UK, EU, and US stock markets for portfolio diversification is limited. India was affected mainly by its own past shocks before the Brexit referendum. However, after the Brexit referendum, Indian markets are getting more and more integrated with other markets. In order to reap the diversification benefits, a prudent investment strategy will need to be developed in the future, especially during times of economic and political uncertainty and market crisis.

Keywords Brexit referendum, volatility transmission, GARCH BEKK, portfolio, diversification

JEL Classification C58, G11, G15

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INTRODUCTION

In 2016, UK's summer was marked by significant political and economic turbulence. On June 23, 2016, the United Kingdom's European Union membership referendum, also known as the Brexit referendum, was held. On this day, the United Kingdom voted 51.9 percent in favor of leaving the European Union, while 48.1 percent voted against it (Alvarez-Diez et al., 2019). Leave campaign had won the majority of votes. The United Kingdom's decision to exit (Brexit) the European Union has raised many questions of what would be the future trading relationship of the UK with that of the EU and the rest of the world and how this will impact the availability of migrant labor, their future access to the Single Market, and product regulations (Driffield & Karoglou, 2019). Brexit has been a major source of uncertainty for around 40% of the UK's business. In the next two trading days following the referendum, global stock markets tumbled. For instance, the leading European stock indices for blue-chip companies like the French CAC 40 and the German DAX decreased by 10%. The UK and US equities did not do well too. FTSE 100 crumbled over 5.8%, and S&P 500 decreased by 5.5%. Brexit had an adverse impact on the Indian market too. Nifty 50 fell by 181.85 points. The week following the referendum, the pound/euro exchange rate fell by more than 7% (Guedes et al., 2019). Since then, the future of the UK economy has remained uncertain.

With the increase in the anxiety of Brexit, more amount of funds was diverted to government bond markets. Immediately following the referendum, investors had shifted their investment to 'risk-free' bond markets. The 10-year US note yields and UK Gilt yields declined by 28 and 35 bps, respectively (Gu & Hibbert, 2021). Brexit had a negative impact on stock markets, the British pound's value, and the price of crude oil. However, it had a positive impact on the value of gold and government bonds. Investors shifted their investments from riskier assets like stocks, crude oil, and the Great Britain pound to traditionally safer and liquid assets like gold, government bonds, US dollars, and Yen. This behavior is mainly noticed when there is a lot of anxiety or uncertainty. Brexit generates continuous fear in the financial markets (Gu & Hibbert, 2021). The global EPU (Economic Policy Uncertainty) index reached its highest level, especially after Brexit. Outright rejection of the UK to continue as a member of the European Union has created a new wave in research trying to investigate the potential impact of Brexit on financial markets.

1. LITERATURE REVIEW

The past few decades witnessed massive turbulence in financial markets resulting in substantial global crises like Black Monday (1987), Asian financial crisis (1997), Subprime mortgage crises (2008), Eurozone crises (2010), and Chinese stock market crash (2015) (BenSaïda et al., 2018). After these significant global crises, numerous researchers have investigated the concept of volatility spillover across the international stock markets. The volatility spillover concept was first discussed in the pioneering work of Engle et al. (1990). In volatility spillover there are two hypothesis tests: The first one is the "Heatwave Hypothesis," which represents own spillover. According to this hypothesis, a particular market's current volatility results from the same market's previous volatility. The heatwave hypothesis suggests that volatility has a country-specific autocorrelation. This event is known as volatility clustering. The second is the "Meteor shower hypothesis," representing cross-spillovers. According to this hypothesis, a particular market's current volatility results from the same market's previous volatility and other markets' previous volatility. Here, the volatility spillover includes both own spillover and cross spillover. This event is known as volatility transmission. Volatility spillover represents shock transmission that cannot be understood by fundamentals (Bekaert et al., 2014).

Volatility spillover is the result of financial events and market integration (He, 2001). The connection between the markets is the consequences of crises and the effects of various political, economic, and financial events. Stock markets are extremely responsive to the occurrence of domestic and global events. In the past, numerous studies have empirically investigated the spillover of volatility across worldwide stock markets during the crisis period and various financial, political, and economic events (Ahmad et al., 2013; Yousaf & Hassan, 2019; McIver & Kang, 2020; Stoupos & Kiohos, 2021). During the Asian financial crisis, the volatility spillover from Japan and USA to Asian emerging markets became bidirectional and stronger. USA and Japan are the dominant market leader in the Asian region (Li & Giles, 2015). US Subprime crisis increased the volatility spillover among the stock markets worldwide (Sehgal et al., 2017; Jebran et al., 2017; Lien et al., 2018; Zorgati et al., 2019). In a nutshell, it can be said that major political and economic events have a significant impact on stock price volatility. The stock market serves as the best indicator of the health of the economy. This study mainly focuses on the political event Brexit, which created significant disruption in the financial markets after the global financial crisis of 2008.

