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DYNAMIC INTERCONNECTIONS AND CONTAGION EFFECTS AMONG GLOBAL STOCK MARKETS: A VECM ANALYSIS

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ABSTRACT

This paper investigates the nature of the associations and the potential existence of both short-run and long-run relationships between the stock market indices of Morocco, France, Germany, the United Kingdom, China, and the United States from January 2014 to January 2024. The purpose of analyzing dynamic interconnections and contagion effects is to determine how the stock markets of these countries influence and relate to each other. The study employs a time series Vector Error Correction Model (VECM) approach, incorporating stationarity, cointegration, and Granger causality tests. Additionally, the Impulse Response Function (IRF) is used to analyze the response of variables to shocks. The bivariate Granger causality test reveals significant causal influences: from France, Germany, and the USA to Morocco; from the USA to the DAX and France; and from the UK to Germany. After establishing the Granger causal relationships, long-run and short-run relationships are further examined. Using the Johansen multivariate cointegration approach, the study suggests a long-term equilibrium among the six stock market indices over time. The short-run adjustments are analyzed using the VECM, which reveals that adjustments in the CAC 40, DAX, and MASI tend to correct deviations from equilibrium, indicating a tendency to move towards equilibrium. For the FTSE 100, S&P 500, and SSEC, the VECM captures the speed and direction of adjustments as these indices respond to short-term disruptions and work towards restoring equilibrium. The findings underscore the importance of closely connected global stock markets, which means that international regulators must coordinate their efforts to reduce the risks of contagion. Policymakers should prioritize improving financial stability through integrated frameworks considering short-term disruptions and long-term equilibrium trends.

Keywords: *Stock market indices, Contagion effects, Co-integration tests, Vector Error Correction Model (VECM), Granger causality*

1. INTRODUCTION

Numerous studies have examined the relationship between market prices and economic indicators employing various econometric approaches (Kılcı, 2019; Naceur & Ghazouani, 2007). However, even with the rapid globalization of market activity in the 21st century, little research focuses on the intricate interconnections among the global stock markets. These markets are not separate entities; they are becoming constantly interconnected, facilitating the rapid transfer of information and capital and increasing the risk of systemic instability, such as those exhibited by the various financial crises that have recently occurred (Mallieswari et al., 2024; Cevik et al., 2024). Understanding these intricate interrelations is crucial since each market's fluctuation can have major and often unpredictable consequences across the globe (Babaei et al., 2023; Bashir et al., 2019; David et al., 2021, Sugiarto et al., 2018).

This research seeks to fill the need by looking at the changing interactions between stock markets across continents, focusing on how these markets interact with each other and collectively react to global economic changes. The indices used in this study include Morocco's MASI (Moroccan All Shares Index) to represent emerging markets, as well as the CAC 40 (Cotation Assistée en Continu) in France, Germany's DAX (Deutscher Aktienindex) along with the British FTSE 100 (Financial Times Stock Exchange 100 Index) for European markets as well as the US S&P 500 (Standard & Poor's 500 Index) and China's Shanghai Composite. These indices offer a complete analysis of both emerging and mature markets in a period characterized by fluctuating economic stability from January 2014 until January 2024. The study's selection of ten years is pertinent, as it covers several economic cycles, such as periods of recession, growth, and recovery. This period provides a complete study of market behaviour in response to various economic and policy conditions in the world. It is particularly useful to study the effects on the economy of important events like market adjustments (Liu et al., 2020), Brexit (Kenourgios et al., 2020), the **Ukraine War, as well as the economic impact of the COVID-19 pandemic (**Baker et al., 2020).

To study these interactions, this research employs a rigorous economic framework that includes vector error correction models (VECM), Johansen cointegration test and Granger causality tests. The research process is thorough, starting with the test for unit root, frequently used in applied economics to prove the non-stationarity of a particular data set (Herranz, 2017). These tests consist of the Kwiatkowski-Phillips-Schmidt-Shin (KPSS) test proposed by (Kwiatkowski et al., 1992), the Phillips-Perron (PP) test developed by (Phillips & Perron, 1988), as well as the Augmented Dickey-Fuller (ADF) test introduced by (Dickey & Fuller, 1979). In order to confirm the non-stationarity in every single data set. These tests are an initial requirement for any further tests of cointegration. Then, Johansen cointegration tests are utilized to identify the presence and the number of cointegrating relations among the indexes. These cointegration relationships are long-term equilibrium relations which support the use of VECM.

VECM is especially adept in modelling non-stationary data sequences integrated in the same order and capturing both the long-term equilibrium relations and the short-term changes. This model is the only one that incorporates error correction factors, which are used to measure the speed and intensity with the indexes returning to equilibrium following a deviation. In addition, the Bivariate Granger causality test is carried out to gain insight into the effects of direction on the indices and provide a deeper knowledge of how a change in one market could trigger changes in the other. This systematic approach seeks to discover not only the presence of cointegration between the indices chosen, which suggests stable long-term relationships, and to evaluate how markets respond to changes in equilibrium. These findings are essential in making strategic investment decisions and for policymakers drafting financial regulations to reduce risks to the system. The results of this research will be a significant contribution to existing research by improving our understanding of the global interdependencies in finance and enhancing our ability to forecast and manage economic instability in a global financial system that is interconnected. The remaining part of this paper is structured as follows: Section 2 reviews the existing literature, Section 3 explains the methodological approach adopted, Section 4 presents findings, and Section 5 formulates recommendations and conclusions to researchers and professionals.

2. REVIEW OF EXISTING STUDIES

The globalization of financial markets has profound implications for economic stability and policymaking. To build a comprehensive understanding of these markets, it is essential to consider both theoretical foundations and empirical findings from past studies. This research integrates basic economic theories with empirical evidence to construct a clear argumentation and literature landscape. The interdependence of global stock markets can be analyzed through several theoretical lenses. One key theory is the Efficient Market Hypothesis (EMH), which posits that stock prices fully reflect all available information. Consequently, any new information about economic events or policies should rapidly influence global stock markets. Another important theory is the International Capital Asset Pricing Model (ICAPM), which extends the traditional CAPM by considering international factors that affect asset prices. These theories provide a basis for understanding how markets interact and influence each other across borders.

Numerous researchers have investigated the dynamic interactions between international stock markets, focusing on causality, cointegration, and the impact of economic events. Econometric models and cointegration tests are crucial tools for analyzing these complex relationships. Cheikh et al. (2022) conducted an empirical study using the VECM to investigate the impact of the COVID-19 outbreak on volatility spillover between oil and Gulf Cooperation Council (GCC) stock markets. The study found notable variations within the GCC group, with certain countries showing clear shock and volatility linkages between oil and equities while others did not. Gil-Alana et al. (2023) performed a comprehensive study on the long memory of stock market prices in Europe, Asia, and North America, specifically focusing on the period between 2009 and 2020. The researchers discovered significant levels of persistence across all the examined series and observed a slight tendency towards mean reversion in the American index. Furthermore, at lower sampling frequencies, the integration orders exhibited lower levels of integration.

