Financial Contagion in European Equity Markets : Evidence from the US Subprime and the Eurozone Crises

Ashish Kumar [1]
Swati Khanna [2]
Sanjay Dhingra [3]
Neena Sinha [4]

Abstract

The study explored the financial contagion between the five European stock markets (Germany, Belgium, France, Netherlands, and Spain) and the impact of the US subprime crisis and Eurozone crisis on it by employing multivariate DCC-GARCH methodology. The dynamic conditional correlation coefficient between Germany and other European markets was statistically significant for the period under review. The rise in the value of the conditional correlation coefficient was more evident during the US subprime crisis period, which signified the impact of this crisis on the financial interdependence of the European stock markets. But not much influence of the Eurozone crisis was observed on the dispersion of returns for all the markets, which was an important finding. The mechanism of rolling regression also corroborated these results. The study also validated the presence of financial contagion between the stock markets (except the Netherlands) during the US subprime crisis period. In contrast, the effect of the Eurozone crisis on financial contagion was significant only for Spain and Belgium. Further, the strength of financial contagion was highest for the stock market of Spain, followed by Belgium, and the least for the Netherlands. The timid reaction of the stock market of the Netherlands reflected that it could be a good choice for portfolio diversification during periods of crisis for investors. Further, governments and other regulators can learn from these findings and formulate appropriate policies to absorb the financial shocks coming from foreign markets, especially during the crisis period.

Keywords : **Financial contagion, financial crisis, dynamic conditional correlation, stock markets, GARCH**

JEL Classification Codes : C58, C49, G1, G15, N25

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The instability in capital markets that began in the summer of 2007 and intensified since mid-September 2008 has had a significant impact on the global economy. The global financial crisis (GFC) of 2008, which has its genesis in the USA, and the subsequent Euro Zone Crisis (EZC) of 2009, are counted among this century's most destructive financial crises. The GFC started with the problem in the US's real estate and housing

[1] *Assistant Professor,* University School of Management Studies, Block D, Guru Govind Singh Indraprastha University, Sector 16 C, Dwarka, New Delhi - 110 078. (Email : ashish_prl@yahoo.com) ; ORCID iD : https://orcid.org/0000-0002-4476-3494
[2] *Assistant Professor (Corresponding Author),* IILM Institute of Higher Education, Lodhi Road, Lodhi Colony, New Delhi - 110 003. (Email : swati.khanna1510@gmail.com) ; ORCID iD : https://orcid.org/0000-0001-9831-4064
[3] *Professor,* University School of Management Studies, Block D, Guru Govind Singh Indraprastha University, Sector 16 C, Dwarka, New Delhi - 110 078. (Email : sdhingra342003@yahoo.com) ; ORCID iD: http://orcid.org/0000-0001-9589-1464
[4] *Professor,* University School of Management Studies, Block D, Guru Govind Singh Indraprastha University, Sector 16 C, Dwarka, New Delhi - 110 078. (Email : dr.neenasinga@gmail.com) ; ORCID iD: https://orcid.org/0000-0002-7183-2168

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sector, which later spread to other sectors and devastated the US financial system. Although the high-risk mortgage market in the United States is seen to be the primary source of this upheaval, however, the GFC of 2008 transcended to other economies very rapidly due to its sheer size and resulted in the form of a debt crisis in the European economies in the very next year and later on culminated in the financial contagion affecting all economies all over the world (Bhanumurthy, 2009; Coulibaly et al., 2013; Terazi & Şenel, 2011). Capital markets and financial institutions in the Eurozone have received their share of the protracted credit cycle and have been heavily impacted by capital market tensions. Since the beginning of 2010, the Euro Area has been dealing with a serious sovereign debt crisis, dubbed the Euro Crisis. Rating agencies downgraded numerous European nations' debt repayment probability as a result of rising government deficits and debt levels, causing a loss of trust in financial markets. During the onslaught of the GFC and EZC, the European stock markets suffered enormous devaluations combined with spiraling volatility in the stock markets (Anagnostidis et al., 2016; Arezki et al., 2011), which also led to a severe fall in demand across the economies. To control the spread of this economic slowdown, governments and regulators intervened swiftly to raise aggregate demand levels in their respective economies by announcing bailout packages to the worst affected sectors, lowering taxes, increasing discretionary expenditures, etc. Despite the best endeavors of the governments and other regulatory institutions, the gravity of the crisis was so elevated that it aggravated the financial system of European economies and resulted in the Eurozone sovereign crisis (Brender et al., 2012).

Over the last decade, there has been a lot of interest in empirical and analytical research on cross-country and cross-market financial crisis transmission. The majority of empirical work has been done to determine the magnitude of financial spillovers to mature and developing economies as well as to identify shock transmission pathways to other nations. Earlier research has frequently focused on contagion to emerging stock markets in South America and Asia as a result of the US financial crisis. Studies related to European stock markets are few. In the light of the fact that equity markets of the Eurozone markets have a robust economic relationship, as reported in many empirical studies (Ahmad et al., 2014; Caporale et al., 2015; Dewandaru et al., 2018), the vulnerability of the European stock markets to various financial shocks is of great interest to investors and financial market authorities. As a result, we present new evidence on gaps in links between crises. The purpose of this paper is to examine the volatility behavior and financial contagion in European stock markets during the subprime crisis and Eurozone crisis periods.

It is crucial to explore the presence of financial contagion among these markets to derive meaningful policy implications. The assessment of the dependence on the financial markets is critical for the market participants, including governments, portfolio managers, investors, and regulators. The knowledge of financial contagion is of immense importance in formulating financial and macroeconomic policies by the governments to safeguard the interests of their respective economies. According to the current trend, research is in high demand since the focus is on determining if contagion evidence is pure or fundamental and studying the dynamic evolution of integration in the short or long run. Therefore, to mobilize empirical testimony about the financial contagion among the European stock markets, we have used the non-contingent crisis theory, which considers financial contagion as a continuation of the interdependence process between markets (Ahmad et al., 2014; Dewandaru et al., 2018). In our study, we have considered the German stock market as the source of crisis, and subsequently, co-movements have been analyzed between Germany and select other European stock markets.

Our study makes an important contribution to the extant literature. First, it identifies the financial integration with the help of dynamic conditional correlation. Second, it assesses the impact of two important crises falling during the study period: the US subprime crisis of 2008 and the Eurozone crisis of 2010 on the financial contagion. Third, it also provides an answer to the question of whether financial crises have an enduring or short-term effect on financial contagion by employing the rolling regression technique. Our study answers all these issues from the viewpoint of developed markets in Europe, on which not many studies have been carried out.

