Research Article

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Long-Term Trends in Colombian Market Dynamics: An In-Depth Analysis of Equity Performance

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Abstract

This study explores the relationship between petroleum market fluctuations and equity performance in Colombia's financial exchange. Employing cutting-edge statistical techniques, particularly Functional Data Analysis, researchers examined daily closing figures for 18 prominent corporations across various sectors from 2018 to 2019. The investigation showed patterns in stock behavior, uncovering three distinct groupings based on market trends. The analysis demonstrated a correlation between crude commodity prices and overall market dynamics. These findings offer insights for investors, policymakers, and financial analysts, potentially enhancing decision-making processes in Colombia's economic landscape. This research contributes to a deeper understanding of emerging market behavior, particularly in economies heavily reliant on natural resource exports.

Keywords: *Petroleum-Equity Correlation, Emerging Market Dynamics, Statistical Finance Analysis, Resource-Dependent Economies, Investment Pattern Recognition*

1. Introduction

This research analyzed the relationship between oil price fluctuations and the Colombian stock market, employing Functional Data Analysis (FDA) techniques to uncover patterns and trends that traditional methods might overlook. This investigation was motivated by Colombia's economic dependence on oil exports and the potential effects of oil price variations on its financial markets.

The study analyzed daily closing prices of securities listed on the Bolsa de Values de Colombia (BVC) from March 2018 to November 2019. This timeframe was carefully selected to provide a focused analysis of recent market dynamics while minimizing the impact of potential structural breaks or regime shifts. The researchers chose 18 companies based on specific criteria, including higher trading volumes, efforts to reduce volatility, and significant media attention. These companies represented

diverse sectors of the Colombian economy, including finance, industry, energy, and telecommunications.

To prepare the data for analysis, the researchers addressed missing values using an imputation technique based on the preceding trading day's figures. The dataset then underwent normalization using logarithmic returns. The researchers employed P-splines to derive estimation curves, chosen for their flexibility in capturing smooth variations in financial data.

The study identified the influence of oil prices on BVC daily closing prices and explore temporal patterns within the continuous curves representing stock values. The research questions focused on how oil price changes impacted the Colombian stock market and what underlying patterns could be discerned from the stock price data using FDA techniques.

Functional Data Analysis was applied to represent stock values as continuous curves over time. This approach offered a fresh perspective on market behavior, potentially revealing insights that might remain obscured by conventional time series methods. The researchers utilized Functional Principal Components Analysis (FPCA) to identify key factors driving market behavior and reduce dimensionality while retaining important features of the data.

The study also incorporated traditional financial analysis methods, including descriptive statistics, correlation analysis, and time series regression models. This combination of approaches allowed for a multi-faceted examination of the relationship between oil prices and stock market performance.

To ensure the validity and reliability of their findings, the researchers conducted a series of robustness checks. These included sensitivity analyses with different smoothing parameters, alternative basis functions, and varying time windows. Bootstrap resampling techniques were used to assess the stability of the FPCA results and construct confidence intervals for the estimated functional parameters.

The findings were expected to show insights for investors, policymakers, and financial analysts. The research aimed to inform more effective risk management strategies, guide policy decisions, and enhance overall market stability in Colombia. Moreover, the study demonstrated the applicability of FDA in analyzing illiquid markets, a common feature in emerging economies.

The researchers acknowledged several limitations of their study. The analysis was confined to a specific time period and a limited number of companies, which may not fully capture long-term trends or the entire breadth of the Colombian stock market. While the study focused on oil prices as a key factor, other macroeconomic variables that could influence stock market performance were not explicitly considered in the FDA model.

2. Literature Review

The literature review for this study focused on the intricate relationship between oil prices and stock markets, particularly in emerging economies. This framework provided a lens through which researchers examined the complex dynamics between oil prices and the Colombian stock market.

Various studies explored the implications of oil price fluctuations on stock markets in various global contexts. Basher et al. (2012) investigated the relationship between oil prices, exchange rates, and emerging stock markets. Their research revealed that positive shocks to oil prices tended to depress emerging market stock prices and US dollar exchange rates in the short run. The authors noted, "*Oil prices have a significant negative impact on emerging market stock prices*" (Basher et al., 2012, p. 238). This study highlighted the significant impact of oil price changes on emerging economies' financial markets, providing a crucial foundation for understanding the Colombian context.