Huang et al. (2000) explored the causality and cointegration of stock markets in the US, Japan, and the South China Growth Triangle. Their research findings revealed that no cointegration was observed among these markets except for Shanghai and Shenzhen. Moreover, their study disclosed that fluctuations in US stock prices significantly impacted the South China Growth Triangle markets rather than Japan. Mohti et al. (2019) analyzed stock market integration among emerging and frontier Asian countries using cointegration tests and cross-correlation coefficients. They found evidence of regional and global integration in all examined markets, with Pakistan showing the highest level and Vietnam demonstrating a lower extent of integration. Shahrier (2022) examined the contagion effects in ASEAN-5 exchange rates during the COVID-19 pandemic using VECM and wavelet analysis. Their findings suggest cointegration among the exchange rates, with the Indonesian rupiah leading to contagion effects in Malaysia and Thailand based on fundamentals. This research underscores the need for timely interventions to prevent short-term contagion from escalating into long-term effects. Stoupos & Kiohos (2022) studied the degree of stock market integration within the Eurozone following the debt crisis in 2010. Their analysis demonstrates a strong level of integration between Germany and the core member states of the Euro Area (EA). In contrast, the degree of integration among the peripheral states of the EA exhibits some variation.

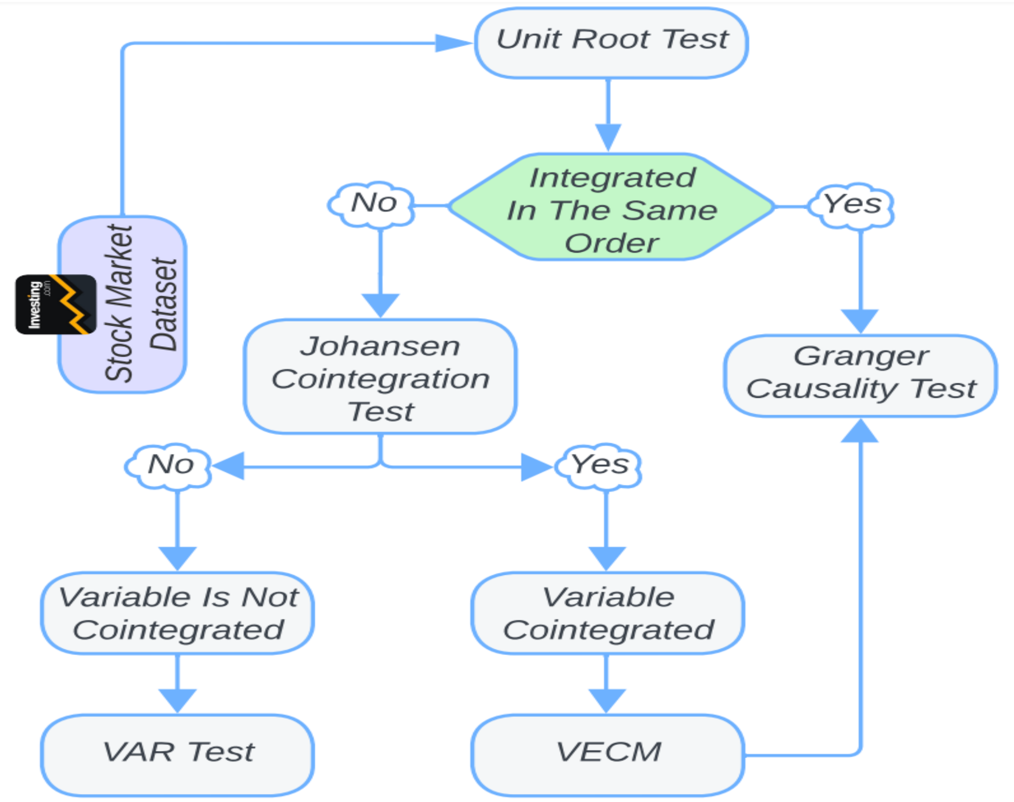
Tang et al. (2019) employed Granger causality testing to construct a network illustrating the influence exerted by 33 prominent global stock market indices. The consistent findings revealed that US indices held the leading position, followed by European and Asian indices. However, the researchers noted lag effects among the global indices. Yarovaya & Lau (2016) conducted a comprehensive analysis of stock market co-movements in times of crisis. They evaluated the potential diversification advantages for UK investors in emerging markets, specifically Brazil, Russia, India, China, and South Africa (BRICS) and Mexico, Indonesia, South Korea, and Turkey (MIST). Their study found that the diversification benefits were relatively modest, with a higher level of conditional correlation during periods of adverse shocks. The research also supported the decoupling hypothesis and underscored the Chinese stock market as the most appealing option for UK investors.

Our study underscores the importance of understanding contagion effects across major international stock market continents: America, Europe, Asia, and Africa. Unlike previous studies that focus on specific crises and periods, our research aims to fill these gaps by analyzing global market interconnections during different crises using various cointegration tests and econometric models. This understanding is crucial for global investors and policymakers in managing and mitigating the risks associated with global financial crises.

3. DATA AND METHODOLOGY

Our study is a comprehensive exploration of how the prices in six major stock markets, including the Moroccan MASI index, France's CAC 40, Germany's DAX, the UK's FTSE 100, the US S&P 500, and China's SSE Composite, change and move together over time. We employ various econometric and statistical tools, such as Rstudio, Jupyter Notebook, and Gretl software, to analyze data uniquely. Our methodology includes robust tests, including the Augmented Dickey-Fuller and Phillips-Perron tests, which provide insights into the consistency of observed trends. The Kwiatkowski-Phillips-Schmidt-Shin test is used to assess the stability of these trends, while the Johansen Cointegration test, Granger Causality test, and the VECM model offer further depth to our analysis. Diagnostic checking tests were also conducted to ensure the reliability of this study, reaffirming the soundness of our findings. Figure 1 provides a visual representation of our proposed approach.

Figure 1. The workflow of this study



Source: Author's Development

3. 1. DATA ANALYSIS

The dataset comprised six time series indexes from six countries. In order to represent the African continent, the Moroccan all-share index (MASI) from the Casablanca stock exchange was included. Similarly, the European continent was represented by the CAC 40, DAX, and FTSE 100 indexes, traded on Euronext Paris, Frankfurt Exchange, and London Stock Exchange, respectively. The representative index for the American continent was the S&P 500, traded on the New York Stock Exchange. The SSEC index from the Shanghai Stock Exchange was also chosen to represent Asia. The data collected spans from January 2014 to January 2024, with monthly observations gathered for further analysis. The selection of these specific stocks was motivated by several factors. By examining the correlation between these stocks, valuable insights can be gained on global economic trends and the interplay between different regions. The analytical insights derived from this study provide valuable information about the long-lasting relationships among indices, assisting investors in better anticipating market fluctuations and making informed decisions.

