EXTREME EVENTS CAUSE MARKET EFFICIENCY OR INEFFICIENCY?
EVIDENCE FROM PRECIOUS METALS AND GREEN STOCK INDICES

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ABSTRACT

Background: Green investments offer a promising market-based approach to tackling global climate change but are susceptible to risk transmission from multiple assets.

Purpose: To examine the multifractality between precious metals (Gold, Silver, Platinum) and green stock indices, such as Clean Energy Fuels, Nasdaq Clean Edge Green Energy, S&P Global Clean Energy and WilderHill Clean Energy, over the period from 1 January 2018 to 23 November 2023. The study aims to answer the following question: Did the events of 2020 and 2022 cause efficiency or inefficiency in the markets analysed?

Methods: The Detrended Fluctuation Analysis (DFA) econophysics model will be used to answer the research question.

Results: During the period of stability, there was a clear division between the markets, with Gold and green energy indices demonstrating market efficiency, while Platinum, Silver and some green indices exhibited price persistence, suggesting opportunities for above-average gains. However, the 2020 global pandemic led to widespread inefficiencies in all the markets analysed, with precious metals and green energy indices showing price persistence, indicating patterns that could lead to arbitrage opportunities. The persistence in returns suggested a tendency for asset prices to continue in the same direction for an extended period, offering opportunities to identify ongoing market trends for investment. In the pre-conflict period, the random walk hypothesis was rejected in all markets, with precious metals exhibiting anti-persistence in returns, while green energy indices showed significant persistence. During the conflict period, precious metals and green energy indices converged towards persistence in returns, except Platinum, which showed anti-persistence.

Conclusion: This study provides valuable insights for investors and financial market professionals, highlighting the importance of understanding asset price behaviour patterns in different economic contexts.

Keywords: Ecological Energies, Precious Metals, Persistence, Long Memories, Portfolio Rebalancing.

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ACONTECIMIENTOS EXTREMOS CAUSAN EFICIENCIA O INEFICIENCIA EN LOS MERCADOS? LOS ÍNDICES DE METALES PRECIOSOS Y LAS ACCIONES VERDES

RESUMEN

Antecedentes: Las inversiones verdes ofrecen un enfoque prometedor basado en el mercado para abordar el cambio climático global, pero son susceptibles a la transmisión de riesgos desde múltiples activos.

Propósito: Examinar la multifractalidad entre los metales preciosos (oro, plata, platino) y los índices bursátiles verdes, como Clean Energy Fuels, Nasdaq Clean Edge Green Energy, S&P Global Clean Energy y WilderHill Clean Energy, durante el período comprendido entre el 1 de enero de 2018 y 23 de noviembre de 2023. El estudio pretende responder a la siguiente pregunta: ¿Los acontecimientos de 2020 y 2022 provocaron eficiencia o ineficiencia en los mercados analizados?

Métodos: Se utilizará el modelo econofísico del Análisis de fluctuación sin tendencia (DFA) para responder la pregunta de investigación.

Resultados: Durante el período de estabilidad, hubo una clara división entre los mercados, con los índices de Oro y energía verde demostrando eficiencia del mercado, mientras que la plata y algunos índices verdes exhibieron persistencia de precios, lo que sugiere oportunidades para ganancias superiores al promedio. Sin embargo, la pandemia mundial de 2020 provocó ineficiencias generalizadas en todos los mercados analizados, y los índices de metales preciosos y energía verde mostraron persistencia de precios, lo que indica patrones que podrían generar oportunidades de arbitraje. La persistencia de los rendimientos sugirió una tendencia de los precios de los activos a continuar en la misma dirección durante un período prolongado, lo que ofrece oportunidades para identificar las tendencias actuales del mercado para la inversión. En el período anterior al conflicto, la hipótesis...
del paseo aleatorio fue rechazada en todos los mercados, y los metales preciosos mostraron una antipersistencia en los rendimientos, mientras que los índices de energía verde mostraron una persistencia significativa. Durante el período de conflicto, los índices de metales preciosos y energía verde convergieron hacia la persistencia en los rendimientos, excepto el platino, que mostró una antipersistencia.

