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Article

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The global financial crisis impact on stock market efficiency: a Fourier unit root tests analysis

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ABSTRACT

This study investigates how the Global Financial Crisis has affected the weak-form Efficient Market Hypothesis (EMH) on the stock prices of sixteen nations throughout the globe based on a suite of Fourier unit root tests. Considering the smooth structural breaks, we employed the Fourier-based unit root tests to assess the weak-form efficient market hypothesis. We used multiple frequency datasets of global financial stock market indexes that span over 20 years to have comprehensive analysis and robustness in the results. The study is performed from distinct sub-sample periods of the global financial crisis, including the pre-crisis period (2000–2007), the crisis and post-crisis period (2008–2020), and the overall sample period (2000–2020). We observed seven stock markets in the total sample period and twelve in the pre-crisis period, which were weak-form efficient across different frequency data sets. During the crisis and post-crisis period, just four out of sixteen stock market indexes were found to be weak in efficiency based on Fourier unit root tests. Given the superior properties of the Fourier unit root tests, this study reiterates that investors may receive a stream of arbitrage benefits in all markets due to the inefficiency of these countries. We offer investment implications that enable forecasting future stock price changes based on past performance and creating trading methods that produce anomalous profits.

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1. Introduction

Stable stock markets are essential for economic progress. Transferring funds from savers to investors via stock markets is crucial for efficient resource management (Malik & Malik, 2022). An inefficient market can negatively affect the economy, whereas an efficient market positively impacts economic growth (Shiguang, 2004). According to the Efficient Market Hypothesis (EMH), market prices properly represent all relevant information, which means that it is not viable to forecast the stock prices, and neither technical analysis nor fundamental analysis will help investors generate abnormal profits (Malkiel, 2003; Barone-Adesi and Sala, 2019). The weak form of EMH argues that current financial asset values include all available historical financial information at any given time and are labeled by the unit root (Lee et al., 2010). The serial correlation (SR) tests, unit root (UR) tests, and variance ratio (VR) tests¹ have been employed to scrutinize whether asset prices are characterized as a trend-stationary process or a random walk.

However, price level profits will degenerate according to their trend path (Chaudhuri & Wu, 2003) if asset values pursue a stationary trend series. With the help of historical data on market prices or stocks, future returns can also be assumed. Because stock values can fluctuate without bounds over time, the

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term 'random walk' refers to the inability to predict their movements. Even though Rehman et al. (2018) and others have previously studied this topic, are stock prices genuinely random? There is no agreement among experts because of the unclear outcomes in the literature.

This study aims to comprehensively examine the weak form of market efficiency across 16 major global equity markets, especially in the global financial crisis (GFC) context. Efficient markets are essential for economic progress and optimal resource allocation, and understanding their behavior during periods of economic turmoil is crucial for policymakers and investors. Traditional unit root tests often fail to capture the complexities of financial markets, particularly during structural breaks. By employing Fourier unit root tests, which can detect smooth structural breaks and non-linear patterns, this study aims to provide a more accurate analysis of market efficiency. This approach offers novel insights into the cyclical behaviors of stock markets and has significant implications for investment strategies and regulatory policies.

In this study, we inspect the effect of weak-form efficiency on stock index prices from 16 nations (Germany et al., Malaysia, South Korea, Brazil, Indonesia, Hong Kong, Singapore, Japan, Philippines, Russia, stock prices Taiwan, UK, and USA). Previous studies like Shaik (2017) have conducted random walk unit root tests on emerging Asian markets (such as India, China, Indonesia, Hong Kong, Malaysia, Pakistan, Philippines, Sri Lanka, Taiwan, and Thailand). Ammy-Driss and Garcin (2023) conducted efficiency tests on ten international stock indices across Europe, the US, Asia, and Australian regions. Raza et al. (2023) conducted informational efficiency tests in emerging Asian nations like China, Malaysia, and Pakistan. Said et al. (2024) performed time-varying informational efficiency for five emerging Asian nations: China, Pakistan, Turkey, India, and Malaysia. Kilic et al. (2023) performed efficient market hypothesis tests among cryptocurrencies. In this paper, we conduct a series of Fourier unit root tests using a comprehensive dataset of sixteen international stock market indices. The mentioned countries were chosen to provide a well-diversified range of economies based on their economic development stage, market size, and, most importantly, their exposure to global financial crises. Moreover, these countries have been selected to represent the world economy well. They are chosen because they are geographically diverse yet contribute significantly to the global economy.

Our study contributes to the academic literature by finding the effects of the global financial crisis on stock market efficiency based on the Fourier unit root test. As per the literature, the earlier studies checked the weak form of EMH in two to three nations or a different combination; however, to the best of our knowledge, this is the very first study that includes sixteen nation's stock indices and tests the market efficiency with the help of Fourier tests for a period of 2000–2022. Further, although few studies have used Fourier tests to assess market efficiency (e.g. Gümüş & Zeren, 2014; Wang et al., 2015), this paper varies in the subsequent facets. First, we employ Fourier unit root tests, which take into account the smooth structural breaks and do not require any related information on the amount or the dates of structural breaks, in contrast to most research, which either do not include structural breaks or use one/two structural breaks like conventional ADF unit root test (Dickey and Fuller, 1981), DF-GLS (Elliott et al., 1996) test, Ng-Perron (Perron, 1989) test. We focused our analysis on Fourier unit root tests due to their ability to capture frequency domain information and provide insights into the cyclical behavior of stock market efficiency. Our decision to employ Fourier unit root tests was motivated by the desire to explore the impact of the global financial crisis across different frequency bands, which complements the traditional time domain unit root tests. While we acknowledge the merits of the multiple breakpoint unit root tests like the Carrion-I-Silvestre et al. (2009) and VAR tests like Kim (2000), we believe that our chosen approach aligns more closely with the objectives of our study, which aims to examine the impact of the financial crisis on stock market efficiency through a frequency domain lens. This allows us to capture the cyclical nature of market dynamics and assess efficiency across different frequency bands, providing insights that traditional time domain tests like the VAR test may not capture. By employing Fourier-based methodologies, we aimed to leverage the advantages of frequency domain analysis to gain a deeper understanding of how efficiency evolves, particularly in the context of the global financial crisis.

Second, our analysis covered significant developed and developing economies spread across the globe and not specific to a particular region or classification. Third, the Fourier tests for the asset markets under investigation during separate sub-sample periods are also implemented to assess robustness.

We have divided the data into three segments, and analysis has been done accordingly. The three segments are (a) the pre-crisis (2000–2007) period, (b) the period of crisis and post-crisis (2008–2020), and (c) the entire sample period (2000–2020). The study period is essential to comprehending the impact of stock markets on the global financial meltdown 2008. The period from 1 January 2008, to 31 May 2009, was defined as ‘crisis period’ by the National Bureau of Economic Research². Hence, this study considers the crisis and post-crisis from 1 June 2008 to 2020. Similar periods are also taken in an earlier study by Kanvinde et al. (2020). Fourth, this study provides a comprehensive analysis based on a daily, weekly, and monthly timeframe, in contrast to other studies which deploy only monthly or annual time-series data.

The following paper is organized subsequently; [Section 2](#) examines the available narratives and literature about the world’s major stock exchanges on market efficiency. The data is described in [Section 3](#) of the report. [Section 4](#) elaborates on the study’s techniques, and [Section 5](#) discusses the experimental results. Section number 6 completes the paper with some closing observations.