The twenty-first century's most remarkable economic and political event is Brexit (Kara et al., 2021). The economic stability of the United Kingdom is at risk due to Brexit, which could have long-term implications. Brexit is likely to generate a significant amount of economic and political uncertainty. The significant political and economic uncertainty increases stock market volatility and affects the financial market by creating financial instability and difficulties (Forbes & Rigobon, 2002; Diebold & Yilmaz, 2009; Bloom, 2009; Diebold & Yilmaz, 2012). Brexit negatively impacted the global equity market (Burdekin et al., 2018). The Brexit referendum adversely affected the travel, leisure, and banking sectors of the British econo-

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my (Ramiah et al., 2017). Brexit instigated policy uncertainty, leading to financial instability in critical markets and damaging the EU and UK's real economy (Belke et al., 2018; Hosoe, 2018; Samitas et al., 2018). Previous studies confirmed that Brexit outcome caused financial contagion as a result of shock and spillover of volatility among European markets would continue to persist (Aristeidis & Elias, 2018; Li, 2020). Apart from equity markets, currency markets, government bonds, and commodity markets were also affected by the political risk in a Brexit Leave vote (Breinlich et al., 2018). The global economy will be affected by a devalued British pound (Cumming & Zahra, 2016). The uncertainty of Brexit is seen higher in those industries of the UK that are having trade relations with the European Union and on those industries of the UK dependent on migrant labor of the European Union (Bloom et al., 2018). Brexit is likely to create policy dilemmas for the UK government (Teague & Donaghey, 2018).

This study analyzes how a political uncertainty like Brexit can change the correlation among these stock markets. As discussed earlier, major stock indices like the French (CAC 40), German (DAX), UK (FTSE 100), and US (S&P 500) had a significant drop immediately after the Brexit referendum. The reason for choosing these indices is discussed here. The French CAC40 and the German DAX are the leading stock indices for European blue-chip companies. London has substantial economic connections all over the world. India, China, Singapore, Hongkong, and other major Asian economies have a significant economic linkage with London (Lai & Pan, 2018). The US economy plays a dominant market leader role, and the USA has a significant dynamic information spillover effect on all Asian pacific markets due to significant portfolio investment inflows received by the Asian markets from the USA (Kim, 2005). When analyzing the returns and volatility spillover among Asian, European, and North American stock markets, it is observed that a specific index is affected mainly by those indices that open or close before it (Singh et al., 2010). Hence, Asian indices are affected by lagged returns of European and US indices. Immediately following the Brexit referendum, the global stock markets like the French CAC40, the German DAX, UK FTSE 100, India NIFTY 50, and US S&P 500 crumbled (Gu & Hibbert, 2021).

Any slowdown or uncertainty in major economies like the USA, UK, and Europe will first affect its own stock market before it affects the stock market of other countries. The stock markets may be affected by their own spillovers (Heatwave hypothesis) and cross-market spillover (Meteor shower hypothesis). These phenomena can be studied using the BEKK GARCH model. Globalization and financial liberalization are the main reason for increased integration among the financial markets (Vo & Ellis, 2018). There is a need to understand this interconnection among the markets of different countries, especially for portfolio managers, international investors, and policymakers, to reap the diversification benefits (Zhou et al., 2012). However, changes in market linkages happen constantly. Capturing the correlation that varies with time could have important implications for monetary policies (Tamakoshi & Hamori, 2014; Boero et al., 2010; Caporale et al., 2017).

During the sub-prime mortgage crisis, Indian stock markets remained unaffected by the volatility spillover of US stock markets among all other countries (Chiang et al., 2013). Indian stock markets were found to be the most efficient market compared to all other markets. Studies suggest that Indian markets are the least risky in terms of market risk (Chiang et al., 2013). India has a negative correlation with that of the Asia Pacific region, which indicates that the impact of the South Asian crisis on India is minimal (Bhar & Nikolova, 2009). Therefore, this negative correlation suggests diversification opportunities to investors. However, Brexit has created uncertainty among the global business community. India's most important trading partners are the EU and the UK. As a result of Brexit, it will increase the bilateral trade cost between the EU and the UK, which in turn will affect their trade flows. Due to this, their trading partners will be affected indirectly (Roy & Mathur, 2016). As a result of Brexit, restrictions are imposed on labor movement, which restricts EU citizens to enter and work in the UK. It has led to labor shortage in the UK. Brexit will adversely impact Indian companies that have heavily invested in the UK and having operations in the UK because barriers might make the migration of laborers and professionals to the UK more difficult. Those Indian companies like TATA that have a UK subsidiary that does business in the Eurozone will

suffer (Chaudhuri, 2020). Companies will consider relocating their plant to other EU countries to enjoy the tariff benefits. United Kingdom used to be India's export market and investment destination within the EU (Tripathi, 2021). Britain was India's gateway to Europe for many Indian firms. Brexit has affected this too. Studies confirm that India and EU would have gained more had UK continued its membership with EU than quitting them (Roy & Mathur, 2016). Thus, the uncertainty of Brexit has an adverse impact on Indian investments. Therefore, this study will examine whether the uncertainty of Brexit has affected Indian markets and whether it has changed the market linkage of the Indian market with other considered markets.