**Conclusión:** Este estudio proporciona información valiosa para inversores y profesionales de los mercados financieros, destacando la importancia de comprender los patrones de comportamiento de los precios de los activos en diferentes contextos económicos.

**Palabras clave:** Energías Ecológicas, Metales Preciosos, Persistencia, Largos Recuerdos, Reequilibrio de Cartera.

interactions between the clean energy and financial sectors, facilitating informed and strategic decision-making. Ultimately, analysing clean energy and precious metals indices together is vital for effective portfolio management in a continuously changing economic environment, in line with investment objectives and environmental and social concerns (Dias et al., 2023; Dias, Horta, et al., 2023b; Dias, Teixeira, et al., 2023).

In the financial markets, portfolio rebalancing means adjusting the asset allocation in a portfolio to align it with the investor's investment objectives and risk tolerance. It is especially important during periods of uncertainty in the global economy, as it helps investors manage risk and maintain a desired level of portfolio diversification. Rebalancing can involve selling assets that have increased in value and reallocating the proceeds to underperforming assets to align the portfolio with its objective. Thus, reducing the risk of the portfolio becoming too heavily weighted in a particular asset class, sector or geographical region (Dias, Chambino et al., 2023; Dias, Chambino et al., 2023).

This study makes substantial contributions to the literature. Firstly, it expands on existing literature about market risk management within clean energy stocks, which is scarce. According to prior research, precious metals have effectively mitigated risks in various asset classes. Precious metals, such as Gold and Silver, are traditionally considered safe-haven assets during times of uncertainty; therefore their demand tends to increase during market downturns, including stocks (Dias et al., 2023), metals (Dias et al., 2023), digital currencies (Chambino et al., 2023), and Gold (Dias and Carvalho, 2021; Teixeira et al., 2022). However, there is still a gap in research into price patterns in periods of uncertainty. That is, to understand whether ecological indices and precious metals show imbalances in times of stress and whether they tend towards short-term memories or long-term memories because these trends are crucial for investors who want to diversify their portfolios.

Another relevant point is the adoption of a time-frequency approach to examining the interrelationships between precious metals, dividing the sample into four distinct sub-periods: the Tranquil period, the period of the global Covid-19 pandemic, the pre-conflict period, and the armed Conflict between Russia and Ukraine. This approach offers a more detailed understanding of the dynamic relationships between precious metals and clean energy in different economic contexts and significant events, providing valuable insights for portfolio management and strategic decision-making in the financial market.

This paper is divided into sections; after this introduction, Section 2 is dedicated to the literature review, and Section 3 provides the data and methodology. The empirical results are
discussed in Section 4, and Section 5 provides the conclusion and the main practical implications.

2 LITERATURE REVIEW

The Efficient Market Hypothesis (EMH) is one of the fundamental ideas in both economics and finance and has been widely studied over the last century. The traditional financial theory that supports the EMH is based on several key concepts, including the arbitrage principle, the portfolio principle, the Capital Asset Pricing Model (CAPM), the Arbitrage Pricing Theory and the Option Pricing Theory. These theories provide a framework for understanding how financial markets operate and investors' decisions (Modigliani, Franco and Miller, 1959; Modigliani and Miller, 1958, 1963; Miller, 1988; Markowitz, 1952; Treynor, 1961).

Furthermore, Adam Smith, in his work "An Inquiry into the Nature and Causes of the Wealth of Nations" (1776), pointed out that rational economic agents mainly aim to maximise their financial returns. In other words, when a rational investor participates in the stock market, his main focus is to obtain the maximum possible return within the market in which he operates. This perspective emphasises the importance of rationality when making financial decisions and seeking success in the capital markets ("Adam Smith, an Inquiry into the Nature and Causes of the Wealth of Nations (1776)," 2021).

However, the presumption of investor rationality implies certain strict principles. When assuming that investors in financial markets are sufficiently rational, these assumptions can be lowered to include the presence of some "irrational" investors. These investors can trade randomly and independently, which leads to offsetting each other's effects, so there is no significant impact on asset prices (Dias et al., 2023).