2. Literature review

The EMH’s importance has been demonstrated throughout time by its stark empirical implications (Hamid et al., 2017; Poshakwale, 2002; Sánchez-Granero et al., 2020; Tığan, 2015). Perron (1989) states that a structural break can restrict the null hypothesis of UR test rejection if not considered. That is why it becomes essential to determine why structural breakdowns in stock price series are considered. During the research period, plenty of structural cracks in the stock market were witnessed because of significant public, monetary, and economic incidents. The 2001 terrorist outbreaks in New York, the 2003 SARS pandemic, the energy tremor caused by soaring oil prices in 2005, the 2007–08 financial crisis, the COVID-19 pandemic, and the Russian-Ukraine war, which had a massive influence on all stock indices around the world, are among the most notable events (Rabbani et al., 2022; Salisu & Shaik, 2022; Shaik, 2022; Shaik et al., 2023; 2023; Singh & Shaik, 2021). These events have rattled the global financial markets in several ways (Abdulla & Rabbani, 2021; Atif et al., 2022; Naeem et al., 2023). However, the above studies have not discussed how these events would impact the market efficiency of the assets under study. In this paper, we employ the Fourier unit root tests to understand the global financial crisis’s impact on the stock market efficiency.

Prior studies (e.g. Lumsdaine & Papell, 1997) utilized UR testing approaches to address the issue of structural breaks. According to Chancharat et al. (2009), a random walk is pursued by sizeable support from the Thai stock market. Similarly, South Korean stock values have a unit root, according to Narayan and Smyth (2005). Hamid et al. (2017) tested the weak form of EMH for every nation in the region and discovered that the monthly prices do not follow a random walk in the Asia-Pacific region. According to Ahmed et al. (2018), the mean deterioration of stock prices is supported by a Lagrange multiplier, generalized autoregressive conditional heteroskedasticity, and half-life volatility shock techniques in various emerging nations and developed countries.

Recently, Salih and Selcuk (2022) studied weak-form market efficiency for the thirteen Islamic market indices in Dow Jones and S&P between 2011 and 2021 and found that. In contrast, seven indices are stationary; six Islamic market indices have unit roots (Abdulla and Rabbani, 2021). This indicates that while market efficiency exists in all investigated emerging market indices, it does not exist in developed country indices. Moreover, Aktan et al. (2022) concluded that under the weak version of the EMH, the European Energy Market might be regarded as being inefficient overall. As a result, there is evidence of lucrative arbitrage opportunities between energy equities. Additionally, stationarity indicators point to the short-term consequences of shocks to energy reserves. Marsani et al. (2022) suggested that the Malaysian extreme stock return does not follow a random walk; only the series during the crisis and recovery periods exhibit weak-form market efficiency. Controlling nonlinearity and a few smooth breakdowns in an unknown functional form can be done using a Fourier function (Chang et al., 2014). We, therefore, apply these Fourier UR tests to investigate weak-form EMH in a set of sixteen nations. We anticipate more reliable outcomes from these further tests.

A substantial body of literature examines stock market efficiency during and after the global financial crisis. Lim et al. (2008) analyzed the market efficiency for Asian countries using rolling bivariate correlation test

statistics during pre, and post-crisis periods. Zhu et al. (2019) analyzed market efficiency using runs and variance ratio tests in Latin American markets. Other studies in the literature include the works of Mishra (2012), Paulo (2013), Amer et al. (2014), Al-Khazali and Mirzaei (2017), Shaik (2017), Malafeyev et al. (2019), etc. However, our study offers unique contributions by utilizing Fourier unit root tests to analyze stock market efficiency during and after the global financial crisis. Unlike previous studies, we focus specifically on the crisis period and include a diverse set of countries for cross-country comparisons. This approach provides a nuanced understanding of how market efficiency evolved during the crisis and offers valuable insights for policymakers, investors, and researchers.

3. Data description

This research is based on daily, weekly, and monthly stock market prices from key global stock indexes, including Australia, India, Argentina, Indonesia, Germany, Brazil, Hong Kong, Taiwan, Philippines, Japan, Malaysia, Russia, South Korea, Singapore, UK, and USA. The data were gathered from Bloomberg for three periods, from 1 January 2000, to 1 March 2020. Our dataset's daily, weekly, and monthly observations are 5092, 1052, and 242, respectively, for all 16 stock market indices. This illustration period is critical because of the change in the dynamics of the stock markets from early 2000, stricter laws, more transparency, and the advancement of technology where most trades (in the USA) are placed through algorithmic trading.

We present the summary statistics in Table 1. Panel A shows the findings daily, showing that the United Kingdom has the lowest mean returns while Argentina has the highest mean returns. Argentina has the lowest minimum returns, while the Philippines has the highest maximum returns. Panel B displays the findings weekly, where the lowest mean returns have been found in the United Kingdom, whereas Argentina has the highest mean returns. The most negligible volatile returns are in Australia, the US, and the UK, while the most erratic returns are in Germany, South Korea, and Brazil. Additionally, Panel C shows the results every month, where the lowest mean returns have been found in the United Kingdom, and Argentina has the highest mean returns. Argentina has been found to have the lowest minimum and the highest maximum returns, respectively. The UK, Malaysia, and Russia have the lowest return volatility, whereas South Korea, India, and Brazil have the highest volatility.

The Jarque-Bera statistic and associated p -values defy the null hypothesis that the market return distributions across different frequencies of the countries under observation are normally distributed. All stock market indexes are found to be negatively skewed and exhibit strong kurtosis values across the board, as shown in Table 1.

Additionally, Figure 1 shows the stock price timeline of 16 stock markets worldwide. We can see structural changes from the trends in the series that have been visualized. Furthermore, the image depicts the estimated time route. From this, we can conclude that it is reasonable to allow smooth structural breaks and that the Fourier approximation is reasonable. We further employ Fourier-based unit root tests on the log-level version of the price series data.

4. Methodology

Unit root analyses determine a series' stationarity. Perron (1989) states that these tests are more likely to accept the null hypothesis even if the progression includes structural discontinuities. As a result, a series of structural breakdowns ought to be considered.

A two-break minimum Lagrange multiplier (LM) test has been suggested by Lee and Strazicich (2003). They also gave the alternative hypothesis that the trend is stationary. Two additional tests explain two structural failures. The ZA test was developed by Zivot and Andrews (1992), and the LP test by Lumsdaine and Papell (1997). Since ZA and LP compute their critical values under the null hypothesis and assume no break, this presents a challenge. As a result, the alternative hypothesis shows that structural breakdowns happen even if the series maintains its unit root. The LM test was developed by Lee and Strazicich (2003), allowing breaks in null and alternative conditions and examining the occurrence of a unit root. Endogenous variables also influence the ideal number of breakpoints. Thus, in two structural failures, the LM test is valid.

Table 1. Descriptive statistics of significant global stock market index returns.