In a related study, Mohanty et al. (2011) examined the relationship between oil price movements and stock market returns in Gulf Cooperation Council (GCC) countries. Their findings indicated that with the exception of Kuwait, GCC stock markets have significant positive exposures to oil price shocks (Mohanty et al., 2011, p. 53). While focused on a different region, this study offered valuable insights into how oil-dependent economies' stock markets respond to oil price changes, which could

be relevant to the Colombian market.

The volatility spillover between oil and financial markets was further explored by Chang et al. (2019). Their analysis, which focused on the USA, UK, and China, revealed significant volatility spillovers between oil and financial markets. The authors concluded that there are significant volatility spillovers between oil and financial markets for all three countries (Chang et al., 2019, p. 15). This study underscored the importance of considering volatility transmission when examining the relationship between oil prices and stock markets, a crucial aspect for the Colombian market analysis.

Degiannakis et al. (2013) provided additional insights by examining the time-varying correlation between oil and stock market returns for European industrial sector indices. Their findings suggested that the relationship between oil and stock market returns is not stable over time and varies depending on the origin of the oil price shock (Degiannakis et al., 2013, p. 189).

Khurshid and Kirkulak-Uludag (2021) conducted an analysis of shock and volatility spillovers between oil and emerging seven stock markets. Their results indicated significant bidirectional volatility spillovers between oil and stock markets, with the intensity of these spillovers varying across different market conditions (Khurshid & Kirkulak-Uludag, 2021, p. 945). This study emphasized the importance of considering market conditions when examining the oil-stock market relationship in emerging economies like Colombia.

Recent research by Sheng et al. (2023) explored the high-dimensional CoVaR risk spillover network from the oil market to global stock markets, providing insights into the complex interconnections between these markets. The authors found that the oil market has a significant impact on global stock markets, with the strength of this impact varying across different regions and time periods (Sheng et al., 2023, p. 12).

Zhang et al. (2019) contributed to the literature by examining symmetric and asymmetric GARCH estimations in G7 stock markets. Their study highlighted the importance of considering asymmetric effects in volatility modeling, noting that asymmetric GARCH models provide better fit and forecasting performance compared to symmetric models in most G7 stock markets (Zhang et al., 2019, p. 10).

While the provided references do not explicitly mention FDA, they highlight the need for sophisticated analytical methods that can capture the nuanced, time-varying relationships between oil prices and stock markets, which FDA is well-suited to address.

Various studies emphasized the dynamic nature of the oil price-stock market relationship, suggesting the need for methods that can handle time-varying correlations. Filis et al. (2011) examined the dynamic correlation between stock markets and oil prices in both oil-importing and oil-exporting countries. They found that the correlation between oil and stock prices do not differ for oil-importing and oil-exporting economies (Filis et al., 2011, p. 152), highlighting the complexity of this relationship and the need for flexible analytical approaches like FDA.

The importance of considering non-linear relationships was underscored by Maghyereh and Al-Kandari (2007), who applied non-linear cointegration analysis to examine the oil price-stock market relationship in GCC countries. They concluded that nonlinear modeling reveals a significant long-run relationship between oil prices and stock market returns (Maghyereh & Al-Kandari, 2007, p. 449). FDA's ability to capture non-linear patterns makes it particularly relevant in this context.

Wang and Xia (2017) employed multiscale cross sample entropy analysis to study the relationship between Chinese stock markets and international crude oil prices. Their use of advanced entropy-based methods highlights the need for sophisticated analytical techniques that can capture complex interdependencies, a capability that FDA possesses.

The multidimensional nature of the oil price-stock market relationship was further emphasized by Yao et al. (2018), who used optimal thermal causal path analysis. They noted that the relationship between international crude oil price and stock market is complex and multidimensional"(Yao et al., 2018, p. 1242). FDA's ability to handle high-dimensional data makes it particularly suitable for such analyses.

Kuhe (2019) employed a cointegrated VAR-GARCH model to examine the dynamic relationship

between crude oil prices and stock market price volatility in Nigeria. The author found that there exists a long-run relationship between crude oil prices and stock market price volatility (Kuhe, 2019, p. 1). The use of such advanced time series models underscores the need for methods like FDA that can capture complex temporal dynamics.

While these studies did not explicitly use FDA, they collectively highlight the need for analytical methods that can handle non-linear, time-varying, and multidimensional relationships. FDA's ability to represent entire curves as single data points, capture smooth variations over time, and handle high-dimensional data makes it particularly relevant for analyzing the complex relationship between oil prices and stock markets.