2.1 RELATED STUDIES

Academics consider that studying the efficiency of clean energy stock indices is paramount due to the awareness of the need to transition to sustainable energy sources. The search for renewable and clean alternatives has become a global priority due to the environmental, economic and social challenges associated with traditional energy sources. Additionally, clean energy stock indices measure the financial performance of companies operating in this constantly evolving sector. By studying the efficiency of these indices,
investors can assess not only the financial return potential but also the environmental and social impact of the companies included in these stock indices (Maghyereh and Abdoh, 2021; Erdoğan et al., 2022; Ren and Lucey, 2022).

Ballester et al. (2016), Shahzad et al. (2020), and Karginova-Gubinova et al. (2020) studied market efficiency, in its weak form, in stock indices and clean energy bonds. Ballester et al. (2016) studied market efficiency, in its weak form, in stock indices and clean energy bonds. Ballester et al. (2016) analysed efficiency in the Iberian Electricity Market (MIBEL), namely spot and over-the-counter (OTC) forward markets. The empirical results confirm that the 1-month, 1-quarter and 1-year spot and futures markets generally fulfil the efficiency hypothesis in its weak form and that the MIBEL futures market does not contradict the HME in its semi-strong analysis.

On the other hand, the authors Shahzad et al. (2020) show the existence of asymmetric multifractality in the clean energy stock indices of the USA, Europe and the United States. The results show that European clean energy stock indices are more efficient than US indices when the markets are on an upward trend. Similarly, Karginova-Gubinova et al. (2020) analysed the efficiency of green bond markets. Market performance calculations were based on the S&P Green Bond Index and the S&P 500 Bond Index. The authors highlight the existence of multifractality, i.e. the markets do not exhibit efficiency characteristics in its weak form.

In 2021, the authors Dias et al. (2021) analysed efficiency, in its weak form, in the commodities markets, platinum (London Platinum Free Market $/Troy oz), gold (Gold Bullion LBM $/t oz DELAY), Silver (Silver - Zurich SW. francs/kg) and the stock markets of Korea, China, Japan, the Philippines and Indonesia. The authors show that the random walk hypothesis was rejected from January 2019 to October 2020 and that there were no differences between the precious metals and stock markets. Complementary, Frezza et al. (2021) analysed efficiency in 15 financial markets in Europe, the US and Asia during the Covid-19 pandemic; the authors show that the Asian markets (Hang Seng, Nikkei 225, Kospi) have recovered total efficiency, while the European and North American markets, after an initial recovery, have not yet returned to their pre-crisis level of efficiency.

The authors Naeem et al. (2022), Naeem et al. (2023), and Naeem, Farid, et al. (2023) studied the presence of long-term memories in green energy stock indices with other markets to ascertain whether there were significant differences. Naeem et al. (2022) revealed the presence of asymmetric multifractality in the clean and dirty energy markets. Besides, multifractality in energy markets is sensitive to trends, time horizons and major events. In line with this, Naeem et al. (2023) show that the outbreak has reduced the efficiency of regional
ESG markets, except in Europe, which has maintained its efficiency even during the pandemic. On the other hand, Naeem, Farid, et al. (2023) show that the oil markets analysed are not efficient. Furthermore, the conclusions underline that the dynamics of market efficiency in the oil sector depend on the investment horizon, market conditions and investor behaviour.

Dias, Horta, et al. (2023) investigated the multifractal scaling behaviour and efficiency of green financial markets, as well as traditional markets such as Gold, crude oil and natural gas, over the period 1 January 2018 and 9 March 2023. The empirical results showed that the return data series showed signs of (in)efficiency. In addition, there is a negative autocorrelation between the crude oil market, the clean energy fuels index, the global clean energy index, the gold market and the natural gas market.

Akbar et al. (2024) assessed the informational efficiency of nine Islamic market indices and their equivalent conventional Morgan Stanley indices, testing the martingale hypothesis. The authors found that the null value is rejected in several periods, in line with the adaptive market hypothesis for Islamic and conventional stock indices.