To the authors' knowledge, the earlier research has not examined the impact of the Brexit referendum on the volatilities of European stock markets like Germany and France, UK, and US stock markets on the Indian stock market using the GARCH BEKK model. Therefore, this study will add to the existing body of knowledge by exploring the impact of Brexit and investigating the linkage between the above-mentioned countries' stock indices on the Indian primary stock index (NIFTY 50) by investigating both return and volatility spillover during the pre- and post-Brexit referendum period. The motivation for this study is that there are many risks associated with Brexit and its impact on the European Union, USA, and UK markets. Understanding its repercussions on the Indian market will help portfolio managers, financial institutions, government, and investors adapt their investment strategies accordingly.

2. METHOD

In this study, the daily closing values of the India, France, Germany, the United Kingdom, and the United States indices abbreviated as Nifty 50 (National Stock Exchange Fifty Index), CAC 40 (Cotation Assistée en Continu Index), DAX (Deutscher Aktien Index), FTSE 100 (Financial Times-Stock Exchange 100 Share Index), and S&P500 (Standard & Poor's 500 Index), respectively, are used. The historical data of indices were obtained from the Wall Street Journal database. The Brexit referendum was held on June 23, 2016. The data sample for this paper is split into two categories. The first group includes the period before the Brexit referendum (from January 1, 2012 to June 22, 2016), and the second group comprises the period after the Brexit referendum (from June 23, 2016 to December 31, 2020). The whole study is grouped into pre- and post-Brexit referendum periods. In comparison to monthly or weekly price data, daily stock returns data provides accurate information on stock price fluctuations. While estimating the BEKK GARCH model, the indices mentioned above were grouped into pairs. This way, four pairs were made: India – France, India – Germany, India – United Kingdom, and India – the United States of America.

This study used the Vector autoregressive model to investigate the likeliness of return spillover over a period and among different markets. This model evaluates the sign and the strength of the cross-correlation among the returns of different markets (Hung, 2019). The VAR model with one and five lags are estimated during the pre- and post-Brexit referendum period, respectively, to study the linkage among the stock indices returns. The VAR model equations used in this study are as follows:

$$r_{india,t} = a + \sum_{i=1}^{n} b_1 r_{India,t-i} + \sum_{i=1}^{n} c_1 r_{france,t-i} + \\ + \sum_{i=1}^{n} d_1 r_{gemany,t-i} + \sum_{i=1}^{n} e_1 r_{UK,t-i} + \\ + \sum_{i=1}^{n} f_1 r_{USA,t-i} + \varepsilon_t, \quad (1)$$

$$r_{france,t} = a + \sum_{i=1}^{n} b_1 r_{India,t-i} + \sum_{i=1}^{n} c_1 r_{france,t-i} + \\ + \sum_{i=1}^{n} d_1 r_{gemany,t-i} + \sum_{i=1}^{n} e_1 r_{UK,t-i} + \\ + \sum_{i=1}^{n} f_1 r_{USA,t-i} + \varepsilon_t, \quad (2)$$

$$r_{germany,t} = a + \sum_{i=1}^{n} b_1 r_{India,t-i} + \sum_{i=1}^{n} c_1 r_{france,t-i} + \\ + \sum_{i=1}^{n} d_1 r_{gemany,t-i} + \sum_{i=1}^{n} e_1 r_{UK,t-i} + \\ + \sum_{i=1}^{n} f_1 r_{USA,t-i} + \varepsilon_t, \quad (3)$$

$$r_{UK,t} = a + \sum_{i=1}^{n} b_1 r_{India,t-i} + \sum_{i=1}^{n} c_1 r_{france,t-i} + \\ + \sum_{i=1}^{n} d_1 r_{gemany,t-i} + \sum_{i=1}^{n} e_1 r_{UK,t-i} + \\ + \sum_{i=1}^{n} f_1 r_{USA,t-i} + \varepsilon_t, \quad (4)$$

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$$r_{USA,t} = a + \sum_{i=1}^{n} b_1 r_{India,t-i} + \sum_{i=1}^{n} c_1 r_{france,t-i} + \\ + \sum_{i=1}^{n} d_1 r_{gemany,t-i} + \sum_{i=1}^{n} e_1 r_{UK,t-i} + \\ + \sum_{i=1}^{n} f_1 r_{USA,t-i} + \varepsilon_t, \quad (5)$$

where $r_{India,t}$, $r_{France,t}$, $r_{Germany,t}$, $r_{UK,t}$, and $r_{USA,t}$ are the stock index returns of India, France, Germany, the UK and the USA, respectively.

To investigate the spillover of volatility or interdependence between India-France, India-Germany, India-UK, and India-USA, this paper uses the (Baba Engle Kraft Kroner) BEKK GARCH model introduced by Engle and Kroner (1995). One of the crucial features of this model is that conditional covariances matrices are allowed to be positive definite by the construction itself (Majdoub & Mansour, 2014). This model lets interaction among the conditional covariance and variances. While estimating, this model provides substantial parameter reduction (Hung, 2019). A bivariate BEKK-GARCH model is being used in this study.

$$R_t = \alpha \Gamma R_{t-1} + u_t, \quad (6)$$

$$u_t \Omega_{t-1} \sim N(0, H_t), \quad (7)$$

where $R_t = [R_{1,t}, R_{2,t}]$ represents returns for the stock market variables and α refers to constant. $u_t = [\varepsilon_{1,t}, \varepsilon_{2,t}]$ denotes residual vector. H_t refers to conditional covariance matrix. Ω_{t-1} represents the set of market information accessible at time *t*-1.