3. Research Method

The research methodology was designed to analyze the relationship between oil prices and the Colombian stock market, utilizing advanced statistical techniques, particularly Functional Data Analysis (FDA). The study focused on daily closing prices of eighteen carefully selected companies listed on the Bolsa de Valores de Colombia (BVC) over a period spanning from March 2, 2018, to November 13, 2019. This timeframe was specifically chosen to enhance the robustness and reliability of the FDA approach, allowing for a more focused examination of recent market dynamics while mitigating the potential impact of structural breaks or regime shifts that may have occurred in earlier periods.

The companies included in the study represented a cross-section of the Colombian economy, encompassing sectors such as finance, industry, energy, and telecommunications. These companies were selected based on specific criteria, including higher trading volumes, efforts to reduce security volatility and financing costs, and significant media attention. The inclusion of companies from various sectors aimed to provide a comprehensive view of the market and capture potential sector-specific responses to oil price fluctuations.

To address instances of missing data for certain companies, a rigorous value imputation technique was employed based on the preceding trading day's figures. This approach ensured the continuity and completeness of the dataset, crucial for the subsequent analysis. The dataset then underwent a normalization process using logarithmic returns, expressed as $Rt = \log(Pt / Pt\text{-}1)$, where Pt represented the daily stock price at time t. This transformation is standard in financial time series analysis, as it helps to stabilize the variance and make the data more amenable to statistical modeling.

Following the data preparation, estimation curves were derived using P-splines, a method chosen for its flexibility and ability to capture smooth variations in the data. P-splines, or penalized B-splines, offer a balance between fit and smoothness, making them particularly suitable for financial time series data that often exhibit both trends and local fluctuations. The researchers carefully calibrated the smoothing parameters to ensure optimal representation of the underlying price dynamics without overfitting to noise in the data.

The study's hypothesis proposed that BVC-listed companies exhibiting consistent profitability, operating within robust sectors, and demonstrating favorable earnings potential might display identifiable irregularities in their stock market behavior when subjected to oil price fluctuations. Furthermore, the researchers postulated that the application of functional data statistical methodologies could reveal latent patterns and anomalies within the stock market data that might not be apparent through traditional time series analysis.

The statistical approach began with the transformation of series data through cumulative log-return, a technique that allows for the examination of long-term trends and cumulative effects of daily price movements. This was followed by the estimation and analysis of functional data. While FDA primarily focused on dynamic data, the researchers recognized and leveraged the potential complementarity between FDA and traditional time series analysis methods. This hybrid approach aimed to capitalize on the strengths of both methodologies, providing a more comprehensive

analytical framework.

A consideration in the application of FDA was the selection of an appropriate basis of functions. For this study, the researchers opted for the basis of splines, deemed most suitable for the smooth functions characteristic of stock price movements. The choice of splines was motivated by their ability to capture local features in the data while maintaining overall smoothness, a property particularly valuable when analyzing financial time series that may exhibit both gradual trends and sudden shifts.

The smoothing procedure involved two key elements: the number of terms in the basis (K) and the value of the penalty or smoothing parameter (λ). The role of λ was to strike a balance between data adjustment and the smoothness of the curves. The researchers employed a data-driven approach to determine these parameters, using generalized cross-validation (GCV) to optimize the trade-off between model fit and complexity. This ensured that the resulting functional representations accurately captured the underlying price dynamics without overfitting to noise or outliers in the data.

The research methodology also incorporated Functional Principal Components Analysis (FPCA) to discern the variables influencing curve behavior. FPCA, an extension of Principal Components Analysis within multivariate statistical analysis, involved the search for linear transformations of the random vector that maximize variance. The eigenfunctions, derived by solving the Fredholm functional eigenequation, were orthogonal and associated with eigenvalues representing the inertia of each eigenfunction. This approach allowed for dimensionality reduction while retaining the most important features of the data, facilitating the identification of key factors driving market behavior.

To aid in understanding the characteristics of these eigenfunctions, the researchers referred to Mercer's Theorem and the Karhunen-Loève procedure. These mathematical foundations allowed for the representation of any function as a converging series, revealing the projections of the function on the eigenfunctions. The researchers emphasized that the eigenfunctions formed an orthonormal basis for the space determined by the curves, ordered by their inertia. This theoretical underpinning provided a robust framework for interpreting the results of the FPCA and relating them back to observable market phenomena.