Review of Literature

There is no dearth of empirical studies that explored the linkages, volatility spillovers, and financial contagion amongst the financial markets globally (Gawade et al., 2019; Khanna & Kumar, 2020; Kumar & Khanna, 2018; Mollah et al., 2016; Perumandla & Kurisetti, 2018; Seth & Panda, 2018). According to the literature, contagion is defined as the transfer of shocks caused by a crisis from one market (or a collection of markets), institute, or nation to another that basic pathways cannot explain. As a result, volatility spillover/transmission and contagion have played a critical role in worldwide economic decision-making. Following the global financial crisis in the United States in 2008 and the subsequent Eurozone upheavals in 2009, the study of regime shifts and financial contagion across economies has re-ignited the interest of researchers and concerned stock market stakeholders to re-examine the role of regime shifts and financial contagion in asset allocation and risk management (Gawade et al., 2019; Khanna & Kumar 2020). The presence of financial contagion has been explored empirically during many crisis periods, such as the US stock market crash in 1987, the Asian Tiger crisis in 1998, the Mexican crisis, the Russian crisis, GFC, etc. However, the results of these studies are not uniform for different crisis periods, which may be attributed to the difference in the financial crisis, the difference in periods, the size and nature of markets involved, the difference in the sample sizes, etc. Junior and Franca (2012) and Syllignakis and Kouretas (2011) found a considerable rise in the interdependence between the equity markets of the US, UK, and many other equity markets after the crash of 1987, the Russian crisis 1998, the dot-com bubble crisis 2001, and the subprime mortgage crisis 2008. Studies also confirmed the presence of financial contagion after the 1987 crash and stated that the financial contagion extended beyond developed markets to emerging markets as well.

Ahlgren and Antell (2010), Baek and Jun (2011), Kali and Reyes (2010), and Singh and Kaur (2015) reported the evidence of financial contagion for the Asian crisis in 1994 and 1997 by using a longer sample period. Financial contagion between equity and currency market has also been reported for the Asian currency crisis period by Kenourgios et al. (2013), in which they found statistically significant interdependence between the two markets. Baek and Jun (2011), in their study on the Asian crisis, also confirmed the presence of contagion for sampled countries from the South-East Asian region. Many recent studies have reported analogous outcomes in the area (Bonga-Bonga, 2018; Gamba-Santamaria et al., 2017; Jiang et al., 2017; Patel, 2017). The results of the study of Wang et al. (2017) are again found to be mixed, in which they studied the testimony for contagion during the GFC. The study reported the presence of financial contagion amongst the G7 countries, Russia and India, but no contagion was reported for Brazil, China, and Japan while considering the US market as a source of financial contagion. Jiang et al. (2017) found that the dynamic conditional correlation showed a significant rise between the stock markets of the US, UK, Germany, Japan, and Hong Kong between the US, Britain, Germany, Japan, and Hong Kong, while it revealed an inverse trend with the Chinese market.

The empirical literature has stated that European equity markets have witnessed many shocks in the past. The results of the past studies demonstrated that the degree of dynamic conditional correlation between the equity markets of Europe and the US was high during the period of the US financial crisis, which indicates the presence of financial contagion between these markets (Horváth et al., 2018; Syllignakis & Kouretas, 2011). Bekaert et al. (2014) also found evidence in favor of the 'wake-up call' hypothesis, which means shocks in one country enter other countries and affect their economic fundamentals.

During the financial crisis of 2007–2009, macroeconomic dynamics were shown to have considerable explanatory power in explaining such conditional correlations (Barunik & Vacha, 2013; Singh & Shrivastav, 2018; Syllignakis & Kouretas, 2011). In a nutshell, these findings lead to the inference that emerging markets are more prone to external shocks during the regime of a financial crisis, which is reflected by a rise in the conditional correlation coefficient. The literature further explains that different methods such as correlation, multivariate GARCH, dynamic conditional correlation, copulas, wavelength theory, etc., have been used to capture financial contagion. Though it is relatively simple to compute the conditional correlation coefficient between two markets, correlation analysis is not equipped to study the impact of financial contagion, which is much broader and more difficult to comprehend. The studies which used the multivariate GARCH model to explore cross-market linkages in the European markets include Antonakakis and Vergos (2013), Kenourgios and Samitas (2011), and Savva and Aslanidis (2010). All these studies provided evidence of interdependence among the European financial markets. Reboredo et al. (2015) also studied interdependence among the Czech Republic, Hungary, Poland, and Romania by applying dynamic copulas, and reported that the interdependence between these markets rose considerably for the period of the global financial crisis. The dynamism in conditional correlation among the European equity markets has also been examined through fundamentals (Büttner & Hayo, 2011; Virk & Javed, 2017). The cross-market linkages between the different markets in Europe are affected by numerous other factors, such as the herding behavior of international investors, their trading style, psychology, etc., rather than fundamental macroeconomic and financial variables alone. Finally, the studies indicated that the high correlation during the crisis era, as evidenced by the constant correlation test, is primarily attributable to cross-market co-movements produced by rational, risk-averse investors' inter-temporal risk-return adjustments during the crisis period.

Even though the literature has addressed all of the major crises that have occurred in the last 30 years, the majority of these studies are focused on developed markets, and the literature on the contagion of the recent Eurozone crisis is quite limited. The absence of literature on the Eurozone crisis's effect on European markets is also indicated by the review of the above-mentioned research. The existing research on European markets also suggests that market synchronization should be revisited since various concerns have been expressed about the emergence of considerable comovements across these markets. Using these insights as a foundation, the current study seeks to fill in the gaps by presenting further empirical data in mature European markets. The deconstruction of selected European stock market volatility into anticipated and unexpected components and an assessment of how the unexpected volatility component increases owing to financial contagion are key contributions to the current research.

To the best of our knowledge, this is the first research that looks at the financial contagion of the Eurozone and subprime crises for five European stock markets from 2000 – 2018. The DCC-GARCH is used in this work to look at financial contagion tendencies. The findings of this study are highly intriguing and differ from previous studies in various ways.

Objective, Data and Methodology

Objective of the Study

To analyze the essence and severity of financial contagion between selected equity markets of Germany, Belgium, France, the Netherlands, and Spain during the US subprime crisis and the Eurozone crisis of 2010.

Data Period and Source

The benchmark indices of the largest stock exchanges of the chosen market have been considered as a proxy for the equity markets. The daily closing values of these benchmark indices for the period of our study ranging from January 2000 – December 2018 were mobilized from the website of Yahoo Finance (www.yahoofinance.com). The details of the benchmark indices for each market are given in Table 1.