The covariance matrix for the bivariate GARCH BEKK model can be presented as follows:

$$H_{ij,t} = \begin{bmatrix} h_{11} & h_{12} \\ h_{21} & h_{22} \end{bmatrix}, \quad (8)$$

The bivariate GARCH BEKK model can be written as follows:

$$H_t = C'C + A'\varepsilon \, \varepsilon' A_{11} + B' H_{t-1} B, \quad (9)$$

$$\begin{bmatrix} h_{11,t} & h_{12,t} \\ h_{21,t} & h_{22,t} \end{bmatrix} = \begin{bmatrix} c_{11,t} & c_{12,t} \\ c_{21,t} & c_{22,t} \end{bmatrix}, \begin{bmatrix} c_{11,t} & c_{12,t} \\ c_{21,t} & c_{22,t} \end{bmatrix} + \\ \begin{bmatrix} \alpha_{11} & \alpha_{12} \\ \alpha_{21} & \alpha_{22} \end{bmatrix}, \begin{bmatrix} \varepsilon^2_{1,t-1} & \varepsilon_{1,t-1}\varepsilon_{2,t-1} \\ \varepsilon_{2,t-1}\varepsilon_{1,t-1} & \varepsilon^2_{2,t-1} \end{bmatrix} \begin{bmatrix} \alpha_{11} & \alpha_{12} \\ \alpha_{21} & \alpha_{22} \end{bmatrix} + \\ \begin{bmatrix} \beta_{11,t} & \beta_{12,t} \\ \beta_{21,t} & \beta_{22,t} \end{bmatrix}, \begin{bmatrix} h_{11,t-1} & h_{12,t-1} \\ h_{21,t-1} & h_{22,t-1} \end{bmatrix} \begin{bmatrix} \beta_{11,t} & \beta_{12,t} \\ \beta_{21,t} & \beta_{22,t} \end{bmatrix}, \quad (10)$$

where *A* represents ARCH parameters and *B* represents GARCH parameters, α_{km} represents the effect of 'k' stock market's volatility on 'm' stock market. β_{km} represents persistence in spillover of volatility between market '*k*' and '*m*'.

Bollerslev and Wooldridge (1992) introduced Quasi Maximum Likelihood estimation. The GARCH BEKK model parameters can be estimated by applying the above likelihood function. The equation can be written as follows:

$$L(\theta) = -Tn/2 + \ln(2\pi) - \\ -\frac{1}{2}\sum_{t=1}^{T}\left(\ln|H_t| + \varepsilon' \left|\frac{1}{H_t}\right| \varepsilon_t \right), \quad (11)$$

where θ refers to vector of parameters to be estimated, *n* denotes number of markets, and *T* represents the number of observations. This study mainly focuses on α and β parameters to assess the characteristics of volatility spillover between markets.

3. RESULTS

The results of the ARCH test, unit root test, and descriptive statistics for before and after the Brexit referendum period, respectively, are presented in Table 1. The sample means are found to be positive. Daily returns have increased in case of India and USA during the post period where as daily returns have decreased in France, Germany and the UK during the post period. Standard deviation measures unconditional variance. The volatility increased during the post Brexit referendum period in all countries as measured by standard deviation. All stock indices' returns are found to be leptokurtic during both the sub-periods. However, all the series became highly leptokurtic during the post Brexit-referendum period. The null hypothesis that return series is normally distributed is rejected by the Jarque-Bera test statistics. As per ADF and PP tests, all stock return series are stationary at the 1 per cent level for both sub-periods. The null hypothesis of ARCH test is that "There is no ARCH effect in the residuals". The ARCH test is statistically significant at the 1% level for all countries except Germany during the post

Table 1. Descriptive statistics of index returns

Descriptive Statistics	India	France	Germany	UK	USA
Pre-Brexit referendum period					
Mean	0.049103	0.027043	0.045778	0.011354	0.045085
Median	0.062737	0.060068	0.109823	0.043830	0.048621
Maximum	3.948298	4.752868	5.292440	3.661275	3.829129
Minimum	–3.952643	–5.493230	–4.816500	–4.779456	–4.021142
Std. Deviation	1.039580	1.255725	1.245974	0.937524	0.848692
Skewness	–0.161712	–0.068820	–0.129165	–0.168718	–0.163397
Kurtosis	3.847366	4.370302	4.170735	4.825365	4.704225
Jarque-Bera	37.29265**	85.98252**	64.56116**	153.7697**	132.8682**
PP test	–34.25442**	–34.78549**	–33.24937**	–33.99883**	–32.65372**
ADF test	–34.27813**	–34.52567**	–33.21837**	–33.63357**	–32.36916**
ARCH test	35.86189**	17.03677**	14.63879**	40.30179**	45.79528**
Observations	1088	1088	1078	1071	1059
Post-Brexit referendum period					
Mean	0.054222	0.019691	0.026679	0.001598	0.049363
Median	0.103768	0.043787	0.066518	0.049690	0.081935
Maximum	8.400291	8.056079	10.41429	8.666807	8.968316
Minimum	–13.90375	–13.09835	–13.05486	–11.51243	–12.76521
Std. Deviation	1.208192	1.266733	1.301815	1.117942	1.235270
Skewness	–1.759126	–1.370725	–0.871199	–1.179954	–1.339523
Kurtosis	28.07427	21.44166	20.67636	20.83422	26.70607
Jarque- Bera	29517.19**	16004.55**	14328.49**	14725.10**	25564.54**
PP test	–36.79915**	–32.52813**	–32.94952**	–33.40182**	–39.47633**
ADF test	–13.31256**	–21.19173**	–20.92702**	–21.86502**	–8.305606**
ARCH test	37.78200**	15.05054**	1.505654	27.42791**	123.9839**
Observations	1105	1105	1090	1092	1078