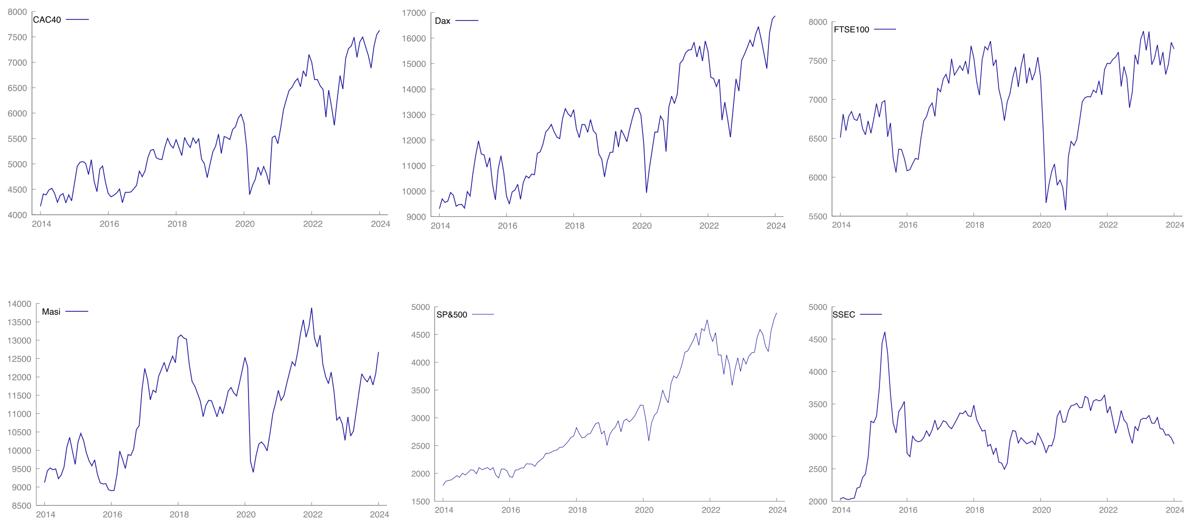
Table 1 is an important part of our analysis as it provides a comprehensive overview of the summary statistics for six stock indices throughout the period. This data is crucial for understanding the fundamental characteristics of these indices, such as measures of central tendency, variability, and distribution shape. Figure 2 visually illustrates the evolution of each index, highlighting their trends and responses to significant global events, particularly the COVID-19 pandemic. The descriptive statistics reveal distinct attributes of the indices' central tendency and variability. The mean and median values indicate typical levels for each index, with notable variability shown by the standard deviation. For instance, the DAX index exhibits the highest variability, reflecting significant fluctuations over the period. Regarding distribution shape, the MASI, CAC 40, S&P 500, DAX, and FTSE 100 indices demonstrate slightly left-skewed distributions with negative kurtosis values, indicating relatively flattened distributions. On the other hand, the SSEC index shows a more symmetric distribution with positive kurtosis. The graphs clearly depict the impact of the COVID-19 pandemic on the stock market indices. All indices, except SSEC, experienced a significant increase in value over the described period despite a period of weakness directly attributed to the pandemic. However, the SSEC index demonstrates a relatively stable trend without significant fluctuations. In conjunction with the descriptive statistics presented in Table 1, these graphical representations enhance our analysis by providing a detailed understanding of the performance and dynamics of international stock market indices. This comprehensive view is crucial for understanding the interconnectedness and responses of these markets to global economic changes.

Table 1. Descriptive Statistics for International Stock Markets

Series	Mean	Median	St. dev.	Min	Max	Kurtosis	Skewness
DAX	12499,13	12313,36	2031,76	9306,48	16872,65	-0,82	0,33
MASI	11131,64	11335,55	1252,67	8898,99	13883,49	-1,00	-0,03
SSEC	3100,94	3119,88	434,06	2026,36	4611,74	2,14	-0,09
CAC 40	5493,23	5312,56	960,24	4165,72	7630,17	-0,69	0,64
S&P 500	3029,48	2816,29	919,01	1782,59	4890,97	-1,19	0,44
FTSE 100	6998,72	7086,42	533,24	5577,27	7876,28	-0,43	-0,59

Source: Author's Development

Figure 2. The stock market plots of DAX, CAC 40, MASI, S&P 500, SSEC, and FTSE 100



Source: Author's Development

3. 2. METHODOLOGY

Our methodology follows a structured approach consisting of four distinct steps. Initially, we employ unit root tests to examine data integration and stationarity, utilizing ACF plots, the PP test, the KPSS test, and the ADF test. Subsequently, after checking stationarity, we determine the optimal lag lengths and assess the long-term cointegrated relationship using the Johansen cointegration method. Thirdly, we evaluate the short-term causal relationship using Granger causality tests upon establishing the long-term cointegrated relationship. Finally, we conclude by considering the VECM model. Detailed explanations of each method used in this study are provided below.

3. 2. 1. STATIONARITY TESTING

When conducting time series analysis, determining whether the data is stationary or non-stationary is paramount. Moreover, in the context of co-integration analysis and VECM, it is crucial to perform stationarity tests to validate the underlying assumptions. In the VECM, one of the assumptions is that the all-time series should exhibit the same level of integration. To this end, our study initiates the implementation of stationarity tests, utilizing established methodologies such as the ADF, KPSS, and PP tests. The ADF test is a standard diagnostic tool for evaluating stationarity, expressed by the following general equation (Dickey & Fuller, 1979).

$$Y_t = \alpha + \beta T + \delta Y_{t-1} + \sum_{i=1}^{m-1} \theta_i \Delta Y_{t-i} + \varepsilon_t$$

Where:

$$\delta = \sum_{i=1}^{m-1} \rho_{i-1} \quad \text{and} \quad \theta_i = -\sum_{k=i+1}^{m} \rho_k$$

In the given context, Y_t denotes the stock data at time t, α represent the constant term β, represents the deterministic trend component, and represents the stationary error term. It is important to note that for subsequent Johansen cointegration analysis, we only consider and include a variable that exhibits non-stationarity and integration of order $I(1)$. The null hypothesis of the ADF test which indicates the presence of a unit root, δ=0 is rejected if the computed test statistic exceeds the critical value. We also employ the Phillips–Perron test (PP) to ensure the reliability of our findings and validate stationary properties (Phillips & Perron, 1988). This test assesses whether a given time series Y_t is integrated of order $I(1)$, addressing potential issues of higher order autocorrelation by introducing a non-parametric correction to the t-test statistic:

$$\Delta Y_t = (\rho - 1)Y_{t-1} + u_t$$

where Δ represents the first difference operator. This approach fortifies the test against unspecified autocorrelation and heteroscedasticity within the disturbance process. During the last phase of our analysis, we utilize the KPSS test to determine stationarity in a time series by evaluating the existence of a deterministic trend (Kwiatkowski et al., 1992). The KPSS test involves breaking down the time series into three distinct components: a deterministic trend β_t, a stochastic trend r_t , and a stationary error term ε_t. This breakdown is represented by the regression equation:

$$Y_t = \beta_t + r_t + \varepsilon_t$$

To conduct the KPSS test, the regression above model is fitted to the stock data, enabling the evaluation of the stationarity of the residual component ε_t. The null hypothesis posits that the time series is stationary, whereas the alternative hypothesis suggests its non-stationarity.