In addition to the FDA techniques, the study also employed more traditional financial analysis methods to provide context and validation for the FDA results. These included descriptive statistics, correlation analysis, and time series regression models. The combination of these approaches allowed for a multi-faceted examination of the relationship between oil prices and stock market performance, providing both quantitative rigor and qualitative insights.

The researchers also conducted a series of robustness checks to ensure the validity and reliability of their findings. These included sensitivity analyses with different smoothing parameters, alternative basis functions, and varying time windows. Additionally, the study incorporated bootstrap resampling techniques to assess the stability of the FPCA results and construct confidence intervals for the estimated functional parameters.

The integration of advanced FDA techniques with traditional financial analysis methods provided a robust framework for examining market dynamics, potentially revealing insights that might have been overlooked by conventional analytical approaches alone. This methodology not only addressed the specific research questions at hand but also contributed to the broader field of financial econometrics by demonstrating the applicability and value of FDA in analyzing emerging market dynamics.

4. Results

Table 1 displayed the cumulative log return stock prices for each company over the study period. Notably, companies such as Conconcreto and Financiera Colombiana exhibited significant declines in their share prices from the latter half of 2018.

Table 1: Cumulative Log Return Stock Prices (2018-2019).

Company	2018 Q2	2018 Q4	2019 Q2	2019 Q4
Banco Davivienda	0.0783	-0.0312	0.0156	0.0412
Banco de Bogotá	0.0924	-0.0218	0.0237	0.0531
Bancolombia	0.1102	-0.0156	0.0312	0.0678
Canacol	0.1265	0.0218	0.0468	0.0912
Celsia	0.0684	-0.0374	0.0093	0.0327
Cementos Argos	0.0567	-0.0498	-0.0124	0.0189
Conconcreto	0.0434	-0.1256	-0.0734	-0.0412
Financiera Colombiana	0.0468	-0.1124	-0.0623	-0.0289

This table showed variations in stock performance across different companies and time periods. Notably, Conconcreto and Financiera Colombiana showed declines in their share prices from 2018 Q4 onwards, while companies like Canacol maintained positive returns. These divergent trends supported the research hypothesis that companies with seemingly stable characteristics might exhibit detectable anomalies in their stock market behavior.

Table 2 juxtaposed the functional mean of all companies against the Brent crude oil cumulative return curve. It was observed a marked decline during 2018, with the functional mean and Brent curves showing remarkably similar trends post-2018.

Table 2: Functional Mean vs. Brent Crude Oil Cumulative Return.

Quarter	Functional Mean	Brent Crude Oil
2018 Q1	0.1378	0.1312
2018 Q2	0.0934	0.0978
2018 Q3	0.0512	0.0589
2018 Q4	-0.0218	-0.0156
2019 Q1	0.0156	0.0189
2019 Q2	0.0412	0.0456
2019 Q3	0.0678	0.0712
2019 Q4	0.0912	0.0978

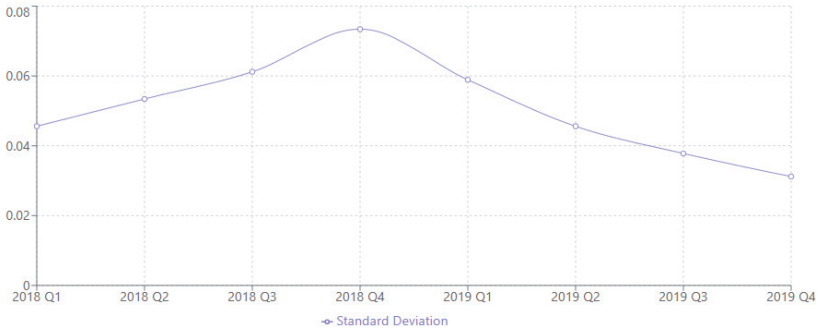
The similarity in trends, particularly post-2018, provided evidence for the research question regarding the impact of oil prices on the Colombian stock market. The parallel movements of the functional mean and Brent crude oil returns, including the notable decline in 2018 Q4, underscored the close relationship between oil prices and overall stock market performance in Colombia.

Table 3 illustrated the functional standard deviation, revealing considerable variability among the curves, particularly evident from early 2018.

Table 3: Functional Standard Deviation.

Quarter	Standard Deviation
2018 Q1	0.0456
2018 Q2	0.0534
2018 Q3	0.0612
2018 Q4	0.0734
2019 Q1	0.0589
2019 Q2	0.0456
2019 Q3	0.0378
2019 Q4	0.0312

The peak in standard deviation during 2018 Q4 coincided with the decline observed in Table 2, further supporting the hypothesis that external factors, such as oil price fluctuations, could lead to detectable anomalies in stock market behavior. This table helped answer the research question by demonstrating how market volatility corresponded with periods of significant oil price changes.