Panel A: Daily period							
	Mean	Maximum	Minimum	Std. Dev	Skewness	Kurtosis	Jarque-Bera
Argentina	0.0008	0.1612	−0.4769	0.0229	−1.9714	44.1783	351366.799***
Australia	0.0001	0.0563	−0.0870	0.0097	−0.5150	8.8028	7369.238***
Brazil	0.0004	0.1368	−0.1210	0.0175	−0.1291	6.9841	3311.431***
Germany	0.0001	0.1080	−0.0888	0.0146	−0.0704	7.6622	4635.863***
Hong Kong	0.0001	0.1341	−0.1358	0.0145	−0.1048	11.0715	13484.146***
India	0.0004	0.1599	−0.1181	0.0144	−0.1866	10.9970	13256.202***
Indonesia	0.0004	0.0762	−0.1131	0.0132	−0.6934	10.1875	10959.908***
Japan	0.0000	0.1323	−0.1211	0.0148	−0.4244	9.4764	8778.159***
South Korea	0.0001	0.1128	−0.1281	0.0148	−0.5981	10.0662	10614.718***
Malaysia	0.0001	0.0450	−0.0998	0.0080	−0.8303	13.6319	23882.692***
Philippines	0.0002	0.1618	−0.1309	0.0126	0.2614	18.0602	47649.272***
Russia	0.0005	0.2523	−0.2066	0.0198	−0.2470	19.4411	56827.311***
Singapore	0.0000	0.0753	−0.0910	0.0110	−0.3433	9.4033	8711.331***
Taiwan	0.0001	0.0652	−0.0994	0.0133	−0.2973	6.8761	3174.821***
UK	0.0000	0.0938	−0.0927	0.0116	−0.1694	9.4344	8787.654***
USA	0.0002	0.1051	−0.0820	0.0112	−0.1425	11.2533	14409.646***
Panel B: Weekly period							
	Mean	Maximum	Minimum	Std. Dev.	Skewness	Kurtosis	Jarque-Bera
Argentina	0.0040	0.2377	−0.3776	0.0506	−0.6482	8.9068	1598.471***
Australia	0.0007	0.0911	−0.1702	0.0206	−1.0169	9.3596	1952.305***
Brazil	0.0018	0.1684	−0.2232	0.0371	−0.4633	6.5464	588.344***
Germany	0.0005	0.1494	−0.2435	0.0315	−0.7096	8.4257	1377.368***
Hong Kong	0.0005	0.1172	−0.1782	0.0300	−0.2375	5.5001	283.608***
India	0.0019	0.1317	−0.1738	0.0303	−0.5702	6.5836	619.337***
Indonesia	0.0020	0.1159	−0.2330	0.0297	−0.8575	8.6068	1495.421***
Japan	0.0001	0.1145	−0.2788	0.0299	−1.1030	10.8893	2935.962***
South Korea	0.0007	0.1703	−0.2293	0.0321	−0.5704	8.5947	1426.359***
Malaysia	0.0006	0.1259	−0.1145	0.0186	−0.3533	8.4294	1312.779***
Philippines	0.0011	0.1618	−0.2015	0.0279	−0.2662	8.2237	1207.354***
Russia	0.0028	0.4009	−0.2777	0.0435	0.0974	13.1982	4534.501***
Singapore	0.0002	0.1532	−0.1647	0.0247	−0.4514	9.4536	1859.583***
Taiwan	0.0002	0.1832	−0.1308	0.0295	−0.3047	6.6449	590.665***
UK	0.0000	0.1258	−0.2363	0.0238	−1.1187	14.9649	6488.356***
USA	0.0008	0.1070	−0.2003	0.0236	−1.0899	11.4757	3357.138***
Panel C: Monthly period							
	Mean	Maximum	Minimum	Std. Dev.	Skewness	Kurtosis	Jarque-Bera
Argentina	0.0171	0.3967	−0.5360	0.1101	−0.5677	6.6443	146.305***
Australia	0.0031	0.0721	−0.1354	0.0363	−0.7932	3.7557	31.007***
Brazil	0.0077	0.1648	−0.2850	0.0695	−0.4167	3.7393	12.463***
Germany	0.0023	0.1937	−0.2933	0.0598	−0.9165	6.1825	135.444***
Hong Kong	0.0022	0.1576	−0.2545	0.0599	−0.5755	4.2480	28.945***
India	0.0083	0.2489	−0.2730	0.0640	−0.4787	4.9917	49.036***
Indonesia	0.0089	0.1834	−0.3772	0.0615	−1.1088	8.8240	389.987***
Japan	0.0003	0.1209	−0.2722	0.0559	−0.7730	4.5053	46.7524***
South Korea	0.0031	0.2025	−0.2631	0.0620	−0.4700	4.7204	38.593***
Malaysia	0.0020	0.1270	−0.1651	0.0398	−0.4724	4.8094	41.838***
Philippines	0.0051	0.1535	−0.2754	0.0570	−0.6305	5.3071	69.416***
Russia	0.0112	0.2852	−0.3393	0.0789	−0.5853	5.3242	68.003***
Singapore	0.0012	0.1930	−0.2736	0.0527	−1.0440	7.6120	257.368***
Taiwan	0.0006	0.2242	−0.2150	0.0614	−0.2118	4.8760	37.141***
UK	0.0002	0.0830	−0.1395	0.0387	−0.6720	3.8428	25.269***
USA	0.0035	0.1008	−0.1515	0.0411	−0.7103	4.2525	36.018***

Note. ***Means significant at a 1% level of significance. 'Std. Dev.' stands for standard deviation. The Jarque-Bera test has a null hypothesis of normality.

Rodrigues and Robert Taylor (2012) and Enders and Lee (2012) proposed a Flexible Fourier Form in response to the issue. This test has the benefit of evaluating many transitory smooth structural breakdowns (Yilanc & Eriş, 2013). As a result, the specification issue is modified to incorporate the correct frequency elements into the estimating equation rather than selecting specific break dates, the structure of the breaks, and the number of breaks.

Trigonometric expansion is used in Fourier UR tests that use approximation to examine the variation in the means. Rodrigues and Robert Taylor (2012) used the GLS-type regression from Elliott et al. (1996), and Enders and Lee (2012) used the LM-type regression equation from Schmidt and Phillips (1992). As a