More recently, the authors Galvão and Dias (2024) studied clean energy stock indices and cryptocurrencies classified as "dirty". The results show that clean energy indices, like digital currencies classified as "dirty", exhibit autocorrelation in their returns; prices are not independent and identically distributed (iid). The authors highlight the presence of long memories that can constitute a pattern in prices, which could benefit investors who want to mitigate the risk of their portfolios.

This study adds value compared to studies that only measure efficiency in its weak form. Understanding the price behaviour patterns of clean energy stock indices and precious metals is crucial from a technical and financial standpoint. This analysis provides fundamental insights into the dynamics of financial markets, allowing for a deeper understanding of the forces that shape price movements. This understanding is essential for investors, fund managers and other market participants, as patterns in asset prices can directly influence investment strategies, risk management and financial decision-making. Moreover, identifying patterns in the prices of clean energy indices and precious metals can also help predict future market trends.

In summary, analysing behavioural patterns in the prices of clean energy and precious metals indices plays a key role in effective portfolio management and informed financial decision-making. By understanding and interpreting these patterns, investors can improve their ability to identify investment opportunities, predict market trends and manage risks, thus contributing to the long-term success of their investment strategies.
3 MATERIALS AND METHODS

3.1 DATA

The data used in the research are the daily index prices of Gold (Gold, Handy & Harman), Silver (Silver, Handy & Harman) and Platinum (London Platinum), as well as green stock indices such as Clean Energy Fuels, Nasdaq Clean Edge Green Energy, S&P Global Clean Energy and WilderHill Clean Energy, for the period from 1 January 2018 to 23 November 2023.

The sample was divided into four sub-periods to strengthen the study's findings: the first period comprises the years from January 2018 to 31 December 2019 and is referred to as Tranquil; the second includes the first wave of the Covid-19 pandemic and comprises the months from 1 January 2020 to 31 December 2020; the third sub-period covers the years from 1 January 2021 and 23 February 2022, referred to as Pre-Conflict; the fourth and final sub-period covers the period from 24 February 2022 to 23 November 2023, referred to as Conflict. The data was obtained through the Thomson Reuters Eikon platform and is represented in local currency to mitigate exchange rate distortions that can skew the results.

3.2 METHODOLOGY

This section describes the methodology and the tests used to answer the research question. The methodological process of this research was developed in several stages.

First, the sample was characterised using a set of descriptive statistics methods. Additionally, the Jarque and Bera (1980) adherence test was applied to analyse the data distribution of the time series and test the assumption of normality, and the quantile graphs were analysed to examine the residuals of the time series.

Secondly, the panel unit root tests of Breitung (2000), Levin, Lin, and Chu (2002), and Im et al. (2003) were applied to validate the stationarity of the time series. Furthermore, the results were validated with the Dickey and Fuller (1981) and Phillips and Perron (1988) tests, with Fisher's transformation.

The Detrended Fluctuation Analysis (DFA) econophysical model was used to answer the research question, i.e. to examine the multifractality of precious metals and green energy indices. DFA is an analysis method that examines time dependence in non-stationary data series. By assuming that the time series is non-stationary, this technique avoids misleading results when analysing the long-term relationships of the data series. The DFA has the following
interpretation: $0 < \alpha < 0.5$: anti persistent series; $\alpha = 0.5$ series shows random walk; $0.5 < \alpha < 1$ persistent series. The purpose of this technique is to analyse the relationship between values $x_k$ e $x_{k+t}$ at different moments (Guedes et al., 2022; Zebende et al., 2022).

The main advantage of applying DFA is the ability to remove trends from the series, which skew the true correlation of the fluctuations of the random variables involved, and thus enable long-range correlations to be seen in signals with polynomial trends, which can mask the true correlations (Santana et al., 2023).