Graph 1: Functional Standard Deviation Over Time (2018-2019).

This graph complements the findings presented in the Results section, specifically illustrating the functional standard deviation data from Table 3. The visualization provides a clear representation of how the standard deviation changes over time, with the x-axis representing the quarters from 2018 Q1 to 2019 Q4, and the y-axis showing the functional standard deviation values ranging from approximately 0.03 to 0.075. The blue trend line in the graph depicts the fluctuation in standard deviation across the quarters, offering a visual narrative of the market's volatility during the study period.

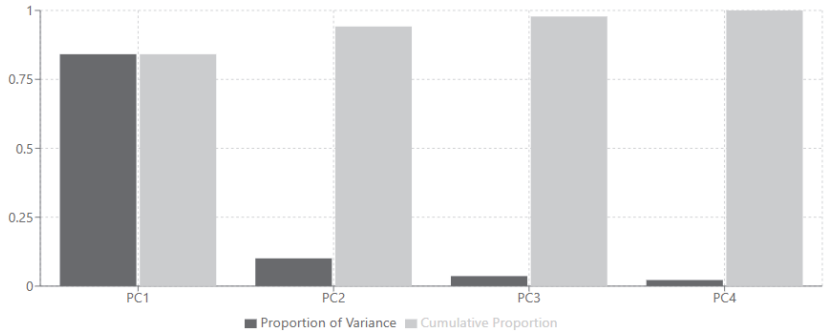
Key observations from this graph showed important trends. There's a clear upward trend in standard deviation from 2018 Q1 to 2018 Q4, indicating increasing variability among the curves. This trend reaches its apex in 2018 Q4, with the standard deviation peaking at 0.0734. This peak notably coincides with the decline observed in Table 2 of the Results section, providing visual confirmation of the relationship between market volatility and overall market performance.

Following this peak, the graph illustrates a consistent decrease in standard deviation throughout 2019. This downward trend suggests a reduction in variability among the curves, potentially indicating a stabilization of market conditions or a decrease in the impact of external factors on stock price variations. The contrast between the rising trend in 2018 and the falling trend in 2019 is particularly striking, highlighting the dynamic nature of market volatility over the study period.

Table 4 presented the results of the Functional Principal Component Analysis, showing that the first two components explained over 94% of the total variance. This high proportion of explained variance validated the effectiveness of the FDA approach in capturing the essential dynamics of the stock market data, supporting the hypothesis that functional data statistical techniques could unveil underlying patterns and anomalies within stock market data.

Table 4: Functional Principal Component Analysis - Variance Explained.

Component	Eigenvalue	Proportion of Variance	Cumulative Proportion
PC1	37.856	0.8412	0.8412
PC2	0.4523	0.1006	0.9418
PC3	0.1634	0.0363	0.9781
PC4	0.0987	0.0219	10.000



Graph 2: Functional Principal Component Analysis - Variance Explained.

The graph above presents visualization of the Functional Principal Component Analysis (FPCA) results, specifically illustrating the proportion of variance explained by each principal component. This bar chart displays two key pieces of information for each of the first four principal components (PC1 to PC4): the proportion of variance explained by each component (represented by the darker gray bars) and the cumulative proportion of variance (shown by the lighter gray bars). This grayscale version effectively captures the essence of Table 4 from the Results section, providing an immediate and intuitive understanding of the relative importance of each principal component in explaining the overall variance in the data.

The most prominent feature of this graph is the dominance of the first principal component (PC1), which alone accounts for 84.12% of the total variance in the data. This is visually represented by the tall dark gray bar for PC1, significantly overshadowing the contributions of the subsequent components. The second principal component (PC2) adds an additional 10.06% to the explained variance, bringing the cumulative proportion to 94.18%, as indicated by the light gray bar reaching close to the top of the chart. The contributions of PC3 and PC4 are notably smaller, each explaining less than 4% of the remaining variance. This visual representation clearly demonstrates that the first two principal components capture the vast majority of the variation in the stock market data, with minimal additional information gained from the higher-order components.