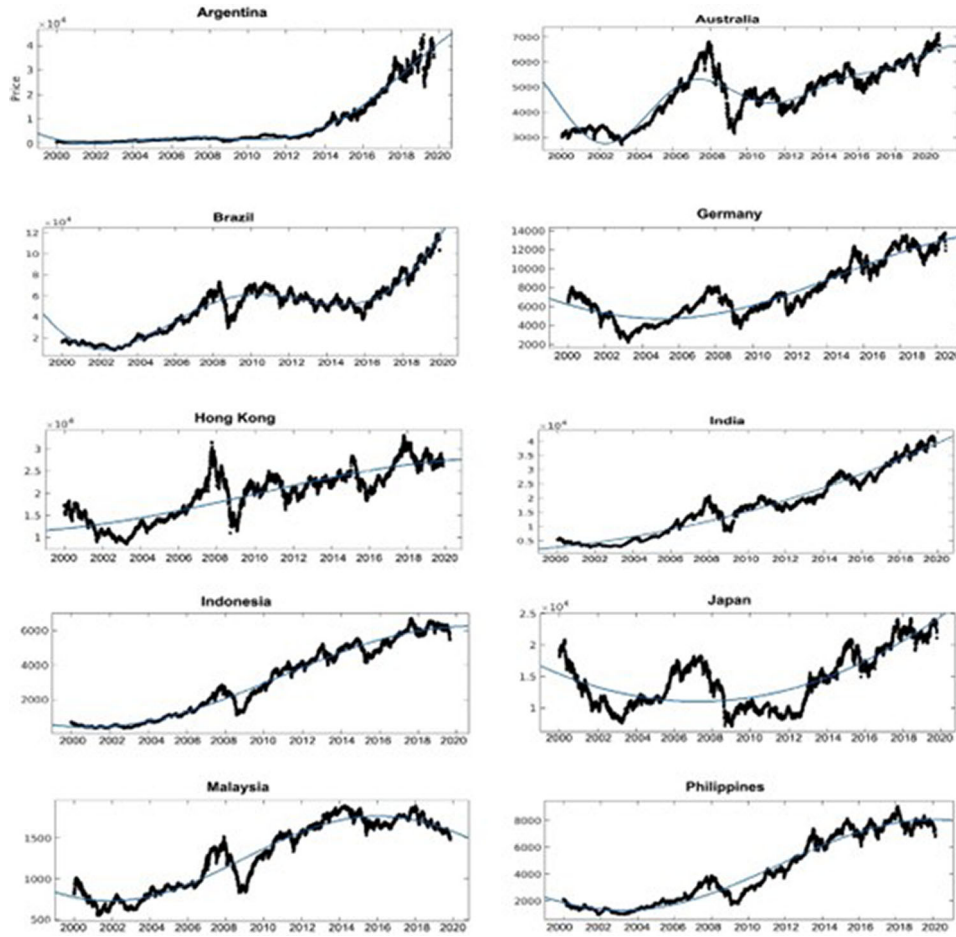


Figure 1. Daily stock market price series data of the 16 countries and related Fourier functions. *Note.* While the black lines represent the price series, the blue line represents the series changed into the Fourier function, and thus, the forms are applied to the analysis. Moreover, the horizontal and vertical sections represent the year and price values, respectively.

result, these tests are referred to as Fourier GLS and Fourier LM unit root tests, respectively. The Dickey-Fuller variant, as per the Fourier UR test, is functional when many breakpoints are not defined non-linearly.

A DF-type UR regression may be expressed in the form of Equation (1) with deterministic terms, $d(t)$ [as a time-dependent function]:

$$y_t = d(t) + \rho y_{t-1} + \gamma t + \varepsilon_t \quad (1)$$

Where $d(t)$ is a deterministic function of t and ε_t is a stationary disturbance. With the help of Equation (1) you can test the unit root's null hypothesis ($=1$) on the presumption that t is inadequately dependent if you know the functional form of $d(t)$. On the other hand, in the case of an unknown and ambiguous functional form of $d(t)$, the null hypothesis cannot be tested. Rodrigues and Robert Taylor (2012) and Enders and Lee (2012) suggest that the Fourier expansion method be used to estimate $d(t)$ as shown in Equation (2).

$$d(t) = \alpha_0 + \sum_{k=1}^n \alpha_k \sin\left(\frac{2\pi kt}{T}\right) + \sum_{k=1}^n \beta_k \cos\left(\frac{2\pi kt}{T}\right), n \leq \frac{T}{2} \quad (2)$$

Where n refers to the figure of frequencies in the approximation, T represents the total number of observations considered, and k represents a particular frequency.

If all $\alpha_k = \beta_k = 0$, if there is no nonlinear trend, conventional unit root tests are suitable. Nevertheless, if a nonlinear trend or break exists, the data-generating procedure must include at least one Fourier frequency, as per the suggestions given by Enders and Lee (2012).

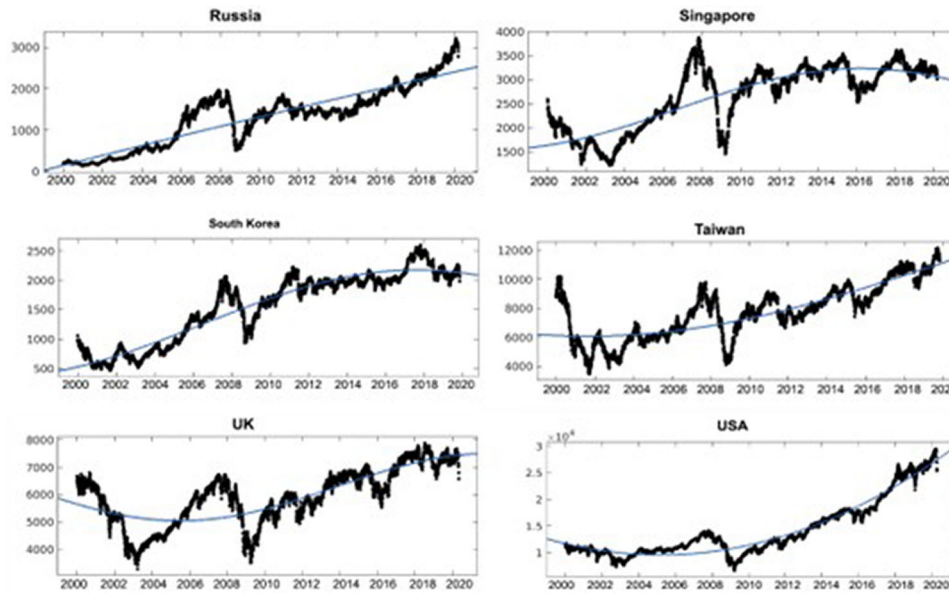


Figure 1. Continued.

$$\Delta y_t = \emptyset \tilde{S}_{t-1} + d_0 + d_1 \Delta \sin(2\pi kt/T) + d_2 \Delta \cos(2\pi kt/T) + \varepsilon_t \quad (3)$$

Here \tilde{S}_t is the detrended series³.

In the case of y_t being non-stationary, \emptyset must be zero. Therefore, for the Fourier LM test, \emptyset the null hypothesis equals 0. Enders and Lee (2012) apply Equation (4) using the DF process, which resembles the LM test regarding its asymptotic properties.

$$\Delta y_t = \rho y_{t-1} + c_1 + c_2 t + c_3 \sin(2\pi kt/T) + c_4 \cos(2\pi kt/T) + \varepsilon_t \quad (4)$$

The essential point to remember is that critical values are affected by the number of steps in Fourier and the number of observations. The unit root of the series is implied by the null hypothesis, which stipulates that it is $\rho = 0$. The de-trending technique given by Elliott et al. (1996) and used by Rodrigues and Taylor is based on GLS-type regression (1996).

$$y_t = c_0 + c_1 t + c_2 \sin\left(\frac{2\pi kt}{T}\right) + c_3 \cos\left(\frac{2\pi kt}{T}\right) + x_t, t = 1, \dots, T \quad (5)$$

$$x_t = \phi x_{t-1} + u_t$$

Rodrigues and Robert Taylor (2012) use Equation (5) to determine if ϕ must be equal to 1 under the null hypothesis. This also denotes a unit root in the series. Becker et al. (2006) argued that for a Fourier function, a stationary test necessitates a minimal alteration to the standard KPSS statistic because the Data Generating Process outlined above corresponds to the one used to generate the regular KPSS test. To begin, solve the following equations to obtain the residuals:

$$y_t = \alpha_0 + \gamma_1 \sin(2\pi kt/T) + \gamma_2 \cos(2\pi kt/T) + v_t \quad (6)$$

$$y_t = \alpha_0 + \beta t + \gamma_1 \sin(2\pi kt/T) + \gamma_2 \cos(2\pi kt/T) + v_t \quad (7)$$

Equation (6) tests the null assumption of level stationarity, whereas Equation (7) tests trend stationarity. The test statistic is as follows.

$$\tau_{KPSS}(k) = \frac{1}{T^2} \frac{\sum_{t=1}^T \hat{S}_t^2}{\hat{\sigma}^2} \quad (8)$$

Where, $\hat{S}_t = \sum_{j=1}^t \hat{v}_j$ and \hat{v}_j are the OLS residuals from regressions (Equations (6) and (7)), respectively. In the next section, each test is used to the price data set of the stock indices.