Note: ** denotes *p*-values < 1% significance level, * denotes *p*-values < 5% significance level.

period. Therefore, the null hypothesis, which states that there is no ARCH effect, is rejected. The ARCH test confirms the presence of the ARCH effect. It implies that the GARCH BEKK model can be used to estimate the spillover of volatility between stock indices.

The raw series of all five countries' stock markets are plotted in Figure 1 and Figure 2. It can be seen that there has been fluctuation in all five countries before and after the Brexit referendum period. However, the post-Brexit referendum period saw a substantial increase in fluctuations.

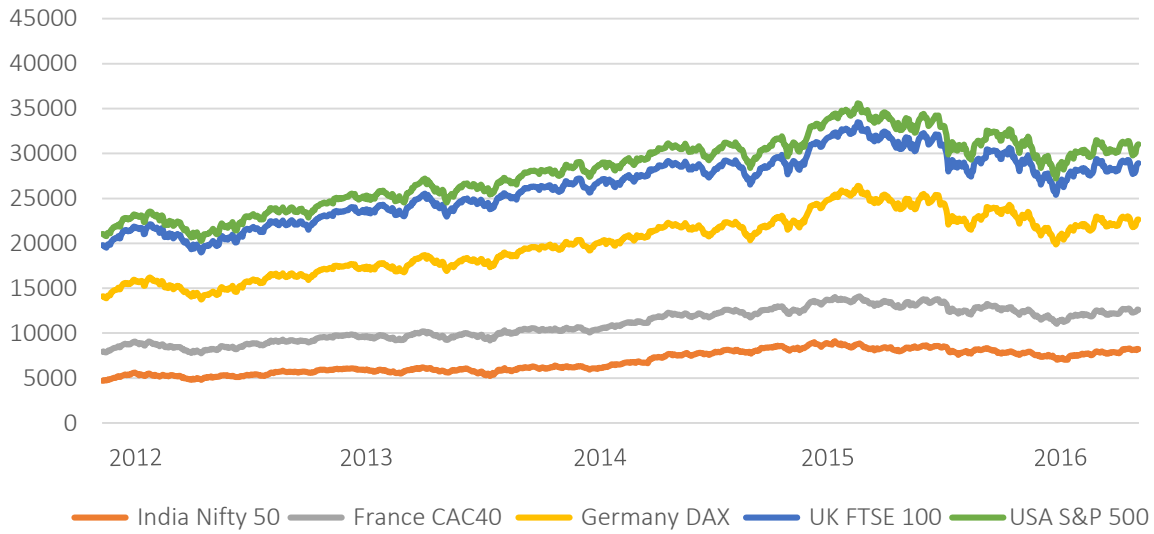

Figure 1. Daily index series for the pre-Brexit referendum period

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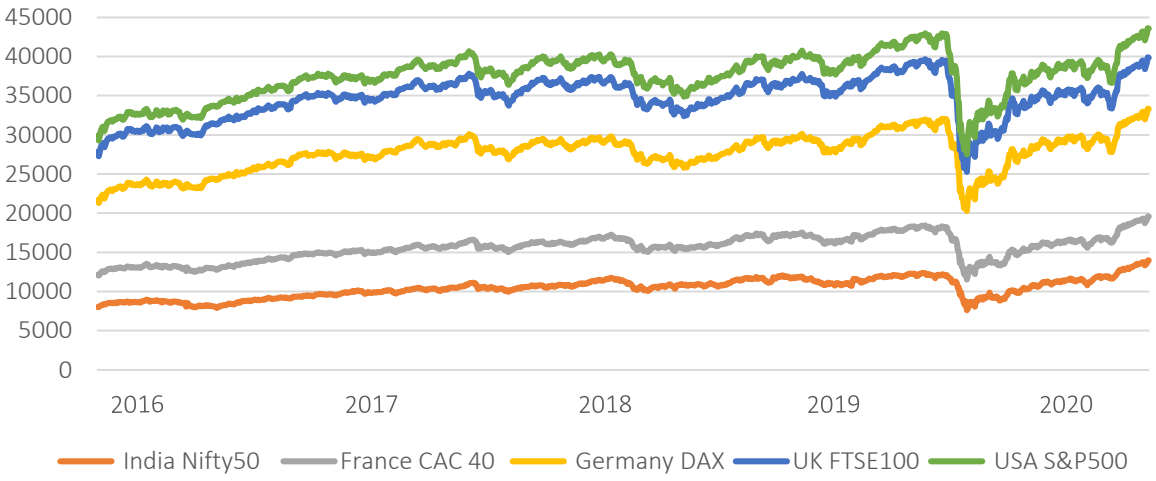

Figure 2. Daily index series for the post-Brexit referendum period

Table 2 presents the sample correlation results for all five stock markets before and after the Brexit referendum periods, respectively. The lowest correlation (0.037896) is between India and USA during the pre-Brexit referendum period. The highest correlation (0.937171) is between Germany and France during the post-Brexit referendum period. In comparison to the period prior to the Brexit referendum, there has been a significant increase in the correlation coefficients between selected countries' stock markets after the Brexit referendum.