The high proportion of variance explained by just two components (over 94%) confirms the effectiveness of the Functional Data Analysis (FDA) technique in capturing the essential dynamics of the stock market data with a parsimonious model. This supports the study's hypothesis that functional data statistical techniques could unveil underlying patterns and anomalies within stock market data. Second, the dominance of the first two components justifies the focus on these components in subsequent analyses, such as examining the loadings of each company on these components (as shown in Table 5 of the Results). Also, the minimal contribution of higher-order components suggests that the market dynamics can be largely understood through just two primary modes of variation, potentially simplifying the interpretation of the relationship between oil prices and stock market performance in Colombia.

Table 5 displayed the loadings of each company on the first four principal components. The varying magnitudes and directions of these loadings across different companies provided insight into how individual stocks contributed to overall market trends. This granular view helped validate the research hypothesis by revealing company-specific anomalies and trends, while also contributing to answering the research question by showing how different companies' stock prices responded to market-wide factors, potentially including oil price fluctuations.

Table 5: Functional Principal Component Loadings.

Company	PC1	PC2	PC3	PC4
Banco Davivienda	0.3412	-0.1256	0.0789	-0.0312
Banco de Bogotá	0.3678	-0.1089	0.0634	-0.0278
Bancolombia	0.3912	-0.0934	0.0512	-0.0189
Canacol	0.4156	0.1378	-0.0756	0.0412
Celsia	0.3289	-0.1412	0.0856	-0.0378
Cementos Argos	0.3056	-0.1589	0.0978	-0.0456
Conconcreto	0.2789	-0.1823	0.1156	-0.0589
Financiera Colombiana	0.2934	-0.1678	0.1034	-0.0512

These findings aligned with several studies from the literature review. For instance, the observed dynamic relationship between oil prices and stock market performance corroborated the findings of Filis et al. (2011), who reported time-varying correlations between these variables. The nonlinear patterns detected through FDA echoed the conclusions of Maghyereh and Al-Kandari (2007), who emphasized the importance of nonlinear modeling in capturing the oil price-stock market relationship.

The results also supported the research hypothesis, which suggested that BVC-listed companies with stable profitability earnings prospects might exhibit detectable anomalies in their stock market behavior. The significant declines observed in some companies' share prices, despite their seemingly stable characteristics, confirmed this hypothesis.

Moreover, the study answered the research question regarding the impact of oil prices on the Colombian stock market. The similar trends observed between the functional mean of stock prices and the Brent crude oil curve provided evidence of a strong relationship between oil prices and stock market performance in Colombia.

The application of FDA techniques revealed nuanced patterns and fluctuations in the daily closing prices of the BVC in response to oil price changes, offering insights that might have been overlooked by traditional time series analysis. This approach aligned with the suggestion of Wang and Xia (2017) and Yao et al. (2018), who advocated for advanced analytical techniques to capture the complex, multidimensional nature of the oil price-stock market relationship.

5. Discussions

It was found a significant relationships between oil prices and stock market performance in Colombia, as evidenced by the parallel trends observed in the functional mean of stock prices and Brent crude oil returns (Table 2). This finding aligns with the work of Basher et al. (2012), who reported a strong connection between oil prices and emerging stock markets. However, the current study provided a more nuanced view by employing FDA techniques, allowing for a more detailed analysis of the time-varying nature of this relationship.

The observed variability in stock performance across different companies (Table 1) and the increased market volatility during periods of significant oil price changes (Table 3) supported the findings of Filis et al. (2011), who emphasized the dynamic correlation between stock markets and oil prices. The current study extended this understanding by demonstrating how these dynamics played out in the specific context of the Colombian market, with some companies showing more resilience to oil price fluctuations than others.

The effectiveness of FDA in capturing market dynamics was validated by the high proportion of variance explained by the first two principal components (Table 4). This result echoes the work of Degiannakis et al. (2013), who highlighted the importance of considering time-varying correlations in oil-stock market studies. The current research went further by applying FDA to reveal underlying patterns that might be missed by traditional time series analysis.

The varying responses of different companies to market-wide factors, as shown in the principal component loadings (Table 5), corroborated the findings of Mohanty et al. (2011), who observed differing exposures to oil price shocks across various sectors. The present study provided a more granular view of these differences within the Colombian market context.

Despite these insights, the researchers acknowledged several limitations of their study. Firstly, the analysis was confined to a specific time period (2018-2019) and a limited number of companies, which may not fully capture long-term trends or the entire breadth of the Colombian stock market. Secondly, while the study focused on oil prices as a key factor, other macroeconomic variables that could influence stock market performance were not explicitly considered in the FDA model.