The period of our study is very comprehensive and also includes into it the period of the US subprime crisis (2007 – 2009) and the Eurozone crisis between the years (2010 – 2012). The span of the study period helped us to examine the vulnerability of the German stock market returns to other equity markets' returns. For our study, the

Table 1. ***Sample Equity Markets and Benchmark Indices : 1/January/2000 – 31/December/2018***

Country	Equity Market	Benchmark Index
Germany	Frankfurt Stock Exchange	DAX 30
Belgium	Euronext Brussels	BEL 20
France	Euronext Paris	CAC 40
Netherlands	Euronext Amsterdam	AEX
Spain	Bolsa de Madrid	IBEX 35

length of the US subprime crisis period has been assumed from August 1, 2007 – May 5, 2009, while for the Eurozone crisis, the same is from January 6, 2010 – December 28, 2012. The choice of economies included in our study is made based on their size (as per the IMFreport), and financial contagion has been explored from the German equity market to other sample European stock markets. Daily returns of the benchmark stock indices have been computed from their daily closing values by using the following mathematical equation:

$$R_t = \ln p_t - \ln p_{t-1} \qquad (1)$$

These return series have been named Germany, Belgium, France, Netherlands, and Spain. The descriptive statistics of these return series are shown in Table 2 for the complete period of the study, Table 3 for the US subprime crisis period, Table 4 for the Eurozone crisis period, and Table 5 for the period of stability, that is, the period excluding these two crisis periods. The separate descriptive statistics will help the readers understand the nature of the returns in stable, unstable, and comprehensive periods.

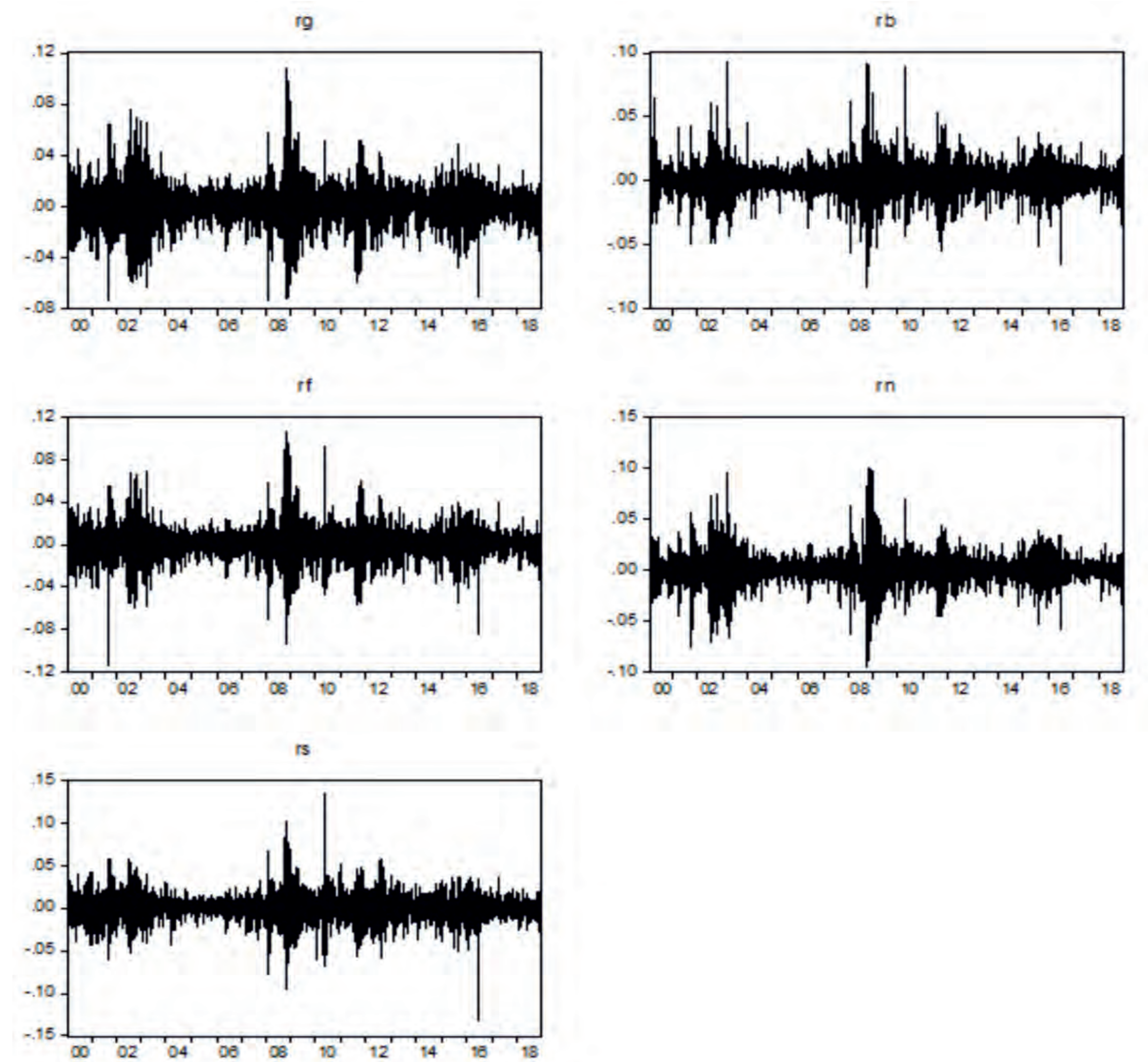
Table 2. ***Descriptive Statistics of the Whole Period : 1/January/2000 – 31/December/2018***

Statistics	Germany	Belgium	France	Netherlands	Spain
Mean	0.00998	0.000002	–0.000040	–0.000059	–0.000058
Median	0.000700	0.000222	0.000202	0.000445	0.000565
Maximum	0.107975	0.093340	0.105946	0.100283	0.134836
Minimum	–0.074419	–0.083193	–0.114495	–0.095903	–0.131852
Std. Dev.	0.014857	0.012442	0.014502	0.014191	0.014760
Skewness	–0.003477	0.037148	–0.055167	–0.042259	–0.058145
Kurtosis	7.535538	9.294873	8.759479	9.890603	9.006931
ADF Test Statistic	–70.1119***	–64.91740***	–43.20431***	–33.25742***	–68.87359***
Jarque – Bera	4051.661***	7805.644***	6535.821***	9353.068***	7109.555***
Observations	4727	4727	4727	4727	4727
$Q5$	17.619***	35.430***	38.246***	44.133***	21.877***
$Q^2 5$	1376.8***	1681.6***	1046.6***	1978.6***	713.72***
ARCH LM test Statistics	159.7906***	404.2296***	140.279***	234.2476***	112.9359***

Note. *** significant at a 1% significance level. Q and Q^2 are Ljung-Box Q statistics for return and squared return series, respectively. ARCH-LM test is Engle's (1982) measure for conditional heteroskedasticity.