The Vector Auto Regression model is used to analyze the return spillover among the selected indices. The lag lengths for pre- and post-Brexit periods are 1 and 5, respectively. The optimum lag lengths were selected based on the suggestions by AIC (Akaike Information Criterion). Table 3 and 4 show the estimated parameters for the VAR mod-

Table 2. Correlation matrix between index returns

Countries	India	France	Germany	UK	USA
Pre-Brexit referendum period					
India	1				
France	0.121987	1			
Germany	0.131873	0.930523	1		
UK	0.157830	0.860864	0.830667	1	
USA	0.037896	0.599648	0.575875	0.606753	1
Post-Brexit referendum period					
India	1				
France	0.442541	1			
Germany	0.411770	0.937171	1		
UK	0.433082	0.880179	0.844237	1	
USA	0.330753	0.660007	0.652553	0.627274	1

Table 3. Pre-Brexit referendum period, VAR model

Vector Autoregression Estimates					
	INDIA_RET	FRANCE_RET	GERMANY_RET	UK_RET	USA_RET
INDIA_RET (–1)	–0.090820**	0.017168	0.028621	0.029581	–0.001025
FRANCE_RET (–1)	0.049768	–0.021151	0.008430	0.004980	–0.007357
GERMANY_RET (–1)	0.084160	–0.103877	–0.049751	–0.099257	0.022393
UK_RET (–1)	0.091441	–0.158377	–0.213790*	–0.154170*	–0.026730
USA_RET (–1)	0.398476**	0.441796**	0.432154**	0.422946**	–0.012913

Note: ** denotes *p*-values < 1% significance level, * denotes *p*-values < 5% significance level.

el for the pre- and post-Brexit referendum periods, respectively. In general, it is noticed that during both pre- and post-Brexit referendum periods, the US market made a significant return spillover on the stock markets of other four nations. Before the Brexit referendum, the UK's first lag return substantially impacted itself and the Germany stock market. However, after the Brexit referendum, the UK's second lag return made a significant return spillover on German, France's stock market and itself. Also, the UK's third lag returns made significant return spillover to the German stock market.

Prior to the Brexit referendum, India's first lag had a significant return spillover on itself and not on any other stock market returns. On the contrary, during the post-Brexit referendum period, India's first lag return had significant return spillover on itself and France, Germany, UK, and US stock market returns. India's fifth lag returns had return spillover on itself, and India's second lag had significant return transmission on USA stock market returns during the post period. It was also observed that the German stock market returns made no significant impact on the other markets during the pre-Brexit period. On the contrary, German stock returns significantly spilled over to India and USA stock market returns during the post-Brexit referendum period. Germany's second lag returns impacted India and the USA stock market, and Germany's fifth lag significantly impacted USA stock market returns. However, France's stock market returns made no significant return spillover on the other markets during both pre- and post-Brexit referendum periods.

Volatility spillover between Indian stock index and rest of the above considered nations stock indices is examined. To investigate the spillover of volatility, the GARCH-BEKK model is used. The estimated outcome of the BEKK model is shown in Table 5. Here A(k,k) represents the ARCH parameter and B(k, k) represents GARCH parameters concerning market k. The essential charac-