Table 2. Results of Fourier KPSS unit root test during different sub-sample periods.

	Panel A: Overall sample period (2000–2020)			Panel B: Pre-crisis period (2000–2007)			Panel C: Crisis & post-crisis period (2008–2020)		
	Daily	Weekly	Monthly	Daily	Weekly	Monthly	Daily	Weekly	Monthly
Argentina	17.9507***	3.8732***	0.8325***	5.2076***	1.0143***	0.1954***	2.5288***	0.5703***	0.1101***
Australia	10.5852***	2.1686***	0.5405***	2.326***	0.3177***	0.0809***	13.2808***	2.196***	0.2107***
Brazil	34.6127***	7.2875***	1.7371***	7.015***	1.4107***	0.2935***	2.7178***	0.4957***	0.0711**
Germany	14.0785***	2.7528***	0.5628***	4.5852***	0.6399***	0.1005***	3.1571***	0.5704***	0.0961***
Hong Kong	9.3437***	1.942***	0.4438***	7.3788***	1.3661***	0.2276***	7.9505***	1.4122***	0.1547**
India	40.7574***	8.3628***	1.921***	6.1107***	1.2208***	0.2503***	4.6736***	0.9392***	0.1793***
Indonesia	5.7329***	1.222***	0.27***	7.4004***	1.5577***	0.3544***	4.5455***	0.9478***	0.1892***
Japan	14.7391***	3.0158***	0.6333***	3.863***	0.4679***	0.0434	5.9982***	1.1508***	0.1986***
South Korea	6.3186***	1.3192***	0.2774***	3.7945***	0.7174***	0.1104***	10.9429***	2.1299***	0.5603***
Malaysia	6.7785***	1.3675***	0.2875***	7.5586***	1.3789***	0.1992***	4.7873***	0.8593***	0.1264***
Philippines	11.8635***	2.4207***	0.5648***	6.8722***	1.2289***	0.2109***	2.8868***	0.5657***	0.0993***
Russia	9.7604***	2.9262***	0.4869***	6.1492***	1.2796***	0.2913***	3.778***	0.7277***	0.1357***
Singapore	34.27***	7.1205***	0.3293***	6.6553***	1.103***	0.1555***	13.123***	2.6519***	0.1035***
Taiwan	13.9244***	2.7878***	0.4524***	7.1641***	1.2426***	0.1609***	7.2947***	1.198***	0.1371*
UK	37.1806***	6.9397***	1.0868***	2.2015***	0.2944***	0.0913***	6.9866***	0.6948***	0.0836***
USA	10.5103***	2.0652***	0.3838***	5.1359***	0.7031***	0.113***	8.6525***	1.5989***	0.2405***

Note. ***, **, *Means significant at 1, 5, 10% level of significance.

5. Empirical results & discussion

We examine the weak-form EMH on the stock prices of sixteen countries spread globally using a battery of Fourier unit root tests that allow smooth structural breaks developed by Becker et al. (2006) and Rodrigues and Robert Taylor (2012). We further investigate the Fourier unit root results' robustness by conducting empirical testing throughout various sub-sample periods and for different frequency time series, namely daily, weekly, and monthly. Previous studies (Shaik, 2022; Shaik & Gulhane, 2021) show that different time frequencies of the same data set generate different results based on statistical tests like normality and stationarity tests.

5.1. KPSS Fourier unit root test

The null hypothesis of stationarity, according to the Fourier KPSS test suggested by Becker et al. (2006), is rejected for all the nations' monthly, weekly, and daily stock market index price data in all three sample periods, i.e. pre-crisis period, post-crisis period and overall study period as shown in Table 2. As a result, all global stock markets corroborate the Weak Form-EMH across different sub-sample periods and frequencies. A time series might be non-stationary and trend-stationary without a unit root; thus, this finding is inconclusive in all cases. The mean can increase or decrease in unit root and trend-stationary systems with time. According to Lee et al. (2010), stationarity tests indicate size distortions rather than a loss of power in the null. The genuine stationarity null hypothesis is overruled in support of the false unit root hypothesis. Therefore, the nonlinear tendencies in stationary testing must be taken into consideration.

5.2. LM Fourier unit root test

We observe three stock market indices (Argentina, India, and Taiwan) are weak or inefficient in daily price series data, three indices (Japan, South Korea, and Taiwan) are weak or inefficient in weekly price series data, and four indices (Germany, Hong Kong, India, and Indonesia) are weak or inefficient in monthly price series data based on LM Fourier unit root test as displayed in Panel A of Table 3. Panel B and Panel C illustrate the outcomes intended for the pre-crisis era (2000–2007) and the crisis and post-crisis (2008–2020). Using daily stock price series data, we can see that six stock market indexes (Argentina, Germany, India, Japan, South Korea, and the United States) that were weak from efficient prior to the crisis are now reverting through crisis and post-crisis. After the global financial crisis, six stock indexes (Argentina, Germany, the Philippines, Russia, the United Kingdom, and the United States) have changed from poor form efficiency to mean-reverting behavior, according to weekly stock price series data. However, Malaysian and Taiwanese stock indexes have grown inefficient during the period of crisis and post-crisis. Similarly, using monthly price series data, we can see that Japan's stock index

Table 3. Results of Fourier LM unit root test during different sub-sample periods.

	Panel A: Overall sample period (2000–2020)			Panel B: Pre-crisis period (2000–2007)			Panel C: Crisis & post-crisis period (2008–2020)		
	Daily	Weekly	Monthly	Daily	Weekly	Monthly	Daily	Weekly	Monthly
Argentina	−4.74***	−2.6361	−1.1456	−3.3248	−3.0245	−3.0277	−6.167***	−4.693***	−2.4857
Australia	−2.3565	−3.086	−3.0784	−1.0074	−0.8248	−0.7925	−3.0973	−2.8838	−1.3766
Brazil	−2.9949	−2.2425	−2.9886	−2.7558	−2.8223	−2.8624	−3.1921	−3.5858	−2.0434
Germany	−2.7523	−3.0838	−3.3277*	−1.3826	−1.7184	−3.443**	−4.216***	−3.0858*	−1.1689
Hong Kong	−3.0386	−3.4893	−4.17**	−2.2236	−2.7997	−3.6792	−2.4258	−2.2315	−0.6905
India	−3.401*	−3.1941	−3.824*	−3.582	−4.0404*	−2.2813	−3.4727**	−3.0032*	−2.5276
Indonesia	−3.3995	−3.6618	−4.087**	−3.6528	−2.3207	−2.2011	−2.6994	−3.3011	−2.497
Japan	−2.8084	−3.7942*	−3.1868	−1.3927	−4.617***	−2.7312	−3.0186*	−3.9111**	−3.2499*
South Korea	−3.7476	−4.312**	−2.0518	−3.7321	−2.9574	−3.9909*	−3.9774*	−1.0591	0.1164
Malaysia	−2.3432	−2.4303	−2.865	−3.3993	−4.0213*	−3.3406	−2.6113	−1.7431	1.5464
Philippines	−2.9352	−2.9675	−3.2318	−3.801*	−2.8334	−3.7923**	−3.705	−3.8119*	−4.0389*
Russia	−3.0281	−3.2607	−3.6214	−3.2167	−2.6977	−3.9373*	−3.6475	−3.8598*	−1.1843
Singapore	−2.9479	−3.4932	−3.6784	−2.457	−2.5153	−2.8415	−2.4596	−2.6479	0.3735
Taiwan	−4.027*	−5.16***	−3.57	−2.6202	−4.0033*	−3.1629	−2.1674	−3.1986	−0.3386
UK	−1.6579	−1.4499	−2.7428	−0.6631	−0.4041	−3.4487**	−2.3044	−4.1884**	0.4202
USA	−3.2505	−2.8077	−3.3632	−2.3777	−2.3789	−3.4861**	−3.1618*	−3.3596**	−2.578