An insight into the descriptive statistics (refer to Table 2) reveals positive returns for the stock markets of Germany and Belgium and negative returns in other stock markets for the comprehensive duration. The average daily return is highest in Germany (0.00998), which means investors can channel their funds into the German stock markets from other markets. The lowest daily returns have been noticed in the stock market of the Netherlands (–0.000059). The return from German stock markets is also the most volatile amongst all the markets as measured from the value of standard deviation (0.014857). This proves that high returns accompany high risk. The lowest level of uncertainty is observed in Belgium's stock markets (0.012442). Further, skewness and kurtosis show the distribution of market returns. It can also be observed from Table 2 that returns from the Belgium stock market are positively skewed, while all other market returns are negatively skewed. Therefore, the Belgium stock market can

Figure 1. *Returns of the European Equity Markets*



be considered good for investments. The returns from the stock markets of Germany, France, Netherlands, and Spain are negatively skewed and asymmetric, which are not considered good from an investment point of view because of the risk involved. The kurtosis statistics indicate that all return series are leptokurtic, which means market returns are non-normal, and there is a potential for extreme gains and losses. To verify and confirm the presence of financial contagion and to determine the dynamic correlation between the market returns, some diagnostic tests have been performed. The stationarity of the data is confirmed by the Augmented Dicky – Fuller (ADF) test at 1%.

The Jarque – Bera test proves that time series data does not come from a normal distribution. Autocorrelation has been ascertained by applying the Ljung – Box Q statistics up to 5 lags for returns and the square of the return series for all the markets. The statistically significant value of the Q-statistic for all the markets leads to the rejection of the null hypothesis of no autocorrelation. The autocorrelated return series for daily and squared values exhibits a strong nonlinear dependence in time series. The results of the conditional heteroskedasticity ARCH-LM test also confirms the presence of the ARCH effect in all return series as the value of the F-statistic for this test is significant. The presence of the ARCH effect in the residuals can also be observed visually in the graphs of stock market returns for each of the chosen markets, which hints at the presence of volatility clustering in these markets (see Figure 1). Therefore, the application of GARCH family models is appropriate to assess the dynamic correlations and explore the financial contagion in the chosen stock markets.

The subprime crisis in the US is commonly known as beginning on August 1, 2007. This period resulted in a widespread downfall in the stock markets all over the world. Descriptive statistics for this period (refer to Table 3) reveal negative returns for all sample stock markets of Europe. A maximum fall has been observed in the Belgium stock market (–0.001865). During this period, all return series are positively skewed. Kurtosis and Jarque – Bera statistics indicate that the markets are not normal during this period.

The historical developments indicate that the Eurozone crisis had its genesis in January 2010 and lasted up to December 2012. For this period, the returns are positive for Germany and Netherlands markets (refer to Table 4). The returns are negative for France and Spain markets and stagnant for the stock market of Belgium. It means even during the period of crisis, the markets of Germany and the Netherlands could escape the flow of negative news coming to their markets. For this period, maximum volatility has been observed for Spain, followed by France, Germany, Belgium, and the Netherlands.

Table 3. ***Descriptive Statistics During the US Subprime Crisis : 1/August /2007 – 05/May/2009***

Statistics	Germany	Belgium	France	Netherlands	Spain
Mean	–0.001041	–0.001865	–0.001348	–0.001749	–0.001125
Median	–0.000528	–0.001332	–0.001000	–0.001321	–0.000350
Maximum	0.107975	0.092213	0.105946	0.100283	0.101176
Minimum	–0.074335	–0.083193	–0.094715	–0.095903	–0.095859
Std. Dev.	0.021774	0.020913	0.023018	0.024058	0.022212
Skewness	0.490302	0.048766	0.360277	0.173025	0.171293
Kurtosis	8.078639	5.947771	6.984545	7.106371	6.589215
Jarque – Bera	478.2307***	155.4922***	293.0749***	303.5538***	232.3720***
Observations	429	429	429	429	429

Note. *** implies significance at a 1% level of significance.

Table 4. *Descriptive Statistics During Eurozone Crisis : 6/January/2010 – 28/December/2012*

Statistics	Germany	Belgium	France	Netherlands	Spain
Mean	0.000323	0.00000	–0.00010	0.00004	–0.000510
Median	0.000745	0.00004	0.000202	0.000215	–0.00025
Maximum	0.052104	0.089550	0.092208	0.070722	0.134836
Minimum	–0.05995	–0.05493	–0.05635	–0.04569	–0.06874
Std. Dev.	0.013998	0.013117	0.015345	0.012442	0.018010
Skewness	–0.22966	0.267999	0.056808	–0.03898	0.431672
Kurtosis	5.262629	7.152593	6.063464	5.476853	7.897379
Jarque – Bera	168.5760***	554.4280***	297.2030***	194.2053***	782.0762***
Observations	759	759	759	759	759

Note. *** significant at 1% level of significance.

Table 5. *Descriptive Statistics During the Stable Period*

Statistics	Germany	Belgium	France	Netherlands	Spain
Mean	0.000190	0.000230	0.000131	0.000124	0.000167
Median	0.000793	0.000340	0.000323	0.000592	0.000748
Maximum	0.075527	0.093340	0.070023	0.095169	0.057891
Minimum	–0.074419	–0.066132	–0.114495	–0.075310	–0.131852
Std. Dev.	0.013976	0.010796	0.012890	0.012862	0.012712
Skewness	–0.137974	0.103676	–0.291462	–0.085497	–0.409438
Kurtosis	6.042572	8.396922	7.659914	8.082710	7.726068
Jarque – Bera	1376.286***	4301.324***	3252.135***	3813.742***	3392.468***
Observations	3539	3539	3539	3539	3539

Note. *** significant at a 1% level of significance.

For the period of stability (refer to Table 5), the highest returns have happened in the equity market of Belgium, followed by the markets of Germany, Spain, France, and the Netherlands. Further, the risk is highest for Germany and the least for Belgium.

Empirical Methodology

Financial contagion can be examined by a plethora of models suggested in the literature. One of the common methods for examining the presence of financial contagion is cross-market correlations, but this is often marred by the shortcoming of heteroskedasticity in the volatility period, that is, during the duration of a financial crisis. Therefore, one should be careful while analyzing the financial contagion. Studies say that in the presence of financial contagion, there is a significant rise in the cross-correlation between the returns of two assets (after adjusting for the heteroskedasticity). If it does not happen, then there will only be interdependence and no contagion. To compute the dynamic correlation amongst the equity markets and control the heteroskedasticity, the multivariate DCC-GARCH model has been employed in several studies (Bala & Takimoto, 2017; Roy & Roy, 2017; Wang & Moore, 2012) along with vector autoregression (VAR) and other GARCH models for estimating volatility spillover and financial contagion.