3. 2. 2. JOHANSEN COINTEGRATION

Cointegration analysis is a valuable tool for understanding the long-term relationships between variables. Researchers use cointegration tests to determine if there is a lasting connection between two or more time series (Poh and Tan, 1997). If there is no cointegrating relationship, the two variables can move independently over time and diverge from each other. In this paper, the Johansen cointegration procedure is employed to examine the presence of a long-term relationship between stock market indices. This procedure encompasses two distinct tests, namely the trace test and the maximum eigenvalue test, which are both based on the principle of maximum likelihood estimation. These tests are used to determine likelihood ratios. The trace test is employed to assess the null hypothesis of cointegrating vectors. If the value of the test statistic is equal to zero, it can be inferred that there is no long-run relationship between the non-stationary variables, thus indicating the absence of cointegration. Conversely, the maximum eigenvalue test is used to evaluate the null hypothesis of cointegrating vectors, with the alternative hypothesis of $r+1$ cointegrating vectors. The Johansen test begins with a vector autoregression of order p, which is represented as:

$$I_t = \mu + A_1 I_{t-1} + \dots + A_p I_{t-p} + \varepsilon_t$$

where I_t represents our $n \times 1$ vector of integrated $I(1)$ stock market indices, while ε_t represents an $n \times 1$ innovations vector. The trace test and the maximum eigenvalue statistics are defined as suggested below:

$$\lambda_{trace} = -T \sum_{i=r+1}^{n} \ln\left(1 - \widehat{\lambda_i}\right)$$

$$\lambda_{max} = -T \ln\left(1 - \widehat{\lambda_{r+1}}\right)$$

The variable T represents the number of observations, while $\widehat{\lambda_i}$ represents the estimated values of the characteristic roots. The primary advantage of this model is its ability to estimate multiple cointegration relationships.

3. 2. 3. GRANGER CAUSALITY

To investigate the immediate fluctuations of cointegrated series, we utilize the Granger causality test. This test allows us to ascertain the causal directionality among various markets. The application of Granger causality aids in identifying any constraints imposed by lagged variables through the examination of interrelationships between multiple time series within a given system (Khan and Khan, 2021). This ensures that information from past values of X_t does not statistically impact the present or future value of Y_t. In other words, X_t does not Granger cause Y_t if the prediction of Y_t based on past values of Y_t alone is not improved by including past values of X_t as well. Mathematically, X_t does not cause Y_t if, $P(Y_t|Y_{t-1}) = P(Y_t|X_{t-1},Y_{t-1})$, where Y_{t-1} represents the past of Y_t and X_{t-1} represents the past of X_t.

3. 2. 4. VECM MODEL

In the field of time-series analysis, datasets frequently exhibit characteristics such as non-stationarity among variables and cointegration. The VECM is a powerful tool that can handle these dynamic attributes present in the data (Maysami and Koh, 2000). By recognizing the presence of unit roots and utilizing the idea of cointegration, VECM enables the assessment of lasting relationships among variables, providing valuable insights into their long-term dynamics. An estimation of a VECM is conducted, which is characterized by l lags and r cointegrating vectors. The model is structured as follows:

$$\Delta Y_t = \alpha + AY_{t-1} + \sum_{i=1}^{l-1} B_i \Delta Y_{t-i} + \varepsilon_t, \quad t \in \mathbb{Z}$$

where Δ represents the first difference operator, with i denoting the lag length. The coefficient matrices A and B, both with dimensions of $n \times m$, where is n the total number of equations. Additionally, vector α encompasses constant terms. The error term ε_t follows an independent and identically distributed (i.i.d.) Gaussian white noise process with mean 0 and variance σ^2 for each element, represented as $\varepsilon_t \sim iid(0, \sigma^2 I)$ where I represents the identity matrix. Selecting the optimal lag length, is crucial for mitigating autocorrelation in errors. The determination of the optimal lag count depends on both the Akaike Information Criterion (*AIC*) and the Schwartz Bayesian Information Criterion (*SBIC*).

4. 4. RESULTS AND DISCUSSION

4. 1. STATIONARITY

The first step in applying the cointegration test is to assess the stationarity of each variable's data. This is necessary to determine if the variables are integrated in the same order, as required for cointegration. In this study, the stationarity of each variable is examined using the ADF test, the KPSS test, and the PP test. In Table 2 the results of the unit root tests are displayed for each stock series, utilizing the ADF, KPSS, and PP tests.

Table 2. Unit Root Tests for Each Stock Market Series

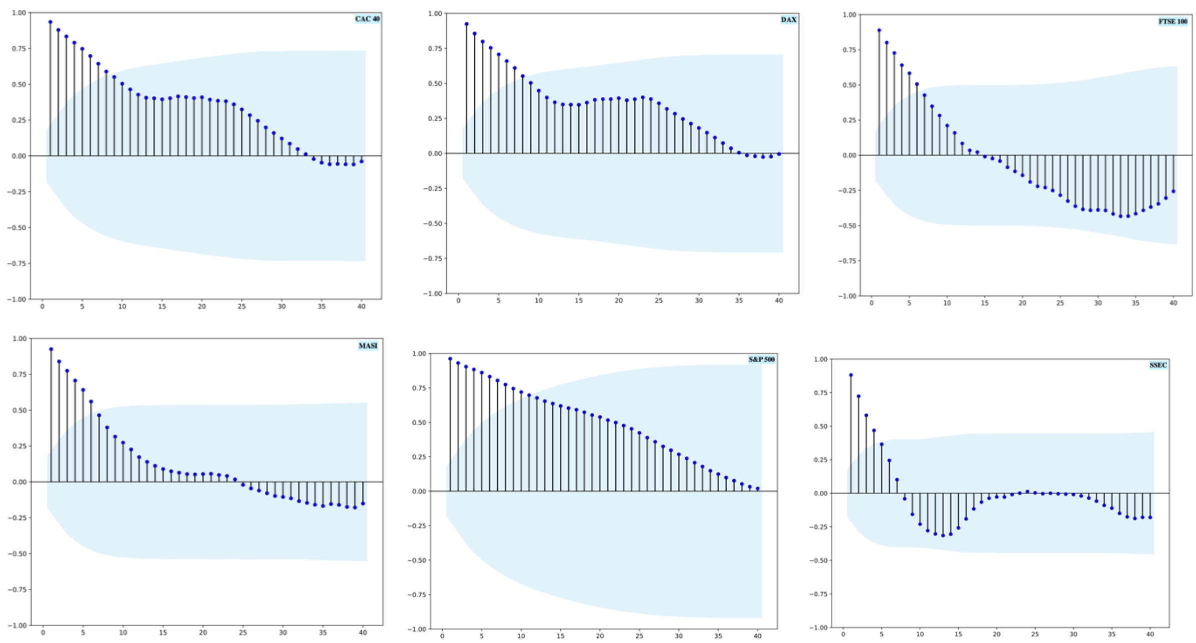
Country	Index	ADF test		KPSS test		PP test	
		Level	1st diff.	Level	1st diff.	Level	1st diff.
Germany	DAX	0.13	0.00***	0.01	0.1*	0.72	0.00***
Morocco	MASI	0.14	0.00***	0.01	0.1*	0.2	0.00***
China	SSEC	0.27	0.00***	0.01	0.1*	0.2	0.00***
France	CAC 40	0.10	0.00***	0.01	0.1*	0.8	0.00***
USA	S&P 500	0.27	0.00***	0.01	0.1*	0.9	0.00***
UK	FTSE 100	0.42	0.00***	0.04	0.1*	0.10	0.00***