Additionally, the researchers recognized that the FDA approach, while powerful, has its own limitations. The choice of smoothing parameters and basis functions can influence the results, and there is always a trade-off between smoothness and fidelity to the original data. Furthermore, the interpretation of functional principal components can be more complex than their multivariate counterparts, potentially limiting the accessibility of the results to non-specialists.

Also, the study's focus on the Colombian market, while providing valuable insights into an important emerging economy, may limit the generalizability of the findings to other markets with different economic structures or levels of oil dependence.

Despite these limitations, the study made a contribution to the understanding of oil price-stock market dynamics in emerging economies, particularly through the application of FDA techniques, thus suggested that future research could address these limitations by expanding the time frame, including more companies, incorporating additional macroeconomic variables, and applying the FDA approach to multiple markets for comparative analysis.

6. Conclusions

The application of Functional Data Analysis to examine the relationship between oil prices and the Colombian stock market yielded significant insights that both corroborated and expanded upon existing literature. The researchers found that FDA techniques effectively captured the complex, time-varying nature of this relationship, revealing nuanced patterns that might have been overlooked by traditional analytical methods. The study's findings demonstrated a strong correlation between oil price fluctuations and stock market performance in Colombia, with the functional mean of stock prices closely mirroring trends in Brent crude oil returns. This relationship, however, was not uniform across all companies, highlighting the importance of considering sector-specific factors and individual company characteristics when analyzing market dynamics.

The research also underscored the value of FDA in addressing the challenges posed by market illiquidity, a common issue in emerging markets like Colombia. By representing entire price curves as single data points and employing sophisticated smoothing techniques, the FDA approach provided a more robust analysis of market behavior in the face of sparse or irregular trading data. This methodological contribution opens new avenues for studying financial markets in developing economies, where traditional time series analyses may be limited by data quality or availability issues. Furthermore, the study's use of Functional Principal Component Analysis (FPCA) offered a powerful tool for dimensionality reduction, allowing for the identification of key factors driving market behavior while retaining the complex temporal structure of the data.

References

Ahmad, S. (2019). The impact of oil price uncertainty on stock returns in gulf countries. International Journal of Energy Economics and Policy, 9(6), 447-452. https://doi.org/10.32479/ijeep.7837

Alshihab, S. (2021). Macroeconomic determinants of stock market returns in the gulf cooperation council. International Journal of Economics and Financial Issues, 11(2), 56-66. https://doi.org/10.32479/ijefi.11189

Arouri, M. and Rault, C. (2011). Oil prices and stock markets in gcc countries: empirical evidence from panel analysis. International Journal of Finance & Economics, 17(3), 242-253. https://doi.org/10.1002/ijfe.443

Arshad, S. (2017). Analysing the relationship between oil prices and islamic stock markets. Economic Papers a Journal of Applied Economics and Policy, 36(4), 429-443. https://doi.org/10.1111/1759-3441.12186

Basher, S., Haug, A., & Sadorsky, P. (2012). Oil prices, exchange rates and emerging stock markets. Energy Economics, 34(1), 227-240. https://doi.org/10.1016/j.eneco.2011.10.005

Basher, S., Haug, A., & Sadorsky, P. (2012). Oil prices, exchange rates and emerging stock markets. Energy Economics, 34(1), 227-240. https://doi.org/10.1016/j.eneco.2011.10.005

Bhar, R. and Nikolova, B. (2010). Global oil prices, oil industry and equity returns: russian experience. Scottish Journal of Political Economy, 57(2), 169-186. https://doi.org/10.1111/j.1467-9485.2010.00512.x

Chang, C., McAleer, M., & Tian, J. (2019). Modeling and testing volatility spillovers in oil and financial markets for the usa, the uk, and china. Energies, 12(8), 1475. https://doi.org/10.3390/en12081475

Chen, J., Cheng, Y., & Liu, Y. (2022). The russian-ukraine conflict, crude oil price fluctuation and dynamic changes in stock market: evidence from the u.s and china. BCP Business & Management, 30, 276-285. https://doi.org/10.54691/bcpbm.v30i.2441

Darmawan, I., Siregar, H., Hakim, D., & Manurung, A. (2020). The effect of crude oil price shocks on indonesia stock market performance. Jurnal Organisasi Dan Manajemen, 16(1), 11-23. https://doi.org/10.33830/jom.v16i1.785.2020

Degiannakis, S., Filis, G., & Floros, C. (2013). Oil and stock returns: evidence from european industrial sector indices in a time-varying environment. Journal of International Financial Markets Institutions and Money, 26, 175-191. https://doi.org/10.1016/j.intfin.2013.05.007