The DCC-M GARCH Method

Mean equation according to stochastic vector method of yields of K assets $\{k_t\}$ can be specified as :

$$r_t = \mu_t + \omega_t \qquad (2)$$

where, $\omega_t = H_t^{1/2} Z_t$ and $E(\omega_t \, \omega_t^{\top}) = I_N$. The conditional variance-covariance matrix of r_t is a $K \times K$ matrix denoted by $H_t = [h_{ijt}]$. The conditional covariance matrix can be decomposed to the standard conditional deviations and a correlation matrix, which is given below :

$$Z_t = D_t R_t D_t \qquad (3)$$

where, $D_t = diag\,(h_{1t}^{1/2}, h_{2t}^{1/2}, ..., h_{kt}^{1/2})$ is the qualified standard deviation and R_t represents the correlation array. For keeping the R_t matrix a positive definite and all its elements ≤ 1, we have decomposed it as:

$$R_t = Q_t^{*-1} \, Q_t \, Q_t^{*-1} \qquad (4)$$

where, Q_t is a positive definite matrix that defines the structure of dynamics and Q_t^{*-1} rescales the elements in Q_t to confirm $|\,qij\,| \leq 1$. Q_t^* is the diagonal matrix having a square root of the diagonal elements of Q_t. Thus, $Q_t^* = diag$ $(q_{11t}^{1/2}, q_{22t}^{1/2}, \ldots \ldots \ldots, q_{nnt}^{1/2})$. Now, Q_t trails the dynamics in the following form :

$$Q_t = (1 - \theta_1 - \theta_2)\, \overline{Q} + \theta_1 \in_{t-1} \in_{t-1}^T + \theta_2 Q_{t-1} \qquad (5)$$

where, $\overline{Q} = cov\,(\in_t \in_t^T) = E\,(\in_t \in_t^T)$ is the unconditional covariance matrix of standard errors and θ_1 and θ_2 are DCC parameters. In equation (5), θ_1 and θ_2 are scalars, and must fulfill the ensuing conditions: $\theta_1 \geq 0$, $\theta_2 \geq 0$, and $\theta_1 + \theta_2 < 1$.

The loglikelihood based on normal distribution to estimate the above model can be stated as follows:

$$\ln(M(\varphi)) = -1/2\, \Sigma_{t=1}^{T} (nln\,(2\pi) + 2\ln(|D_t|) + \ln(|R_t|) + \eta_t \, D_t^{-1} R_t^{-1} D_t^{-1} \eta_t^T \qquad (6)$$

where, φ represents the parameters of the method.

Financial Contagion

To comprehend the presence of financial contagion in the study, we have applied the OLS (ordinary least square) regression model, wherein the dynamic conditional correlation coefficient has been regressed with the conditional variance of the return from the German stock market and other markets. The following equation has been used for this purpose:

$$\rho_{ijt} = a + b_1 h_{it} + b_2 h_{jt} + \varepsilon_t \qquad (7)$$

where, ρ_{ijt} is the estimated coefficient of conditional interaction between German stock market returns and the other four benchmark market returns in such a way that i = Germany's benchmark index returns and j = other benchmark indices returns. The volatility of the German stock market is conditional denoted by h_{it} , and the volatility of other index returns is h_{jt}. A positive value of bi (i = 1,2) obtained with the least square technique by estimating the above method would imply that conditional correlation rises with an increase in volatility, which provides a piece of evidence in favor of financial contagion. Further, for monitoring the consequences of financial contagion in the Eurozone crisis and the US subprime crisis, Eq. (7) is re-estimated with the help of dummies for these two crisis periods along with their interactive terms with the conditional variance (see equation 8). The period for the crisis has been taken from the study of Horta et al. (2014).

$$\rho_{ijt} = a + b_1 d_{GFC} + b_2\, d_{EZC} + b_3\, d_{GFC} * h_{it} + b_4\, d_{EZC} * h_{jt} + b_5\, d_{GFC} * h_{it} + b_6\, d_{EZC} * h_{jt} + \varepsilon_t \qquad (8)$$

In our study, we have used the value of adjusted R^2 as the indicator for the degree of financial contagion. The greater the value of R^2 , the higher will be the intensity of financial contagion.

Data Analysis and Results

Correlation Analysis

The study of the correlation between two markets is useful in analyzing the degree of interdependence, volatility spillover, and financial contagion. It reflects the tendency of the return of the two time series to move in tandem with each other. If two series are correlated with each other, then the chances of volatility spillover and financial contagion will become higher.

Analysis of Cross Static Unconditional Correlation

The results of the unconditional static correlation in Table 6 show that overall, there is a medium to high degree of correlation between the returns of all the stock markets included in the study. The returns of the German stock market have the highest correlation with the returns of the France stock market, followed by the Netherlands, Spain, and Belgium stock markets. The highest correlation (0.926) has been observed for France and Netherlands stock market returns ; whereas, the Belgium stock market is least correlated with each other (0.7764). If an asset is negatively or uncorrelated with another asset, it is known as a hedge; if it has a positive correlation but not a perfect one with another asset, it is termed a diversifier. Thus, from the static unconditional correlation values analysis, we may infer that all stock markets may be considered diversifiers for the German stock market. So are all other markets for each other. But one must not forget that these correlational values are static and unconditional,

Table 6. ***Cross Static Unconditional Correlations : 1/January/2000 – 31/December/2018***

	Germany	Belgium	France	Netherlands	Spain
RG	1				
RB	0.7797	1			
RF	0.8935	0.8430	1		
RN	0.8672	0.8557	0.9260	1	
RS	0.7967	0.7764	0.8719	0.8192	1

therefore, no inference can be drawn based on these values alone as these values do not contain the impact of other exogenous variables. For interpreting the financial contagion, dynamic conditional correlation values are more important as the correlation between two markets is captured dynamically for different periods.

Analysis of Dynamic Conditional Correlation

The results of univariate GARCH estimates, as derived from the multivariate DCC-GARCH model, are produced in Table 7. These results show that the values of the ARCH (α) and the GARCH coefficients (β) of the univariate GARCH model are significant and positive, and their sum is also found to be less than one for each stock market, which shows the persistence of volatility in all five stock markets. The result of the Wald test further confirms the persistence of volatility in all markets. Wald test has a null hypothesis that the sum of ARCH and GARCH coefficients ($\alpha + \beta$) is unity, which has been rejected by our results. Besides this, DCC parameters θ_1 and θ_2 are also significant, which means there is a substantial time-varying co-movement between the chosen markets. Further, their sum ($\theta_1 + \theta_2$) is less than one, which establishes that our DCC-MGARCH model is stable and the results are reliable.