Table 4. Post-Brexit referendum period, VAR model

Vector Autoregression Estimates					
	INDIA_RET	**FRANCE_RET**	**GERMANY_RET**	**UK_RET**	**USA_RET**
INDIA_RET (–1)	–0.359948**	–0.310017**	–0.304373**	–0.292016**	–0.226555**
INDIA_RET (–2)	–0.046460	–0.030224	–0.006640	–0.011808	0.093611*
INDIA_RET (–3)	0.002347	–0.024865	–0.008145	0.006332	0.057258
INDIA_RET (–4)	0.020446	0.012831	–0.017770	0.078708	0.017336
INDIA_RET (–5)	0.149103**	–0.022108	–0.034767	–0.018102	–0.062634
FRANCE_RET (–1)	–0.015400	0.097686	0.094872	0.063501	0.022423
FRANCE_RET (–2)	–0.193972	0.138835	0.215549	0.154307	–0.061901
FRANCE_RET (–3)	0.067940	0.013244	–0.005705	0.058578	0.042006
FRANCE_RET (–4)	0.036917	–0.026661	–0.122085	–0.053460	–0.100882
FRANCE_RET (–5)	0.026252	–0.139555	–0.214069	–0.116091	–0.156202
GERMANY_RET (–1)	0.098246	–0.038875	–0.014647	–0.029679	0.144894
GERMANY_RET (–2)	0.232676*	0.102718	0.078679	0.088031	0.272127**
GERMANY_RET (–3)	0.117204	0.002127	–0.031025	–0.046202	0.036485
GERMANY_RET (–4)	0.013574	–0.002202	0.055477	0.005152	0.167581
GERMANY_RET (–5)	0.052037	0.121970	0.147827	0.111262	0.235699**
UK_RET (–1)	0.014785	–0.014385	–0.086935	–0.030332	–0.090558
UK_RET (–2)	0.127077	–0.184655*	–0.207939*	–0.159309*	0.052807
UK_RET (–3)	0.061913	0.124163	0.173790*	0.072994	0.067609
UK_RET (–4)	0.101588	0.132572	0.166683	0.095547	0.024183
UK_RET (–5)	–0.114866	0.057813	0.093201	0.032471	–0.046733
USA_RET (–1)	0.282904**	0.166699**	0.182901**	0.186268**	–0.158849**
USA_RET (–2)	0.106233*	0.211464**	0.176999**	0.138875**	0.055185
USA_RET (–3)	–0.168118**	–0.194738**	–0.180840**	–0.190436**	–0.284801**
USA_RET (–4)	–0.120253*	–0.108140	–0.078191	–0.072088	–0.148995**
USA_RET (–5)	0.061521	0.027433	0.060708	0.021642	–0.030607

Note: ** denotes *p*-values < 1% significance level, * denotes *p*-values < 5% significance level.

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Table 5. Parameter estimates for the bivariate GARCH BEKK model

Parameter	India Nifty50 & USA S&P500		India Nifty50 & UK FTSE100		India Nifty50 & France CAC 40		India Nifty50 & Germany DAX	
	Pre Brexit referendum period	Post Brexit referendum period	Pre Brexit referendum period	Post Brexit referendum period	Pre Brexit referendum period	Post Brexit referendum period	Pre Brexit referendum period	Post Brexit referendum period
Conditional Mean								
mu1.	0.08048236**	0.0897043**	0.058604360**	0.0881337**	0.0419405	0.0951011**	0.0553444*	0.0963833**
mu2.	0.08531982**	0.0882601**	0.022315209	0.0175031	0.0213635	0.0898070**	0.0706061**	0.0716854**
Conditional Variance								
A011	0.91081590**	0.2958076**	0.928404672**	0.2656475**	0.2079160**	0.2622542**	0.2526693**	0.0963833
A021	0.00729514	0.0808812**	0.120135124**	0.0962370**	0.0301436	0.1122155**	0.0335084	0.0716854**
A022	0.16933886**	0.2346354**	0.185153231**	0.2017063**	1.1758660**	0.2271390**	0.2469316*	0.0963833
A11	0.25462355**	0.2102694**	0.309507801**	0.2576251**	0.2818612**	0.2282923**	0.2565865**	0.0716854**
A21	0.03913291	0.1585346**	0.055017516	0.0901637**	0.0655591	0.1321359**	0.0229646	0.0963833**
A12	0.50000000**	−0.1389748**	−0.390043578**	−0.0180977	−0.2069405**	0.0862847*	−0.1140273**	0.0716854
A22	0.23484674**	0.4915875**	0.237016398**	0.4178937**	0.2843392**	0.3871304**	0.2321429**	0.0963833
B11	0.00000100	0.8616929**	0.000001000	0.8444153**	0.8597930**	0.8504571**	0.9237603**	0.0716854
B21	0.21042540*	−0.1740152**	−0.202878250*	−0.2256607**	0.2308109	−0.2858672**	0.0178819	0.0963833
B12	−0.07571478	0.2380892**	0.109180021	0.2258051**	0.1786257	0.1871505**	0.0346525**	0.0716854
B22	0.89745604**	0.8220165**	0.944784947**	0.8955140**	0.0000010	0.9011962**	0.9535895**	0.0963833

Note: ** denotes *p*-values < 1% significance level, * denotes *p*-values < 5% significance level.

teristic of the BEKK model is that causal relation can be systematically explained among variance and covariance. All diagonal elements of ARCH parameters A(k, k) suggest that the responses of volatility in market k are dependent on its own lagged shocks. However, all off-diagonal elements of the ARCH parameters A(k, m) capture the past cross innovations. This means that the past cross innovations or shocks are transmitted from stock market k to stock market m. In other words, when shocks hit market k, the shock is propagated to stock market m. The ARCH parameters A(m, k) capture the same effects but from the opposite direction. The results of GARCH BEKK are reported in pairs of the India stock index and the four other countries' stock indices.

Similarly, all off-diagonal elements of the GARCH parameters B(k, m) suggest that the 'm' stock market's volatility is dependent on 'k' stock market's volatility (Mohammadi & Tan, 2015). These results are also presented in pairs of Indian stock indices and the four other countries' stock indices. It is essential to emphasize the conditional variance and conditional covariances when reporting the diagonal elements of the GARCH BEKK model (Vo & Ellis, 2018). A(1,1) A(2,2) are the ARCH term of variance equation, which indicates auto regressiveness (ARCH effects). All the diagonal elements A(1,1) A(2,2) except Germany showcased statistically significant ARCH effects for pre- and post-periods. This result indicates conditional variances are dependent on the market's past shocks (Hung, 2020). The result implies that the volatility of India, the USA, the UK, and France equity markets are dependent on their own past innovations.