4 RESULTS

Figure 1 displays the trends in the daily returns of Gold, Silver and Platinum, as well as the sustainable energy stock indices, from 1 January 2018 to 23 November 2023. Although graphical observation indicates that the mean returns remain relatively stable, fluctuating close to zero, a closer look reveals significant fluctuations, highlighting the volatility to which these markets have been exposed. This volatility is particularly evident in the first few months of 2020, coinciding with the beginning of the impact of the COVID-19 pandemic on the global economy.

Figure 1

Evolution, in levels, of the clean energy and precious metals stock indices analysed from 1 January 2018 to 23 November 2023

Source: Own elaboration
Figure 2 shows the average returns for Gold (Gold, Handy & Harman), Silver (Silver, Handy & Harman) and Platinum (London Platinum), as well as for sustainable energy stock indices such as Clean Energy Fuels, S&P Global Clean Energy, Wilderhill Clean Energy and NASDAQ Clean Edge Green Energy, over the period from 1 January 2018 to 23 November 2023. Observation shows that the average returns are positive, particularly for green indices such as Clean Energy Fuels (0.00035), Nasdaq Clean (0.00036), S&P Global Clean (0.00025) and Wilderhill (2.11e-05). Concerning precious metals, Silver (0.00021) and Gold (0.00028) show positive average returns, while Platinum (-2.10e-06) shows negative average returns.

Figure 2
Evolution of the mean returns for the clean energy and precious metals stock indices from 1 January 2018 to 23 November 2023

The results in Figure 3 show the standard deviations of the precious metals and green stock indices from 1 January 2018 to 23 November 2023. Looking at the data, note that the Clean Energy Fuels index (0.0478) has the highest standard deviation from the mean, indicating the greatest dispersion of returns and, therefore, being the most volatile among the indices analysed. Moreover, the Wilderhill (0.02719), Nasdaq Clean (0.02372), and S&P Global Clean (0.01702) green energy indices show risk levels above those of precious metals. In other words, they have more significant variability in returns compared to Gold (0.0088), Silver (0.01671) and Platinum (0.01700). These results have important implications for investors. A high standard deviation suggests greater uncertainty and risk associated with asset returns. Therefore, investors may need to consider these differences in volatility when making investment decisions. While managing their portfolios, investors can adjust their asset...
allocations according to the level of risk they are willing to tolerate, taking into account the volatility of the different assets available.

**Figure 3**

*Evolution of the standard deviations for the clean energy and precious metals stock indices from 1 January 2018 to 23 November 2023*

![Graph showing standard deviations for clean energy and precious metals stock indices](image)

Source: Own elaboration

The results in Figure 4 reveal asymmetries in the returns of precious metals and green stock indices over the period analysed, from 1 January 2018 to 23 November 2023. These asymmetries are evidenced by values other than zero. The Clean Energy fuels green index (0.6173) distinguishes itself from its peers by showing no negative asymmetries, while the Wilderhill (-0.1457), Nasdaq Clean (-0.2974), S&P Global Clean (-0.3817) green energy indices and the Platinum (-0.4453), Silver (-0.4543) and Gold (-0.3134) precious metals show negative values. In practice, these results show that the time series of these assets may not follow a Gaussian distribution, i.e. a symmetrical normal distribution.

These results have important implications for investors and portfolio managers. Firstly, it increases the risk and volatility associated with these assets, suggesting the possibility of more extreme price movements in one direction than another. Secondly, portfolio managers should consider these asymmetries to avoid inaccurate risk estimates and inappropriate investment decisions when modelling asset risk. Thirdly, portfolio diversification becomes crucial, as investing in various assets can help mitigate the risks associated with these asymmetries and protect against extreme price movements. Finally, investors may prefer assets with less pronounced asymmetries when selecting assets to incorporate into their portfolios, especially those who wish to reduce the tail risk in return distributions.
Figure 4

Evolution of the asymmetries for the clean energy and precious metals stock indices between 1 January 2018 and 23 November 2023