The average dynamic conditional correlation values between the German stock market return and other return series are reported in Table 8. The mean value of DCC for each pair has been tested for the hypothesis that it is statistically different from zero. For, if the mean DCC value is equal to zero, then it is more appropriate to employ the CCC-MGARCH (constant conditional correlation multiple GARCH) models; else, the DCC-MGARCH

Table 7. ***Univariate GARCH Estimates : 1/January/2000 – 31/December/2018***

Statistics	Germany	Belgium	France	Netherlands	Spain
μ	0.000646***	0.000548***	0.000485***	0.000473***	0.000455***
Ω	0.000002***	0.000002***	0.000001***	0.000001***	0.000002***
α	0.085257***	0.116296***	0.088282***	0.102201***	0.094648***
β	0.904587***	0.867450***	0.905272***	0.889573***	0.898161***
$\alpha + \beta$	0.98	0.97	0.98	0.98	0.98
Wald Test	–3.557633***	–4.667948***	–2.667050***	–2.521822**	–2.633146**
θ^1			0.029697***		
θ^2			0.961308***		

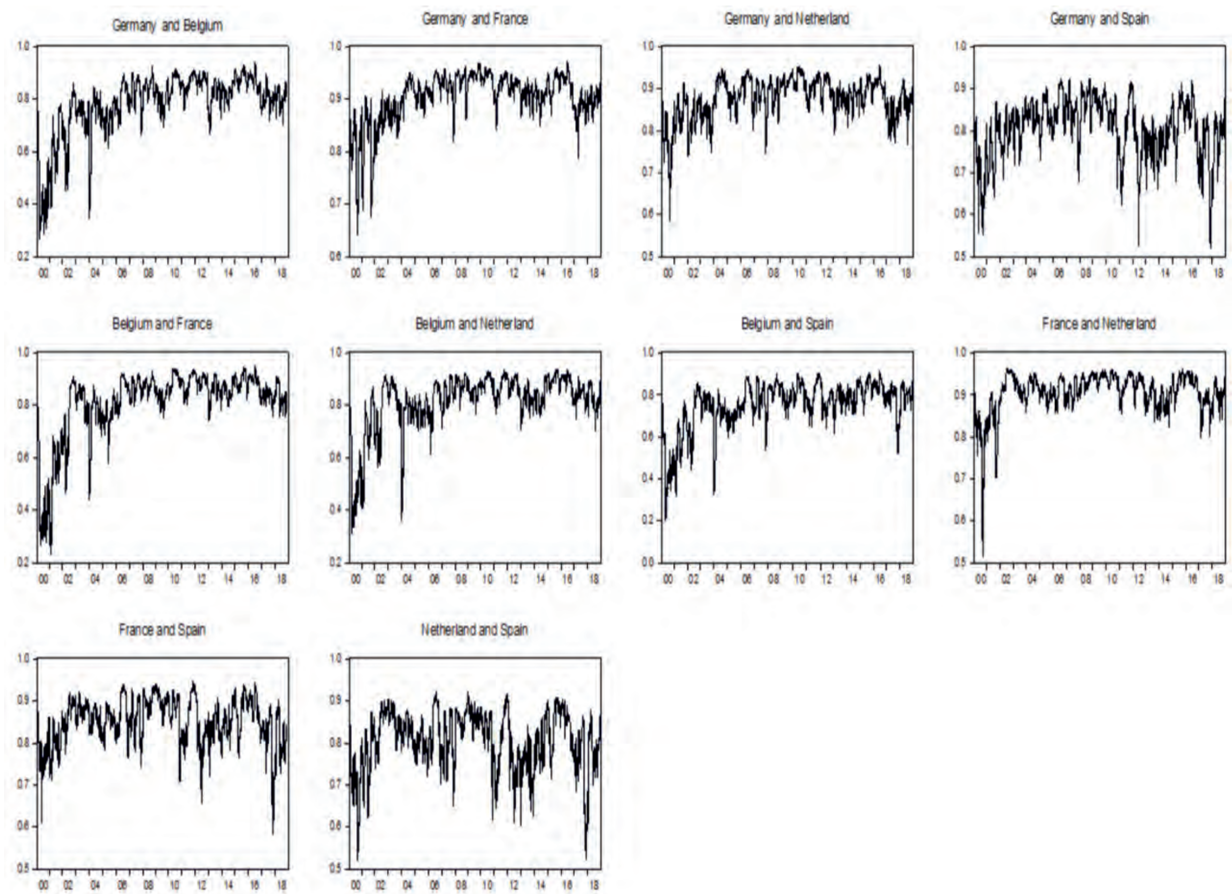
Note. *** significant at a 1% level of significance.

Table 8. ***Average Conditional Correlations : 1/January/2000 – 31/December/2018***

Statistics	Germany	Belgium	France	Netherlands	Spain
Germany	1				
Belgium	0.783113***	1			
France	0.904124***	0.811655***	1		
Netherlands	0.877623***	0.817430***	0.906404***	1	
Spain	0.804957***	0.752232***	0.851227***	0.805188***	1

Note. ***significant at 1% level.

Figure 2. ***Dynamic Conditional Correlations***



model will be more reliable. In our case, all mean values are significantly different from zero ,therefore, our choice of the DCC-MGARCH model is efficient. The graphs of DCC coefficients are shown in Figure 2. From it, we may ascertain that the correlation between the returns is time-varying for each of the pairs for the sample markets. The correlation value is relatively higher in the crisis period for both crises analyzed in the study, which confirms the notion that the correlation between the equity markets is comparatively high during the period of turmoil. These results are similar to Gallegati (2012), which indicates that each market pair is affected by different financial crises occurring over the entire period.

The Study of Financial Contagion

Table 9 displays the effect of conditional variances on the correlation between the stock market of Germany and other European stock markets using the ordinary least squares method (based on equation 7). The empirical results reveal that the conditional variance coefficient of the German stock market is negative for Belgium, France, and the Netherlands, implying a decrease in conditional correlation between German stock markets and these three stock markets when the volatility in the German stock markets rises. The coefficient of the German stock market

Table 9. ***Financial Contagion in European Markets***

Independent Variables	M1 Germany, Belgium	M2 Germany, France	M3 Germany, Netherlands	M4 Germany, Spain
Constant	0.7603***	0.9076***	0.8767***	0.7638***
h_g	–7.1275***	–5.4515***	3.1222***	3.8267***
h_j	10.65773***	5.2645***	3.4662***	–0.7560***
Adjusted R^2	0.0742	0.0551	0.0315	0.0832

Note. *** significant at a 1% level of significance.

volatility is positive for the stock market of Spain, implying an increase in conditional correlation between German and Spain equity markets. Considered in conjunction with volatility in Germany's stock markets, volatility in returns from Belgium, France, the Netherlands, and Spain carry a statistically significant favorable effect on the correlation between German stock markets and other stock market's returns. It reflects that the correlation with the German market also increases when volatility increases in these markets. Therefore, the evidence supports the presence of financial contagion between major European stock markets. The degree of financial contagion has been computed with the help of adjusted R^2 value, which is the highest between Germany and Spain (0.0832) and least between the stock markets of Germany and the Netherlands (0.0315). The increased degree of financial contagion between Germany and other European markets has also enhanced the susceptibility of these markets to exterior shocks. The same has also been reported in the past, establishing that in the presence of financial contagion, the mutual dependence between the markets rises (Sehgal et al., 2018). Likewise, because of greater market integration, the prices of the assets in one market are affected by common factors in connected markets, and the returns from the stock market in one market can be verified by their covariances with the rest of the markets (Baele, 2004; Shogbuyi & Steeley, 2017).