Note: *p-value < 5%, **p-value < 1%, ***p-value < 0.1%.

Source: Author's Development

The p-values obtained from the ADF test for all indices at the initial level exceed the significance threshold of 5%, indicating non-stationarity. Conversely, the p-values for all indices at the first difference are lower than the significance threshold of 0.1%, suggesting that all series achieve stationarity after undergoing one differencing procedure. The p-values acquired from the KPSS test for all indices at the specified level are below the significance threshold of 5%, implying the presence of non-stationarity. However, after implementing first differencing, the p-values for all indices are at 0.1%, which suggests stationarity. These findings are further supported by the results of the PP test, where the p-values for all indices surpass the 5% threshold, thereby confirming non-stationarity. Furthermore, the p-values obtained after first differencing for all indices are below the significance threshold of 0.1%, indicating stationarity following the application of first differencing. Thus, it can be concluded that the series are integrated of order $I(1)$. Additionally, Figure 3 shows the ACF plots that indicate the non-stationarity of all series. In summary, the ADF, KPSS, and PP unit root tests and the ACF plot provide strong evidence that each stock market index contains a unit root and is non-stationary at the level.

Figure 3. ACF Plots of the stock markets DAX, CAC 40, MASI, S&P 500, SSEC, and FTSE 100



Source: Author's Development

4. 2. COINTEGRATION TESTS

The Johansen cointegration test was used to investigate the long-term relationship between the variables. This test consists of two statistics: the trace test and the maximum Eigen value test. To determine the appropriate lag length for the six stocks, we considered various lag selection criteria, including the *AIC*, *BIC*, and the Hannan-Quinn information criterion (*HQC*). Table 3 shows the optimal number of VAR lags p identified by the VAR vector autoregressive model. The *AIC* information criteria indicate the lowest values at p=8. Therefore, the Johansen test and VECM will be utilized at order 8 for all indices. The Johansen cointegration test was used with a lag of 8, as shown in Table 4. The results of the trace statistic indicate that we can reject hypotheses H_1, H_2, and H_3 in favor of $r=0$, $r \geq 1$, and $r \geq 2$, respectively, based on the 5% critical values. However, when $r=4$, the trace statistic falls below the critical value, so we cannot reject H_4. Thus, at a 5% significance level, evidence suggests that the various stock market indices have at most three cointegration relationships.

Table 3. Optimal number of lags

Lag	AIC	BIC	HQC
1	80.551	83.302	81.667
2	80.439	84.059	81.908
3	80.687	85.176	82.508
4	80.927	86.286	83.102
5	80.980	87.207	83.506
6	80.994	88.090	83.874
7	80.608	88.573	83.84
8	80.256*	89.090	83.841

Source: Author's Development

Table 4. Johansen cointegration test

H_i	Eigen value	Trace test	Critical value
0	0.480	144.144*	40.076
1	0.208	70.884*	33.877
2	0.187	44.652*	27.585
3	0.132	21.366*	21.131
4	0.041	5.428	14.2639
5	0.006	0.704	3.841

Source: Author's Development

4. 3. GRANGER CAUSALITY TEST

To examine the short-term dynamics of cointegrated series, we use the Granger causality test as a methodological approach to discern causal relationships. This statistical test facilitates the directional causality between distinct markets. The null hypothesis of the Granger test suggests that the price series of the initial market does not exert a causal influence on the price series of the subsequent market. Table 5 presents the results of the Granger causality tests, which provide a clear identification of causal relationships among the six financial markets. These relationships were found to be statistically significant at a 5% significance level. Notably, causality is not observed for the Moroccan stock market. Conversely, within the subset of four stock markets excluding China, Granger causality is evident, signifying that these markets influence the MASI. This observed causality suggests that shocks experienced by one market have a more pronounced impact on the other markets. In particular, the results highlight the US as the most integrated market, exhibiting Granger causality effects on the Moroccan, France, and Germany markets. Furthermore, the UK market, in turn, influences the Moroccan and US markets while being influenced by none of the other markets. in the analyzed set.

Table 5. Granger Causality Test Across Stock Markets

Null Hypothesis (H_0)	p-value	Granger-cause
MASI Granger cause DAX	0.300	No
MASI Granger cause SSEC	0.178	No
MASI Granger cause CAC 40	0.347	No
MASI Granger cause S&P 500	0.096	No
MASI Granger cause FTSE 100	0.181	No
CAC 40 Granger cause DAX	0.226	No
CAC 40 Granger cause SSEC	0.365	No
CAC 40 Granger cause MASI	0.014	Yes
CAC 40 Granger cause S&P 500	0.164	No
CAC 40 Granger cause FTSE 100	0.259	No
DAX Granger cause CAC 40	0.103	No
DAX Granger cause SSEC	0.325	No
DAX Granger cause MASI	0.006	Yes
DAX Granger cause S&P 500	0.419	No
DAX Granger cause FTSE 100	0.305	No
SSEC Granger cause CAC 40	0.132	No
SSEC Granger cause MASI	0.414	No
SSEC Granger cause S&P 500	0.540	No
SSEC Granger cause FTSE 100	0.366	No
S&P 500 Granger cause DAX	0.038	Yes
S&P 500 Granger cause SSEC	0.800	No
S&P 500 Granger cause MASI	0.000	Yes
S&P 500 Granger cause CAC 40	0.024	Yes
S&P 500 Granger cause FTSE 100	0.085	No
FTSE 100 Granger cause DAX	0.074	Yes
FTSE 100 Granger cause SSEC	0.139	No
FTSE 100 Granger cause MASI	0.016	Yes
FTSE 100 Granger cause S&P 500	0.024	Yes
FTSE 100 Granger cause CAC 40	0.094	No