Under the ARCH parameter A(1, 2), 1 always represents India and 2 represents the USA, the UK, France and Germany. The result suggests that A(1,2) parameter estimates are statistically significant for the USA, UK, France, and Germany during the pre-Brexit referendum period. However, it is statistically significant only for the USA and France during the post-Brexit referendum period. When shocks hit the Indian stock market, the shocks were propagated to the USA and France stock markets before and after the Brexit referendum. On the contrary, when shocks hit Indian markets, the shocks were transmitted to the UK and German stock markets only for the pre-Brexit referendum period. This result indicates that past cross innovations or shocks originating from the Indian market influenced the current volatility of the UK, France, Germany, and US stock markets before the Brexit referendum. Even after the Brexit referendum, the past innovations of the Indian markets continued to impact the stock returns of the USA and France significantly. The past innovations of the Indian stock markets had no significant influence on the UK and German stock markets after the Brexit referendum. The past shocks of the USA, the UK, France and Germany had no substantial effect on the Indian markets before the Brexit referendum. On the contrary, the past innovations of the USA, UK, France, and German markets have a substantial influence on the Indian markets after the Brexit referendum.

Additionally, there are three patterns demonstrated by the GARCH effects: First, the diagonal GARCH parameters B(1,1) and B(2,2) indicate that each conditional variances are dependent on their past for the given period (Hung, 2020). A significant GARCH effect was noticed in the USA, India and the UK before and after the Brexit referendum. However, a significant GARCH effect was observed in France only after the Brexit referendum, and a significant GARCH effect was observed in Germany before the Brexit referendum. Second, the off-diagonal elements of the GARCH parameters B(k, m) indicate that the volatility of the stock market 'm' depends on the volatility of the stock market 'k'. Thirdly, the GARCH parameters B(m, k) capture the same effects but in the opposite direction. That is, the 'k' stock market's volatility depends on the 'm' stock market's volatility. Similarly, under GARCH parameter B(1, 2), 1 represents India and 2 represents the USA, UK, France and Germany.

It is found that there was a unidirectional spillover of volatility from India to Germany before the Brexit referendum. However, there was no spillover of volatility from India to France, UK, and the USA before the Brexit referendum. On the contrary, it is found that there is spillover of volatility from India to France, UK, and the USA after the Brexit referendum. There is significant spillover of volatility from USA and UK to India before the Brexit referendum. However, there is no spillover of volatility from France and Germany to India

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before the Brexit referendum. On the contrary, it is seen that there is spillover of volatility from the UK, the USA, and France to India after the Brexit referendum. However, there is no volatility spillover from Germany to India after the Brexit referendum too. In summary, it is found that there is strong evidence of bidirectional spillover of volatility between India and France, between India and the UK, and between India and the USA after the Brexit referendum.

There are significant ARCH effects in India, the USA, the UK, and France before and after the Brexit referendum. German market had a significant ARCH effect before the Brexit referendum. During the study period, the stock markets of India, the UK, the USA, and France depend on their own history B(k, k). In a nutshell, it can be inferred that there was a significant increase in the bidirectional volatility spillover between India and other three countries' stock markets, namely France, USA, and UK, in the post-Brexit referendum period as compared to the pre-Brexit referendum period. It is also observed that there was asymmetry in volatility spillover. That is, the transmission of shocks from one market to another was not uniform. The result suggests an increase in correlation of volatility transmission between India and the other three stock markets, namely the USA, France, and the UK, after the Brexit referendum. This means that India and the other three markets are substantially integrated in the post-Brexit referendum period. This is valuable information for investors who diversify their portfolios in order to minimize risk.

CONCLUSION

This study aims to investigate the spillover of return and volatility between the stock markets of India and four countries, namely France, Germany, the UK, and the USA, and compare market interactions before and after the Brexit referendum using the VAR model and the bivariate GARCH BEKK model. The results suggested that India did not make a significant return spillover to any other country's stock market during the pre-Brexit period except itself. However, during the post-period, India made substantial return spillover to itself and the other four countries. Before the Brexit referendum period, the past shocks of the USA, the UK, France, and Germany had no considerable influence on the Indian stock market volatility. However, after the Brexit referendum, the past shocks of the USA, the UK, France, and Germany had a considerable influence on the Indian market volatility. Overall, the findings reveal strong evidence of bidirectional spillover of volatility between India and the UK, between India and the USA, and between India and France after the Brexit referendum. Thus, to minimize risk, investors must take caution while investing funds in the Indian stock market along with the EU, UK, and US stock markets. India remained unaffected by the volatility spillover from the US stock market since sub-prime crisis. However, after the Brexit referendum, India was affected by the external shocks of the EU, UK, and US markets, and there was bi-directional volatility spillover between them. Hence, an appropriate asset allocation strategy needs to be developed to enjoy the benefits of diversification in these markets, especially in times of political and economic instability and market crises. Thus, there is a possibility that Indian stock markets will be further exposed to these external shocks in the future.

AUTHOR CONTRIBUTIONS

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