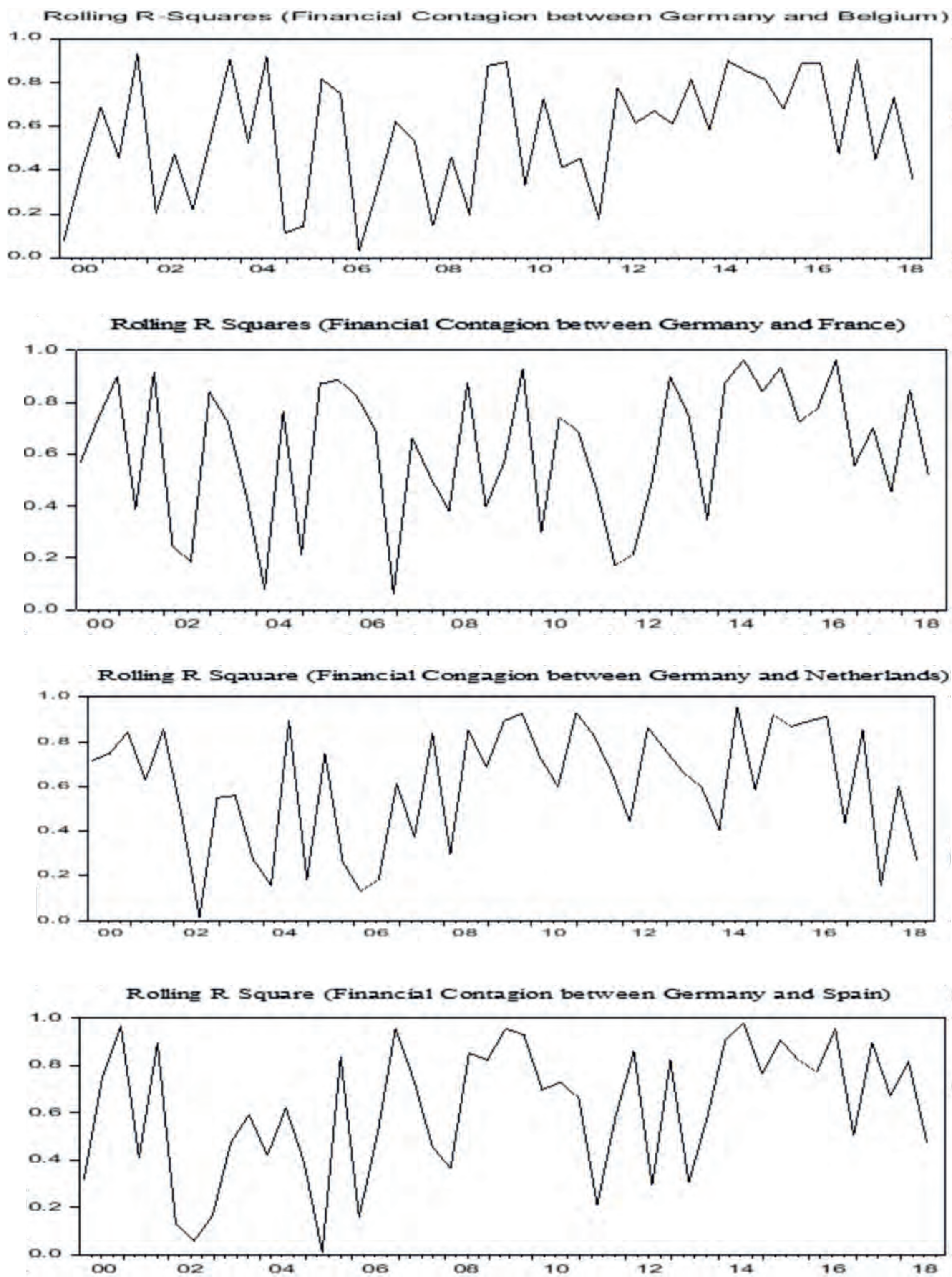
The results presented in Table 10 are based on equation 8, in which we have used two dummy variables: *dgfc* and *dezc,* as a proxy for the US subprime crisis and Eurozone crisis, respectively, along with interactive variables. It can be seen from the results of M5 in Table 10 that the correlation between German and Belgium stock market

Table 10. ***Financial Contagion in European Markets During the Crisis Period***

Exogenous Variables	M5 Germany, Belgium	M6 Germany, France	M7 Germany, Netherlands	M8 Germany, Spain
Constant	0.7601***	0.8955***	0.8693***	0.7999***
DGFC	0.0514***	0.0283***	0.0010	0.0199***
DEZC	0.0564***	0.0067	0.0017	–0.0741***
dgfc × hgermany	–1.8540*	0.4587	1.2552	–2.4203**
dezc × hgermany	1.9915	–2.4608***	–2.1570***	7.3685***
dgfc × hj	3.0822***	–0.1309	–0.2199	4.4448***
dezc × hj	1.5953	4.1325***	5.6557***	–1.6403***
Adj. R^2	0.1198	0.1136	0.1239	0.1023

Note. *** significant at the 1% level of significance.

Figure 3. ***Rolling Regression***



returns rose throughout the tenure of the global financial turmoil, which is primarily because of the rise in volatility in the Belgium stock market and which is a clear signal of financial contagion between these two markets during the US subprime crisis period. Similar results have been obtained for France and Spain. However, no contagion impact has been observed between Germany and Netherlands during the period of the US subprime crisis. The signs of financial contagion during the period of the European zone crisis are found between Germany and Belgium only. Thus, a key finding of our study is that the impact of the subprime crisis is greater than the impact of the Eurozone crisis. The select European markets also display herding behavior, which can be due to the increased degree of financial liberalization and globalization of these economies. These results also indicate that investors looking for diversification in their portfolio by investing in other European markets will be at a disadvantage. Our findings support most crisis contingent theories of asset market linkages in Europe.