Note. ***, **, *Means significant at 1, 5, 10 level of significance.

shifted from being weak to efficient before the crisis to mean reversion from 2008 to 2020. The stock indices of Germany, South Korea, Russia, the United Kingdom, and the US exhibit the opposite trend. Overall, we find that owing to the global financial crisis, seven stock indices daily data, eight stock indices weekly data, and six stock indices monthly price series data influence stock market efficiency.

Like the Fourier KPSS test, the Fourier LM test has significant drawbacks. Although the LMUR test with Fourier estimate has sufficient power and time frame for the sorts of breaks commonly employed in economic research, after adding more frequency components to the equation, it has been analyzed that the test's power rapidly diminishes. Moreover, this happens when the estimating equation contains a prominent figure of frequency components.

5.3. GLS Fourier unit root test

We find that seven stock market indices (Argentina, India, Japan, South Korea, Taiwan, UK, and the USA) in daily price series data, seven indices (Germany, Hong Kong, India, Indonesia, Japan, Taiwan, and the UK) in weekly price series data, and seven indices (Germany, Hongkong, India, Indonesia, Japan, Singapore, and the USA) in monthly price series data are weak form inefficient during the overall sample period (2000–2020). Furthermore, Panel B and Panel C highlight the outcomes for the period of pre-crisis from 2000 to 2007 and the phases of crisis and post-crisis from 2008 to 2020. In the daily stock price series data, four stock market indices (Argentina, Brazil, Hong Kong, and Russia) highlighted that the weak form is efficient throughout the pre-crisis period and mean reverting throughout the crisis and post-crisis period. In the weekly stock price series data, we observe that five stock indices (Argentina, Brazil, Russia, Singapore, and the USA) have shifted from weak form efficiency to mean reversion after the financial meltdown. At the same time, 4 stock indices (Germany, Hong Kong, Malaysia, and the Philippines) have become weak from efficiency during the crisis and post-crisis periods. Similarly, in the case of monthly price series data, we observe less impact of the global financial crisis on monthly price series data based on this test. Based on Fourier GLSUR test results, our study shows that five stock indices daily data, nine stock indices weekly data, and three stock indices monthly price series data have an impact on the efficiency of the stock market because of the global financial crisis.

Although local GLS detrending can produce unit root tests with good power properties and sample size when equated to Enders and Lee (2012)'s OLS and FD detrended tests, their limit null distributions are unknown, and this detrending method can result in momentous power loss in case of sizeable primary value. These may be the test's primary flaws; thus, the researchers employ the Fourier ADF test instead (Table 4).

5.4. ADF Fourier unit root test

The Dickey-Fuller variant, as per the Fourier UR test, is functional when many breakpoints are not defined non-linearly. The small number of parameters in this test avoids the loss of power if the drive

Table 4. Results of Fourier GLS unit root test during different sub-sample periods.

	Panel A: Overall sample period (2000–2020)			Panel B: Pre-crisis period (2000–2007)			Panel C: Crisis & post-crisis period (2008–2020)		
	Daily	Weekly	Monthly	Daily	Weekly	Monthly	Daily	Weekly	Monthly
Argentina	−4.204**	−2.4064	−1.4921	−3.3338	−3.2753	−3.3134	−6.342***	−5.049***	−3.0155
Australia	−3.0071	−2.2071	−3.405	−3.7071*	−2.9361*	−2.8145	−5.097***	−5.206***	−2.6748
Brazil	−2.2221	−2.3433	−2.5647	−3.0287	−3.0229	−2.8095	−3.896*	−3.9175**	−2.8141
Germany	−3.1039	−3.6038**	−3.600**	−3.8868*	−3.8828*	−3.0256	−3.8519*	−3.632	−1.628
Hong Kong	−3.3117	−3.6956*	−4.340**	−3.3414	−3.6943*	−3.6587	−3.8612*	−3.2439	−1.3165
India	−3.455**	−3.2272*	−3.646**	−3.6703*	−4.0323**	−2.8865	−4.044***	−3.4543**	−2.6161
Indonesia	−3.5362	−3.7776*	−4.235**	−3.3597	−1.2304	−2.5116	−3.4345	−3.3179	−2.3574
Japan	−3.506**	−4.319***	−3.608**	−4.467***	−4.1149	−1.9783	−3.5485**	−2.5557	−3.1164*
South Korea	−3.8452*	−3.2027	−2.1607	−4.525***	−2.8714	−4.6799**	−2.0334	−2.9196	−1.677
Malaysia	−3.2768	−3.3859	−3.5307	−4.801***	−4.665***	−3.2232	−4.982***	−3.2249	−1.279
Philippines	−2.9057	−2.8535	−3.1	−4.739***	−4.2394**	−3.3417	−3.7258*	−3.4909	−0.9207
Russia	−2.9201	−3.072	−3.4016	−3.2484	−2.7082	−3.9867*	−4.2687**	−4.1703**	−2.9053
Singapore	−3.5632	−2.4772	−3.8792*	−4.2069**	−2.2738	−2.9092	−3.9301**	−3.6852*	−2.0335
Taiwan	−4.71***	−5.462***	−3.7418	−4.3317**	−4.719***	−3.3015	−4.1189**	−4.0202**	−0.9693
UK	−3.8*	−3.8249*	−3.6326	−4.203***	−3.3967	−2.8928	−4.0867**	−2.2649	−0.9031
USA	−3.7103*	−3.5209	−3.7989*	−4.4428**	−2.9632	−2.4965	−4.0531**	−4.277**	−2.0986

Note. ***, **, * Means significant at 1, 5, 10% level of significance.

Table 5. Results of Fourier ADF unit root tests.