Source: Author's Development

4. 4. VECM ESTIMATION RESULTS

In this section, we present the findings of the VECM model estimation. The model was estimated using eight lags and three cointegrating relationships, including a constant term and no restrictions. The analysis covers the period from September 2014 to January 2024, comprising 113 observations. Table 6 displays the beta matrix, which exhibits the long-term relationships among the selected financial variables. Meanwhile, Table 7 illustrates the alpha matrix. The beta matrix shows that there are significant cointegration relationships between the selected stock market variables. The coefficients in the beta matrix denote the magnitudes of each stock's contribution to the corresponding cointegrating relationship. The CAC 40, DAX, and MASI coefficients indicate a robust positive cointegration within these markets, signifying a shared long-term equilibrium. Conversely, the coefficients of FTSE 100, S&P 500, and SSEC emphasize potential prospects for diversification or interconnectedness among these markets. The alpha matrix offers valuable insights into the immediate adjustments of individual stock variables when faced with deviations from the long-term equilibrium. These adjustments are essential for comprehending markets reactions to short-term shocks. Negative adjustments observed in CAC 40, DAX, and MASI indicate a propensity to rectify deviations from the equilibrium, whereas positive adjustments imply a return to the equilibrium state. In the case of FTSE 100, S&P 500, and SSEC, the adjustments indicate the velocity and direction of market corrections after short-term disruptions.

Table 6. The relationships among the selected variables in the long term

Indices	Cointegrating Vector 1	Cointegrating Vector 2	Cointegrating Vector 3
CAC 40	1.000	0.000	0.000
DAX	0.000	1.000	0.000
MASI	0.000	0.000	1.000
FTSE 100	-0.557	-1.316	-1.884
S&P 500	-0.875	-1.490	0.011
SSEC	0.232	-1.663	-3.413

Source: Author's Development

Table 7. The short-term adjustments of each stock variable

Indices	Cointegrating Vector 1	Cointegrating Vector 2	Cointegrating Vector 3
CAC 40	-0.837	0.457	-0.172
DAX	-1.305	1.061	-0.256
MASI	-0.451	0.550	-0.182
FTSE 100	-0.363	0.261	-0.094
S&P 500	-0.475	0.419	-0.113
SSEC	-0.007	0.313	0.050

Source: Author's Development

Our analysis of the impulse responses over a 24-period following the shock revealed several key findings. In Figure 4, the CAC 40, for instance, showed predominantly positive and statistically significant trends across multiple periods, particularly about itself, DAX, and FTSE100. Conversely, negative responses were evident in the context of SSEC and MASI. In Figure 5, the DAX displayed a positive shock correlation with DAX and CAC 40 and a negative correlation with SSEC and MASI. In Figure 6, the MASI exhibited positive responses with DAX, CAC 40, and MASI. In Figure 7, the FTSE 100 demonstrated positive correlations with FTSE 100, DAX, and CAC 40 and negative correlations with SSEC and MASI. In Figure 8, the S&P 500 indicated positive correlations with CAC 40, DAX, S&P 500, and FTSE 100 but negative correlations with other indices. Lastly, in Figure 9, the SSEC showed negative correlations with the S&P 500 and FTSE 100, as well as MASI, but positive correlations with DAX.

Figure 4. CAC 40 Response (Author's Development)

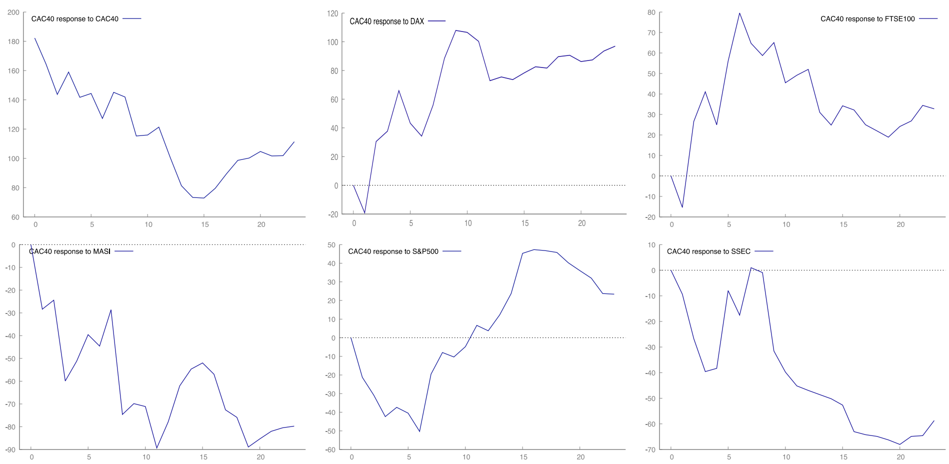


Figure 5. DAX Response (Author's Development)

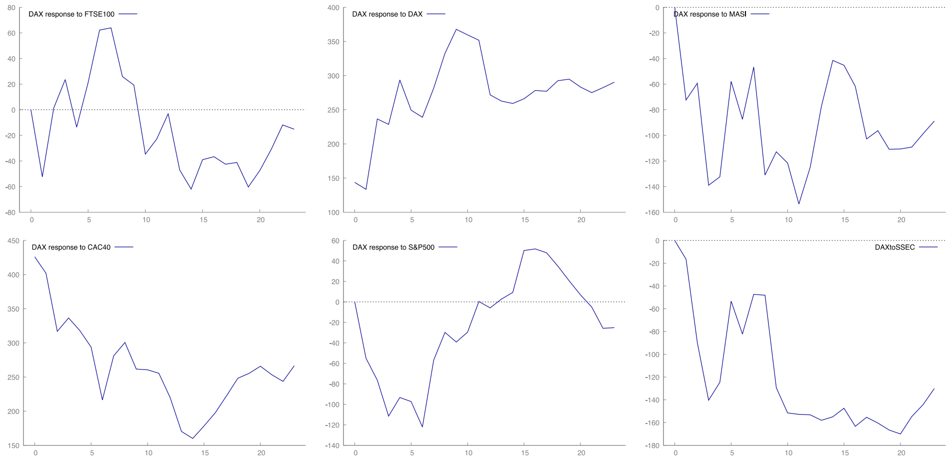


Figure 6. FTSE 100 Response (Author's Development)