Further, to assess the robustness of our results, we have computed rolling values of r - squares between Germany and the rest of the markets. The graphs of rolling regression are presented in Figure 3. The values of the regression keep on changing for different window periods, which corroborate our earlier results. The value of rolling regression is highest for the period of the US subprime crisis of 2008 for all the given markets.

Discussion and Conclusion

In this study, we have explored the (a) dynamic linkages, (b) financial contagion between the top five European stock markets (Germany, Belgium, France, Netherlands, and Spain), and (c) the impact of two important financial crises namely, US subprime crisis of 2008 and Eurozone crisis from 2010 to 2012 on the financial contagion by employing multivariate DCC-GARCH methodology. The coefficient of dynamic conditional correlation between Germany and other European markets remains statistically significant for the entire study period. However, this relationship is not static over the study period. The rise in the value of the conditional correlation coefficient is more evident with the rise in volatility in the stock markets, especially in the US subprime crisis period, which signifies the impact of this crisis on the financial interdependence of the European stock markets. But not much impact of the Eurozone crisis has been observed on the dispersion of returns for all the markets, which is an important finding. Our study also assumes that financial contagion has its genesis in Germany, the largest economy in Europe, and wields a substantial effect on other markets in the area. Our results also confirm the presence of financial contagion among the stock markets during the phase of the US subprime crisis for all the markets except the Netherlands ; whereas, the effect of the Eurozone crisis on financial contagion is significant only for Spain and Belgium. These results of increased correlation in the time of the US subprime crisis are in accordance with the studies (Dewandaru et al., 2018; Mollah et al., 2016; Mohti et al., 2019; Niţoi & Pochea, 2020). The increased degree of financial contagion among the European markets favors the contagion effect in the European markets. Other reasons which lead to close linkages between these markets can be increased sensitivity to cross-market investment, changes in international oil prices, opportunities for diversification, and reaction to financial liberalization (Bernoth & Erdogan, 2012). Besides this, behavioral anomalies such as fear, pessimism, and herding also increase the market linkages (Niţoi & Pochea, 2020). Another important observation in our results is that all stock markets are not equally receptive to the flow of shocks originating from Germany.

The strength of financial contagion, as measured by the value of adjusted R^2 , is highest for the stock market of Spain, followed by Belgium, and the least for the Netherlands. The evidence of the rolling regression also confirms that the conditional correlation between the markets was high during the US subprime crisis and also varied with time. For the post-crisis period, a high degree of conditional correlation has been observed between Germany and all other markets with the exception of the Netherlands. In a nutshell, relatively strong financial interdependence has been observed between Germany and Spain, followed by Germany and Belgium. But the stock market of the Netherlands is not reactive to the shocks coming from Germany during both the crisis periods. The reasons for the higher degree of financial interdependence of few markets with each other can be because of historical linkages and trade interdependence between them (Nikkinen et al., 2020). Further, the weak reaction of the stock market of the Netherlands reflects that it can be a good choice for portfolio diversification during periods of crisis. In general, our study stipulates new insights into the field of financial contagion of stock markets in the light of our testimony from the European markets' perspective.

Managerial and Theoretical Implications

The outcome of our study has critical implications for investors, especially for formulating the optimal portfolio strategy. The empirical results explicitly state that all stock markets are swayed by common factors during the phase of financial contagion, therefore, portfolio diversification by investing in divergent markets is not useful. For investors ready to put their money into Europe's emerging economies, the results are crucial. The vulnerability of the European stock markets to various financial shocks is of great interest to investors and financial market authorities. Contagion analysis in the context of European markets is critical for potential Eurozone members and regulatory entities in both the Eurozone and non-Eurozone. Moreover, it is beneficial for the regulators to comprehend the network forms of the equity markets to frame meaningful regulations and strategies to counter the impact of financial contagion through the phase of a financial crisis, especially when it is coming from a developed country (US) or has its origin in the same region (Europe).

Limitations of the Study and Scope for Future Research

Our study mainly focuses on studying the impact of volatility spillover from Germany on select European financial markets, ignoring many other macroeconomic factors and financial variables such as exchange rate, commodity prices, etc., which is also the limitation of the study. Therefore, this study can be extended by including these variables in the study and observing their impact before, during, and after a global financial crisis. The study can also be extended by assessing the effect of financial contagion on different industries and sectors, as it is improbable that all sectors are equally affected by cross-border volatility. The contagion phenomena may also be explored in a non-parametric framework, and it will be a tremendous effort if notions of spatial econometrics and local correlation analysis can be used. In terms of future research, more structural techniques to assess financial contagion should be developed so that they may be utilized systematically for policy analysis at diverse institutions such as international organizations, governments, and central banks.

Authors' Contribution

Dr. Ashish Kumar and Dr. Swati Khanna conceived the idea and developed qualitative and quantitative designs to undertake the empirical study. Dr. Swati Khanna extracted research papers with high repute, filtered these based on keywords, and generated concepts and codes relevant to the study design. Prof. Neena Sinha and Prof. Sanjay Dhingra verified the analytical methods and supervised the study. Dr. Swati Khanna collected the data. The same was further transcripted and translated into English by all the others. The numerical computations were done by Dr.Ashish Kumar using EVIEWS. Dr.Swati Khanna and Dr. Ashish Kumar wrote the manuscript in consultation with both authors.

Conflict of Interest

The authors certify that they have no affiliations with or involvement in any organization or entity with any financial interest or non-financial interest in the subject matter or materials discussed in this manuscript.

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About the Authors

Dr. Ashish Kumar is an Assistant Professor in Finance at the University School of Management Studies (USMS), GGSIP University, New Delhi. He obtained his PhD in finance from Maharishi Dayanand University, Rohtak, India. His industry and academic experience extend to 18 years. He is a keen researcher and has contributed more than 50 research papers and articles in journals of national and international repute.

Dr. Swati Khanna is an Assistant Professor in the area of finance and accounting. She has completed her doctorate from Guru Gobind Singh Indraprastha University. Her industry and academic experience extend to 10 years. She is a keen researcher and has contributed research papers and articles published in journals of national and international repute.

Professor Sanjay Dhingra is serving as a Professor at the University School of Management Studies, GGSIP University, Delhi. His industry and academic experience extend to more than 20 years. He has published over 50 research papers in management journals and proceedings of international conferences.

Professor Neena Sinha is serving as a Professor at the University School of Management Studies, GGSIP University, Delhi. She served as Dean, University School of Management Studies, GGSIP University, from August 2017. She has also been an academic visitor to the University of Manchester (UK), Osaka University (Japan), and Saint Petersburg State University (Russia). She has published over 90 research papers in management journals and proceedings of international conferences.