	Panel A: Overall sample period (2000–2020)			Panel B: Pre-crisis period (2000–2007)			Panel C: Crisis & post-crisis period (2008–2020)		
	Daily	Weekly	Monthly	Daily	Weekly	Monthly	Daily	Weekly	Monthly
Argentina	−5.400***	−3.6678	−2.6804	−3.9031	−3.3093	−2.4516	−6.3975***	−5.2105***	−3.4857
Australia	−2.7271	−6.48***	−3.7024*	−4.568**	−3.5886	−3.3322	−4.1097**	−3.7195*	−6.596***
Brazil	−2.9704	−2.9305	−3.031	−0.8458	−1.8103	−0.8738	−3.7958	−4.5941**	−4.8942**
Germany	−3.115	−2.9754	−3.1924	−2.9047	−3.0234	−1.9279	−8.5364***	−3.9994	−4.4174**
Hong Kong	−3.4555	−3.8563*	−4.3862**	−2.0081	−2.5143	−0.4485	−3.9207**	−4.1893**	−3.6616*
India	−3.5675	−3.4048	−3.9494	−1.5288	−1.7808	1.5339	−4.1967**	−3.5602*	−4.4314**
Indonesia	−3.4461	−3.6965	−4.1309*	−1.5427	−0.6511	1.6603	−2.2031	−3.3682	−1.6824
Japan	−2.6211	−3.1217	−2.8507	−3.7225	−3.9877	−3.502	−3.3042	−3.5242	−3.3385
South Korea	−3.7792	−4.85***	−2.1523	−3.3534	−2.0879	−5.593***	−10.535***	−3.1694	−2.224
Malaysia	−3.1802	−3.1724	−4.2508*	−2.3397	−2.5657	−2.4126	−3.5356	−3.0656	−0.8872
Philippines	−2.9757	−3.0114	−3.2592	−3.8202	−1.2196	−1.5099	−4.1217*	−4.3088**	−4.987***
Russia	−3.1287	−3.403	−3.8278	−3.1381	−2.6312	−3.9887	−3.7545	−4.2831**	−1.464
Singapore	−3.1493	−5.89***	−4.0925*	−3.0535	−1.8155	−2.8573	−3.1577	−3.2469	−2.7369
Taiwan	−3.987**	−5.58***	−4.952***	−2.6959	−4.040*	−3.7933	−3.398	−4.5676***	−2.8296
UK	−3.336	−2.9027	−3.8873*	−4.521**	−3.8595	−3.7139	−3.9596**	−11.705***	−2.2348
USA	−3.8684	−3.1629	−3.8531	−3.6386	−2.976	−1.9872	−3.7936	−3.6372*	−2.7299

Note. ***, **, * means significant at 1, 5, 10% level of significance.

root test contains too many dummy variables. This test can be used with Enders and Lee's version of LM (2012) or Rodrigues and Taylor's version of DFGLS (2012). In particular, the DF type of the Fourier test is resistant to high initial values.

We find that two stock market indices (Argentina and Taiwan) in daily price series data, five indices (Australia, Hong Kong, South Korea, Singapore, and Taiwan) in weekly price series data, and six indices (Australia, Hong Kong, Indonesia, Malaysia, Singapore, Taiwan and the UK) in monthly price series data are mean reverting during the entire sample period based on ADF Fourier unit root test put forth by Enders and Lee (2012) as shown in Panel A of Table 5. Panel B & Panel C show the outcomes for pre-crisis from 2000 to 2007 and crisis and post-crisis from 2008 to 2020. In the case of daily stock price series data, we observe that six stock market indices (Argentina, Germany, Hong Kong, India, South Korea, and the Philippines), which were weak from efficient during the pre-crisis period, have resulted in mean revert throughout the phase of crisis & post-crisis. In the weekly stock price series data, we observe that eight stock indices (Argentina, Australia, Brazil, Hong Kong, India, Philippines, Russia, and the UK) have shifted from weak form efficiency to mean reversion after the global financial crisis. Similarly, in the case of monthly price series data, we observe that six stock indices (Australia, Brazil, Germany, Hong Kong, India, and the Philippines) have changed from weak to efficient during the pre-crisis period to mean reversion from 2008 to 2020. In contrast, the stock indices of South Korea show the opposite behavior. Overall, based on Fourier ADF UR test results, it has been analyzed that six stock indices daily data, eight stock indices weekly data, and seven stock indices monthly price series data have an impact on the

Table 6. Summary of the Fourier unit root tests.

		Fourier KPSS									Fourier LM									GLS Fourier									Fourier ADF											
		OVE			PRE			CPC			OVE			PRE			CPC			OVE			PRE			CPC			OVE			PRE			CPC					
		D	W	M	D	W	M	D	W	M	D	W	M	D	W	M	D	W	M	D	W	M	D	W	M	D	W	M	D	W	M	D	W	M						
DEVELOPED MARKETS																																								
1	Australia	Y	Y	Y	Y	Y	Y	Y	Y	Y																														
2	Germany	Y	Y	Y	Y	Y	Y	Y	Y	Y				Y			Y	Y	Y				Y	Y	Y	Y														
3	Hongkong	Y	Y	Y	Y	Y	Y	Y	Y	Y				Y									Y	Y		Y														
4	Japan	Y	Y	Y	Y	Y	Y	Y	Y	Y				Y			Y		Y	Y	Y	Y	Y		Y															
5	Singapore	Y	Y	Y	Y	Y	Y	Y	Y	Y													Y	Y		Y		Y												
6	UK	Y	Y	Y	Y	Y	Y	Y	Y	Y							Y		Y		Y	Y		Y	Y															
7	USA	Y	Y	Y	Y	Y	Y	Y	Y	Y							Y	Y	Y		Y	Y		Y	Y															
Emerging markets																																								
8	Argentina	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y																													
9	Brazil	Y	Y	Y	Y	Y	Y	Y	Y	Y							Y	Y																						
10	India	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y				Y		Y		Y	Y		Y	Y	Y	Y															
11	Indonesia	Y	Y	Y	Y	Y	Y	Y	Y	Y				Y																										
12	Malaysia	Y	Y	Y	Y	Y	Y	Y	Y	Y							Y																							
13	Philippines	Y	Y	Y	Y	Y	Y	Y	Y	Y				Y			Y		Y	Y																				
14	Russia	Y	Y	Y	Y	Y	Y	Y	Y	Y							Y		Y																					
15	South Korea	Y	Y	Y	Y	Y	Y	Y	Y	Y							Y	Y																						
16	Taiwan	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y					Y																							

Note. 'Y' indicates that the market is weak form efficient, and the empty cell indicates that the series is not weak form efficient. Based on the MSCI report, we have classified the data into developed and emerging nations.

Table 7. Results of the traditional unit root tests.

		KPSS			PP			ADF		
		D	W	M	D	W	M	D	W	M
1	Australia	0.050	0.057	0.053	−5009.00*	−1097.44*	−241.79*	−17.40*	−9.60*	−5.12*
2	Germany	0.100	0.094	0.082	−4349.27*	−1066.77*	−231.64*	−15.09*	−9.87*	−5.61*
3	Hongkong	0.080	0.071	0.078	−4561.73*	−1231.70*	−209.95*	−15.51*	−10.30*	−5.82*
4	Japan	0.180	0.200	0.198	−5176.78*	−1089.77*	−234.91*	−17.32*	−10.29*	−5.52*
5	Singapore	0.090	0.100	0.100	−4830.22*	−1051.87*	−248.04*	−17.87*	−10.91*	−5.09*
6	UK	0.150	0.151	0.159	−4947.44*	−1088.56*	−224.93*	−16.87*	−10.03*	−5.61*
7	USA	0.070	0.049	0.050	−4809.84*	−1111.95*	−215.40*	−16.21*	−10.23*	−5.95*
8	Argentina	0.160	0.170	0.130	−4644.59*	−983.47*	−191.44*	−17.05*	−10.12*	−6.17*
9	Brazil	0.190	0.160	0.130	−4197.63*	−1232.06*	−191.95*	−15.52*	−9.04*	−5.38*
10	India	0.130	0.119	0.120	−4307.82*	−1019.98*	−221.06*	−16.50*	−9.53*	−4.84*
11	Indonesia	0.090	0.080	0.070	−4578.02*	−1142.48*	−246.04*	−16.31*	−9.82*	−6.14*
12	Malaysia	0.110	0.090	0.110	−5042.19*	−1073.63*	−212.98*	−16.21*	−10.48*	−6.00*
13	Philippines	0.250	0.230	0.250	−4930.83*	−1069.96*	−221.45*	−16.26*	−9.58*	−5.60*
14	Russia	0.190	0.160	0.140	−4186.19*	−1168.11*	−233.84*	−15.43*	−9.15*	−5.40*
15	South Korea	0.090	0.070	0.050	−5001.11*	−1033.29*	−237.68*	−16.14*	−9.16*	−5.63*
16	Taiwan	0.130	0.120	0.130	−4696.75*	−1151.09*	−227.76*	−15.63*	−8.10*	−6.27*

Note. 'D, W, M' signify the daily, weekly, and monthly datasets for the overall sample period considered in this study.