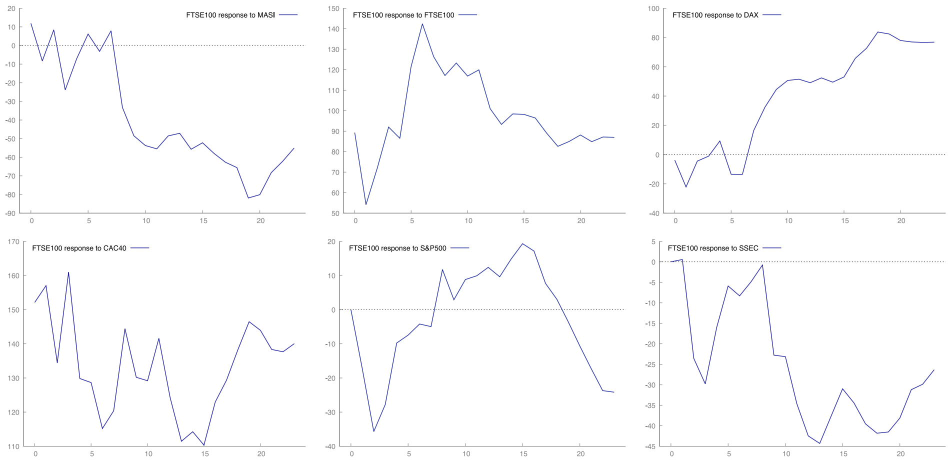


Figure 7. MASI Response (Author's Development)

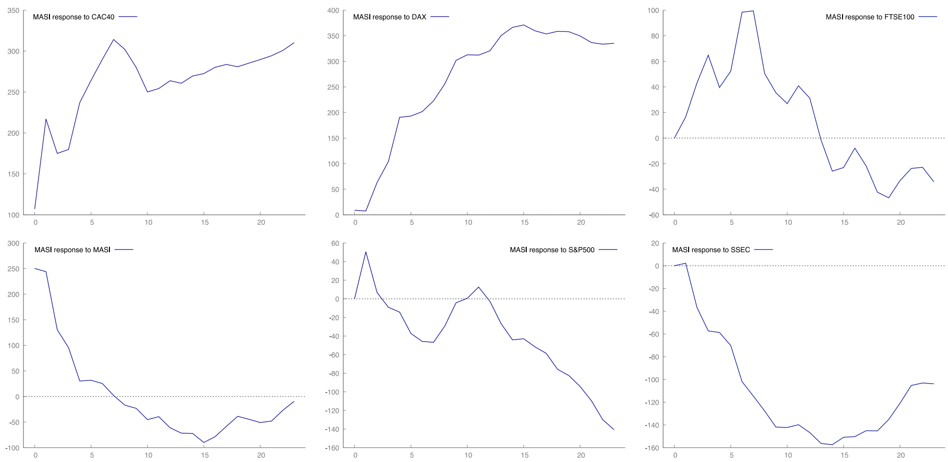


Figure 8. S&P 500 Response (Author's Development)

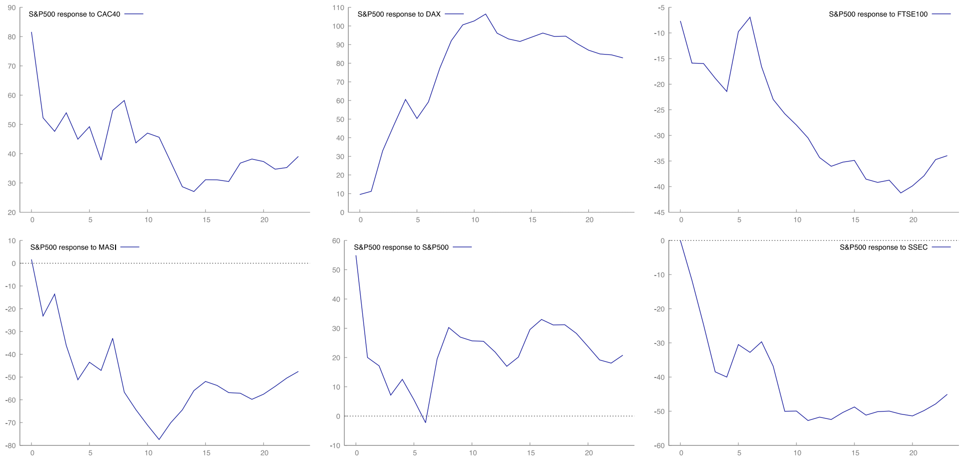
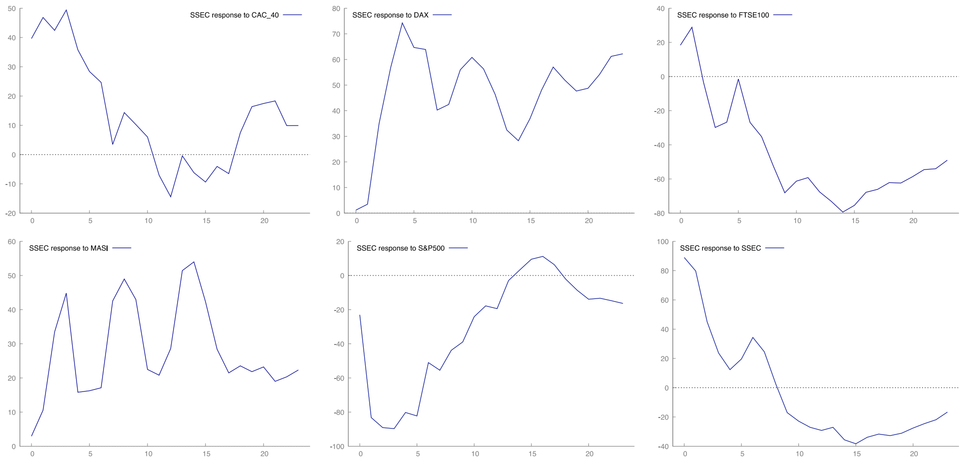


Figure 9. SSEC Response (Author's Development)



4. 5. MODEL DIAGNOSTIC TESTING

To determine the reliability of the estimated VECM, diagnostic tests are performed on the model's residuals for validation purposes. The results of these assessments provide supportive evidence for the credibility of the model. Specifically, the Doornik-Hansen normality test produces a chi-square statistic of 16.615, with a corresponding p-value of 0.1647, indicating that the residuals closely approximate a normal distribution. Consequently, at a significance level of 5%, we do not reject the null hypothesis, confirming the normality of the residuals. As for autocorrelation, the F statistic is computed to be 1.267, under an approximate F(36, 261) distribution. The associated p-value for this test is 0.1516, suggesting no significant autocorrelation at lag 1 in the residuals of the model. This implies that, at a conventional significance level (such as 0.05), we fail to reject the null hypothesis of no autocorrelation, indicating the absence of significant serial correlation at lag 1. Similarly, for the ARCH effect, the assessment reveals no significant evidence of conditional heteroscedasticity (ARCH effect) in the residuals at lag 1. The Lagrange Multiplier (LM) statistic is calculated to be 436.050, with degrees of freedom equal to 441, and a p-value of 0.5576. This p-value suggests that, at a conventional significance level, we do not reject the null hypothesis of no ARCH effect, indicating that the variance of the residuals does not show significant dependence on past squared residuals. Furthermore, we examined the stationarity of the residuals to ensure the stability of the model.