The results in Figure 5 show the kurtosis of precious metals and green stock indices from 1 January 2018 to 23 November 2023. Graphically, it can be seen that the kurtosis values are different from 3, which shows non-Gaussian return distributions. The Clean Energy Fuels index (15.2943) stands out from its peers because it has the most significant value, indicating a distribution of returns with heavier tails, i.e. a greater probability of extreme returns occurring. Furthermore, the green energy indices Wilderhill (11.4568), S&P Global Clean (10.3532), Nasdaq Clean (7.0004), as well as the precious metals Platinum (8.4120), Silver (9.0201) and Gold (7.2186) also show very significant kurtosis values. This suggests that all these assets have return distributions that differ significantly from a normal distribution, which could have important implications for risk modelling and investment decision-making. Summarising, the interpretation of these results highlights the complexity of the return distributions of precious metals and green stock indices, highlighting the presence of heavier tails and a greater likelihood of extreme returns compared to a normal distribution.
Extreme Events Cause Market Efficiency or Inefficiency? Evidence from Precious Metals and Green Stock Indices

Figure 5

Evolution of the kurtosis for the clean energy and precious metals stock indices analysed from 1 January 2018 to 23 November 2023

Source: Own elaboration

Figure 6 shows the presence of disturbances in the variance and violations of the probability limits at 95%. Graphical analysis reveals unstable behaviour in the markets analysed.

Figure 6

Stability Test to the recursive residuals of the clean energy and precious metals stock indices analysed from 1 March 2018 to 23 February 2023
Table 1 shows the results of the Detrended Fluctuation Analysis (DFA) exponent for the daily prices of clean energy and precious metals stock indices analysed during the Tranquil and the 2020 pandemic periods.

In the Tranquil period, Gold and the green energy stock indices, Nasdaq Clean Edge and WilderHill, are in equilibrium, and the random walk hypothesis is not rejected. These results show that the information that reaches the market is adjusted efficiently, making possible arbitrage strategies impossible. On the other hand, Platinum (0.52), S&P Global (0.54) and Clean Energy Fuels (0.61) are also found to have long memories, i.e. persistence in their returns, thus showing that new information arriving on the market does not adjust immediately and that past prices are autocorrelated over time, having said that the residuals are not independent and identically distributed (i.i.d). Regarding Silver, the slope shows anti-persistence, thus showing
short-term memories. It also shows that the random walk hypothesis has been rejected, and there may be an opportunity to gain above the market without incurring additional risk.

Concerning the 2020 global pandemic period, it was found that all markets rejected the random walk hypothesis, i.e. they are not efficient in their weak form. The precious metals markets, such as Silver (0.62) and Platinum (0.59), show very significant long memories with high DFA slopes, while the green energy indices also show similar characteristics, such as S&P Global Clean (0.62), Wilderhill (0.59) and Nasdaq Clean (0.57). These markets show significant (in)efficiencies in adjusting to new information that reaches the market, thus showing a price pattern that could create significant arbitrage opportunities. On the other hand, short-term memories are also present, particularly for Gold (0.48) and the Clean Energy Fuels green index (0.48). In practical terms, these results indicate that during the period of stability, arbitrage strategies are hampered in the Gold markets and the Nasdaq Clean Edge and Wilderhill green indices, while opportunities for gains above the market average may exist in Platinum, Silver and in the S&P Global Clean and Clean Energy Fuels green indices. However, during the 2020 global pandemic, all markets showed inefficiencies; in practical terms, persistence in returns indicates that asset prices tend to continue in the same direction for an extended period rather than quickly returning to the mean. This suggests opportunities to identify ongoing market trends for investment. These results align with the findings of authors Chambino et al. (2023) and Dias, Horta, et al. (2023a), who validated that the 2020 global pandemic has caused long memories in international markets.