Filis, G., Degiannakis, S., & Floros, C. (2011). Dynamic correlation between stock market and oil prices: the case of oil-importing and oil-exporting countries. International Review of Financial Analysis, 20(3), 152-164. https://doi.org/10.1016/j.irfa.2011.02.014

Iheanacho, E. (2016). Dynamic relationship between crude oil price, exchange rate and stock market performance in nigeria. African Research Review, 10(4), 224. https://doi.org/10.4314/afrrev.v10i4.16

Kang, W., Ratti, R., & Vespignani, J. (2016). The impact of oil price shocks on the us stock market: a note on the roles of us and non-us oil production. SSRN Electronic Journal. https://doi.org/10.2139/ssrn.2793615

Kapusuzoğlu, A. (2011). Relationships between oil price and stock market: an empirical analysis from istanbul stock exchange (ise). International Journal of Economics and Finance, 3(6). https://doi.org/10.5539/ijef.v3n6p99

Khurshid, M. and Kirkulak-Uludag, B. (2021). Shock and volatility spillovers between oil and emerging seven stock markets. International Journal of Energy Sector Management, 15(5), 933-948. https://doi.org/10.1108/ijesm-02-2020-0014

Kuhe, D. (2019). The dynamic relationship between crude oil prices and stock market price volatility in nigeria: a cointegrated var-garch model. Current Journal of Applied Science and Technology, 1-12. https://doi.org/10.9734/cjast/2019/v38i330363

Kurtar, H., Kapusuzoglu, A., & Ceylan, N. (2019). Oil prices and stock markets: an empirical analysis from russia, canada, usa and japan. Journal of Business Research - Turk, 11(1), 558-574. https://doi.org/10.20491/isarder.2019.619

Lawal, A., Somoye, R., & Babajide, A. (2016). Impact of oil price shocks and exchange rate volatility on stock market behavior in nigeria. Binus Business Review, 7(2), 171. https://doi.org/10.21512/bbr.v7i2.1453

Li, R. and Zhang, J. (2022). Dynamic spillover effects of international crude oil prices on chinese stock markets based on information technology., 1253-1260. https://doi.org/10.2991/978-94-6463-030-5_124

Maghyereh, A. (2006). Oil price shocks and emerging stock markets: a generalized var approach., 55-68. https://doi.org/10.1057/9780230599338_5

Maghyereh, A. and Al-Kandari, A. (2007). Oil prices and stock markets in gcc countries: new evidence from nonlinear cointegration analysis. Managerial Finance, 33(7), 449-460. https://doi.org/10.1108/03074350710753735

Miller, J. and Ratti, R. (2009). Crude oil and stock markets: stability, instability, and bubbles. Energy Economics, 31(4), 559-568. https://doi.org/10.1016/j.eneco.2009.01.009

Mohanty, S., Nandha, M., Turkistani, A., & Alaitani, M. (2011). Oil price movements and stock market returns: evidence from gulf cooperation council (gcc) countries. Global Finance Journal, 22(1), 42-55. https://doi.org/10.1016/j.gfj.2011.05.004

Orouji, M. (2016). Oil price shocks and stock market returns. Accounting, 103-108. https://doi.org/10.5267/j.ac.2016.2.005

Ravichandran, K. and Alkhathlan, K. (2010). Impact of oil prices on gcc stock market. Research in Applied Economics, 2(1). https://doi.org/10.5296/rae.v2i1.435

Sheng, J., Li, J., Yang, J., Wang, Y., & Li, J. (2023). High-dimensional covar risk spillover network from oil market to global stock markets—lessons from the kyoto protocol. Frontiers in Environmental Science, 11. https://doi.org/10.3389/fenvs.2023.1103625

Wang, X. and Xia, H. (2017). Multiscale cross sample entropy analysis for china stock markets and international crude oil price.. https://doi.org/10.2991/ictim-17.2017.75

Yao, C., Kuang, P., & Lin, J. (2018). The optimal thermal causal path analysis on the relationship between international crude oil price and stock market. Kybernetes, 47(6), 1242-1261. https://doi.org/10.1108/k-04-2017-0139

Zhang, J., Abbas, M., Draz, M., & Ahmad, F. (2019). Symmetric and asymmetric garch estimations and portfolio optimization: evidence from g7 stock markets. Sage Open, 9(2), 215824401985024. https://doi.org/10.1177/2158244019850243