*Signify the level of significance at 5%.

stock market efficiency because of the global financial crisis. In the pre-crisis period, 12 countries confirmed the weak-form EMH, whereas only four countries confirmed this post-crisis. This indicates the global financial crisis's profound impact on the international stock markets.

Table 6 summarizes the four Fourier unit root tests employed in this study by classifying the stock markets into developed and emerging nations based on the MSCI report⁴. By examining the findings separately for each cluster of countries, we aim to discern whether significant differences exist in the relationship between weak-form efficiency and stock prices across different market segments. This approach will enhance the robustness and generalizability of our results, providing valuable insights for investors, policymakers, and researchers interested in understanding the dynamics of stock market efficiency. There are several reasons why differences in results exist between different countries within developed and emerging markets. Firstly, the level of market maturity and efficiency infrastructure varies between countries within each cluster, potentially influencing the degree to which weak-form efficiency impacts stock prices. Secondly, differences in investor behavior, regulatory environments, and market microstructure could also contribute to divergent outcomes between countries within developed and emerging markets.

Further, we conducted conventional unit root statistical tests on the 16 international stock indices considered in this study. Clearly, the results from Table 7 show that the daily returns of all the global indices are unit root stationary based on the ADF (Dickey and Fuller, 1981), PP (Phillips & Perron, 1988), and KPSS (Kwiatkowski et al., 1992) tests for the overall sample period. However, it is essential to understand that the traditional unit root tests assume a linear data structure and are limited in their flexibility to accommodate complex data structures, often leading to incorrect inferences about the presence of unit roots. They may have lower power in the presence of structural breaks or non-linearities, resulting in a higher likelihood of Type-II errors. At the same time, the Fourier unit root tests employed in this study offer significant advantages by effectively handling structural breaks and non-linearities, providing greater flexibility, and improving the results' accuracy and reliability, unlike traditional unit root tests. These benefits make Fourier Unit Root Tests particularly valuable for analyzing financial time series data, especially in significant economic events like the Global Financial Crisis and the COVID-19 pandemic (Raza et al., 2023).

6. Conclusion

This empirical study investigates the weak form of market efficiency across 16 major global equity markets using Fourier-based unit root tests, particularly in the context of the Global Financial Crisis. The study uses daily, weekly, and monthly datasets to determine whether these equity markets follow a random walk pattern individually.

Key findings include the rejection of the null hypothesis of stationarity for most countries' daily, weekly, and monthly data across all sample periods using the Fourier KPSS test. The Fourier LM test indicates that the GFC impacted the efficiency of stock markets in seven indices' daily data, eight indices' weekly data, and six indices' monthly data. Similarly, due to the GFC, the Fourier GLS UR test impacts five indices' daily data, nine indices' weekly data, and three indices' monthly data. The Fourier ADF test reveals that the GFC affected six indices' daily data, eight indices' weekly data, and seven indices' monthly data. Notably, twelve countries demonstrated weak-form EMH before the crisis, while only four did during and after the crisis.

Overall, the study found seven stock markets were weak-form efficient over the entire sample period, and twelve were efficient before the crisis. However, only four markets remained efficient during and after the crisis. This suggests that stock indices might have been mean-reverting during and post-crisis, aligning with previous studies on BRICS nations. The study revisits the random walk behavior in global stock market indexes, expanding on previous research limited to specific regions and periods. It concludes that investors might benefit from arbitrage opportunities due to information inefficiencies in markets where EMH is rejected during different sub-sample periods. This finding underscores the need for robust regulatory oversight to enhance information efficiency, especially during financial crises.

The results are crucial for policymakers and investors. Market efficiency affects market development and trading strategies, as stock prices in a weakly efficient market follow random walks, making future price predictions based on historical data challenging. The study offers investment implications, suggesting that forecasting future stock price changes based on past performance could lead to trading strategies yielding abnormal profits.

Future research could be extended to other assets like commodities, precious metals, and cryptocurrencies and cover recent crisis periods like the COVID-19 pandemic and the Russian-Ukraine war periods. While the study focuses on Fourier unit root tests for stock market efficiency, it does not directly assess market efficiency regarding price fairness or systematic profit-making strategies. Instead, it examines stock price behavior over time, emphasizing the influence of external factors and structural changes associated with the GFC. The study's limitations include data constraints and the diverse nature of global markets, which may affect generalizability. Future research could incorporate additional factors such as trading volume and liquidity, compare different methodologies, and explore dynamic efficiency over time. Addressing these limitations and exploring suggested avenues could enhance understanding market efficiency's implications.

Notes

1. Previous literature includes the works of Worthington and Higgs (2004); Mishra (2012); Paulo (2013); Amer et al. (2014); Afego (2015); Alam et al. (2016), Al-Khazali and Mirzaei (2017), Shaik (2017); Shaik & Maheswaran, (2017b, 2019, 2020), Mehmet (2019), Malafeyev et al. (2019), Kanvinde and Shaik (2020) etc.
2. https://www.nber.org/system/files/working_papers/w16589/w16589.pdf.
3. According to Enders and Lee (2012), LM principle is employed to estimate the following regression $\Delta y_t = \delta_0 + \delta_1 \Delta \sin(2\pi kt/T) + \delta_2 \Delta \cos(2\pi kt/T) + u_t$. Further, a detrended series is constructed as $\tilde{S}_t = y_t - \tilde{\psi} - \tilde{\delta}_0 t - \tilde{\delta}_1 \sin\left(\frac{2\pi kt}{T}\right) - \tilde{\delta}_2 \cos\left(\frac{2\pi kt}{T}\right)$, $t = 2, \dots, T$. Once we subtract $\tilde{\psi}$ from y_t , it follows that $\tilde{S}_1 = 0$.
4. <https://www.msci.com/documents/10199/7424d920-cdcb-462c-9e16-4c450ed70e2a>.

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Author contributions

Muneer Shaik – conception, design, and project administration. Mustafa Raza Rabbani – analysis and interpretation of data. Mustafa Raza Rabbani – original draft, review, and editing. Prateek Kamdar – original draft, analysis, and proofreading. Himani Grewal– data collection, analysis, and interpretation. Nishad Nawaz – original draft, analysis, and proofreading. Himani Grewal– data collection, analysis, and interpretation. Sahar Vahdati – original draft, analysis, and proofreading. Himani Grewal– data collection, analysis, and interpretation. Afzal Saifi – original draft, analysis, and proofreading. Himani Grewal– data collection, analysis, and interpretation and Himani Grewal – original draft, analysis, and proofreading. Himani Grewal– data collection, analysis, and interpretation.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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Data availability statement

The data can be made available on request.

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