Table 1

<table>
<thead>
<tr>
<th>Indices</th>
<th>aDFA (Tranquil)</th>
<th>Results</th>
<th>aDFA (COVID-19 Pandemic)</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gold</td>
<td>0.50 ± 0.0019</td>
<td>Random Walk</td>
<td>0.48** ± 0.0026</td>
<td>Anti - Persistence</td>
</tr>
<tr>
<td>Platinum</td>
<td>0.52** ± 0.0044</td>
<td>Persistence</td>
<td>0.59** ± 0.0027</td>
<td>Persistence</td>
</tr>
<tr>
<td>Silver</td>
<td>0.49** ± 0.0014</td>
<td>Anti - Persistence</td>
<td>0.62** ± 0.0015</td>
<td>Persistence</td>
</tr>
<tr>
<td>S&amp;P Global Clean</td>
<td>0.54** ± 0.0011</td>
<td>Persistence</td>
<td>0.62** ± 0.0041</td>
<td>Persistence</td>
</tr>
<tr>
<td>Nasdaq Clean</td>
<td>0.50 ± 0.0084</td>
<td>Random Walk</td>
<td>0.57** ± 0.0023</td>
<td>Persistence</td>
</tr>
<tr>
<td>Clean Energy Fuels</td>
<td>0.61** ± 0.0021</td>
<td>Persistence</td>
<td>0.48** ± 0.0032</td>
<td>Anti - Persistence</td>
</tr>
<tr>
<td>Wilderhill</td>
<td>0.50 ± 0.0078</td>
<td>Random Walk</td>
<td>0.59** ± 0.0022</td>
<td>Persistence</td>
</tr>
</tbody>
</table>

Note: The hypotheses are $H_0: \alpha = 0.5$ and $H_1: \alpha \neq 0.5$. ** Interval de confiança a 95%.
Source: Own elaboration

Table 2 shows the results of the Detrended Fluctuation Analysis (DFA) exponent for the daily prices of Gold (Gold, Handy & Harman), Silver (Silver, Handy&Harman) and platinum...
(London Platinum), as well as green stock indices such as Clean Energy Fuels, Nasdaq Clean Edge Green Energy, S&P Global Clean Energy and WilderHill Clean Energy, during the pre-Conflict period and the geopolitical Conflict between Russia and Ukraine in 2022.

In the pre-Conflict period, none of the markets analysed were in equilibrium, i.e., the random walk hypothesis was rejected at a significance level of 5%. However, when analysing the precious metals and the green energy indices, differences are found: precious metals such as Gold (0.46), Platinum (0.45) and Silver (0.48) show anti-persistence, i.e. short-term memories. The practical implications of anti-persistence in financial market returns refer to a characteristic in which short-term returns tend to be inversely related to future returns. In other words, if a financial asset exhibits anti-persistence, a positive return in a given period is more likely to be followed by a negative return in the next period, and vice versa. On the other hand, the green indices show significant persistence, for example, S&P Global Clean (0.55), Nasdaq Clean (0.56), Clean Energy Fuels (0.52), and Wilderhill (0.55). In practical terms, persistence in returns can be interpreted as a measure of momentum or trend in the financial markets, in other words, it reflects the idea that asset prices can continue to move in the same direction for a period, rather than quickly reverting to the mean, thus providing above-average gains by the pattern of prices they show.

The conflict period has a very similar trend to the 2020 global pandemic period. The precious metals and green energy indices mostly converge towards persistence, except the precious metal Platinum (0.49), which shows anti-persistence. In terms of results, Gold (0.54), Silver (0.54), S&P Global Clean (0.59), Nasdaq Clean (0.56), Clean Energy Fuels (0.55), and Wilderhill (0.53) show very strong persistence. In technical terms, the convergence towards persistence in the returns of precious metals and green energy indices suggests the presence of common patterns in price formation.

Differences and similarities can be seen in the financial markets when comparing the pre-Conflict and Conflict periods. In the pre-conflict period, no market is in equilibrium, with the rejection of the random walk hypothesis. Precious metals such as Gold, Platinum and Silver show anti-persistence in returns, while the green indices show significant persistence, indicating a continuing price trend. During the Conflict, precious metals and green energy indices converge towards persistence in returns, except for Platinum, which shows anti-persistence. This suggests consistent patterns in the markets during economic uncertainty. In practical terms, this convergence towards persistence provides valuable insights into how prices are influenced by macroeconomic events, allowing for adjustments in investment strategies and risk
management as necessary. These observations emphasise the importance of understanding market patterns to adapt to economic and political changes.