5. DISCUSSION

The findings of this study highlight the robust and enduring interconnections among global stock market indices, as evidenced by the Johansen cointegration test. Indices such as the CAC 40, DAX, and MASI consistently exhibited synchronous movements between January 2014 and January 2024, indicating a significant degree of integration driven by shared economic fundamentals and investor behaviours across these economies. This cointegration suggests that economic shocks or structural changes affecting one market will likely have repercussions on others, reflecting the interconnected nature of global financial markets. Previous studies, such as Cheikh et al. (2022) and Mohti et al. (2019), have similarly documented the integration of global stock markets and the transmission of financial shocks, corroborating our findings.

Our application of Granger causality analysis revealed significant causal relationships, particularly noting the substantial influence of the US on the Moroccan, French, and German markets. This underscores the role of the US market as a pivotal conduit for transmitting financial shocks across borders. Understanding this phenomenon is crucial for comprehending how global economic events and policy decisions originating in the US can swiftly impact other economies. Like Huang et al. (2000), who found significant causality from the US to the South China Growth Triangle markets, our study emphasizes the interconnectedness and interdependence of global financial markets.

The impulse response analysis provided insights into the immediate reactions of markets to shocks. Positive responses in indices such as the CAC 40, DAX, and FTSE 100 indicate that these markets promptly adjust towards equilibrium following disruptions, suggesting that market participants exhibit adaptive behaviours to restore stability. In contrast, negative responses in other indices highlight varying sensitivities and vulnerabilities to economic disturbances, which may be attributed to differing economic structures and regulatory environments. Studies like Gil-Alana et al. (2023) have shown similar adaptive behaviours in various markets, supporting our observations. To further enhance the discussion, Table 8 presents a comprehensive comparison of justifications, focusing on cross-country case studies.

Table 8. Summary of Economic, Market, Regulatory, and Historical Factors Influencing Global Stock Market Indices

Index	Economic Fundamentals	Market Structure	Regulatory Environment	Historical Context
S&P 500	Large economic size, global trade influence, major financial flows	High liquidity	Robust, ensures transparency and stability	Leader in financial innovations and reforms
DAX and CAC 40	EU membership, shared policies, significant trade relationships	Similar structures, high investor confidence	Harmonized within the EU, fosters stability.	Shaped by the European debt crisis and policy responses
MASI	Emerging market status, ties with Europe	Lower liquidity and depth, higher shock sensitivity	Ongoing reforms for stability and foreign investment.	Influenced by recent economic reforms and market liberalization
SSEC	Distinct policies, capital controls	Market segmentation, government interventions	Strict controls limit foreign investment.	Gradual market liberalization and economic reforms
FTSE 100	Global economic ties, financial sector prominence	High liquidity and depth	Supports market integrity and investor protection	Influenced by Brexit and regulatory adjustments

Source: Author's Development

From a policy perspective, the insights into the long-term relationships and short-term dynamics among global stock markets are invaluable for developing effective regulatory frameworks and policy responses. Policymakers can leverage these findings to implement coordinated measures that mitigate cross-market contagion risks and enhance overall financial stability. By comprehending the transmission mechanisms of financial shocks, policymakers can proactively safeguard against systemic risks and foster resilient financial systems globally. This aligns with the conclusions of Shahrier (2022) and Stoupos & Kiohos (2022), who stressed the importance of understanding contagion effects for policy development. This study offers investors significant implications for portfolio management and diversification strategies. Understanding the interconnectedness of global markets enables investors to optimize risk-adjusted returns by strategically allocating investments across correlated markets. The findings underscore opportunities for capitalizing on market movements and managing portfolio risks through informed decision-making based on global market dynamics.

6. CONCLUSION

This paper investigates the interconnections among six major stock indices from January 2014 to January 2024. Our analysis aims to demonstrate long-term relationships and short-term dynamics and explore causality within these indices. To achieve these objectives, we employ robust methodologies, including Johansen cointegration, VECM, and Granger causality. Our rigorous approach guarantees the credibility of our results, providing valuable perspectives into global stock market dynamics. The Johansen cointegration analysis revealed substantial long-term relationships among the selected indices, indicating a shared long-term equilibrium. This underscores deep economic integration and market interdependencies across these regions, suggesting the influence of shared economic fundamentals, common global trends, and consistent investor behaviours that transcend national borders. The use of VECM provided additional information on the short-term dynamics of these financial variables. This detailed examination highlighted the resilience of positive cointegration observed within markets such as the CAC 40, DAX, and MASI.

Our study also examined the immediate adjustments of individual stock market variables in response to deviations from long-term equilibrium, as revealed by the alpha matrix. These adjustments offer a valuable understanding of market reactions to short-term shocks, enhancing our understanding of the mechanisms behind stock price movements. Identifying negative adjustments in specific markets, such as the CAC 40, DAX, and MASI, suggests a propensity to correct deviations from equilibrium, while positive adjustments indicate a return to equilibrium. The Granger causality analysis provided essential insights into the causal relationships between stock market indices, clarifying the direction and magnitude of interactions. These findings have direct implications for academics, practitioners, and policymakers navigating the complexities of the global financial landscape. For instance, our study represents a comprehensive global stock market dynamics analysis, offering valuable insights into significant stock market indices' long-term relationships and short-term dynamics. The observed cointegration patterns, deviation-from-equilibrium adjustments, and cause-and-effect relationships offer critical guidance for improving decision-making and risk management in the financial sector.

In conclusion, the findings of this study offer valuable perspectives for a deeper understanding of the interconnectedness of global stock markets. This understanding can facilitate more informed decision-making and effective risk management strategies, enhancing financial stability and efficiency. However, despite the valuable findings offered by our study, it is important to acknowledge its limitations. The analysis conducted in our study is limited to only six major stock indices, which may not provide a complete representation of the intricate nature of the global financial market. A more comprehensive understanding of global market dynamics could be achieved by including a wider range of indices. Additionally, while our study employs robust methodologies such as Johansen cointegration, VECM, and Granger causality, it is crucial to recognize that these techniques have inherent limitations. For instance, cointegration and causality tests can be sensitive to the specifications of the model used and may fail to capture non-linear relationships or structural breaks adequately.

7. DECLARATIONS

Funding: This research received no external funding.

Availability of Data and Material: The data that support the findings of this study were obtained from the Investing.com site and are available from the corresponding author upon reasonable request.

Competing Interests: The authors declare that they have no competing interests.

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