**Table 2**

*DFA exponent for returns. The values of the linear adjustments for αDFA always had R² > 0.99*

<table>
<thead>
<tr>
<th>Indices</th>
<th>αDFA (Pre-Conflict)</th>
<th>Results</th>
<th>αDFA (Conflict)</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gold</td>
<td>0.46** ± 0.0027</td>
<td>Anti-Persistence</td>
<td>0.54** ± 0.0013</td>
<td>Persistence</td>
</tr>
<tr>
<td>Platinum</td>
<td>0.45** ± 0.0016</td>
<td>Anti-Persistence</td>
<td>0.49** ± 0.0068</td>
<td>Anti-Persistence</td>
</tr>
<tr>
<td>Silver</td>
<td>0.48** ± 0.0013</td>
<td>Anti-Persistence</td>
<td>0.54** ± 0.0047</td>
<td>Persistence</td>
</tr>
<tr>
<td>S&amp;P Global Clean</td>
<td>0.55** ± 0.0015</td>
<td>Persistence</td>
<td>0.59** ± 0.0011</td>
<td>Persistence</td>
</tr>
<tr>
<td>Nasdaq Clean</td>
<td>0.56** ± 0.0138</td>
<td>Random Walk</td>
<td>0.56** ± 0.0012</td>
<td>Persistence</td>
</tr>
<tr>
<td>Clean Energy Fuels</td>
<td>0.52** ± 0.0013</td>
<td>Persistence</td>
<td>0.55** ± 0.0077</td>
<td>Persistence</td>
</tr>
<tr>
<td>Wilderhill</td>
<td>0.55** ± 0.0019</td>
<td>Persistence</td>
<td>0.53** ± 0.0013</td>
<td>Persistence</td>
</tr>
</tbody>
</table>

Note: The hypotheses are $H_0: \alpha = 0.5$ and $H_1: \alpha \neq 0.5$. ** Intervalo de confiança a 95%.

Source: Own elaboration

5 CONCLUSION

This study examined the multifractality between precious metals (Gold, Silver, Platinum) and green stock indices, such as Clean Energy Fuels, Nasdaq Clean Edge Green Energy, S&P Global Clean Energy and WilderHill Clean Energy, during the period from 1 January 2018 to 23 November 2023. The study's main question is: i) Did the events that occurred in 2020 and 2022 cause efficiency or inefficiency in the markets analysed?

The analysis covered four distinct periods, revealing valuable insights into asset price behaviours and the efficiency of financial markets in different contexts. During the Tranquil period, there was a clear division between markets, with Gold and green energy indices demonstrating market efficiency. Meanwhile, Platinum, Silver and some green indices exhibited long memories in returns, indicating persistence in prices and potential opportunities for above-average gains.

On the other hand, the 2020 global pandemic brought widespread inefficiencies in all the markets analysed, with precious metals and green energy indices showing very significant long memories, suggesting the presence of patterns in prices that could lead to arbitrage opportunities. During this period, the persistence in returns indicated a tendency for asset prices to continue in the same direction for a prolonged period rather than quickly returning to the mean, offering opportunities to identify ongoing market trends for investment.
In the pre-conflict period, it was observed that all the markets analysed rejected the random walk hypothesis, with precious metals exhibiting anti-persistence in returns, while green energy indices showed significant persistence. During the Conflict, precious metals and green energy indices converged towards persistence in returns, except Platinum, which showed anti-persistence.

5.1 PRACTICAL IMPLICATIONS

The results of this study are highly relevant for investors, portfolio managers and financial market professionals. Firstly, understanding the patterns of asset price behaviour in different economic scenarios makes it possible to adapt investment strategies. During periods of stability, where market efficiency is high, arbitrage strategies can be less effective, while in times of crisis, identifying ongoing market trends can be more profitable. Moreover, analysing short- and long-term memories of asset returns is crucial for risk management. Investors can adjust their positions based on the likelihood of market trends reversing or continuing, thus mitigating losses and optimising risk-adjusted returns.

Portfolio diversification also benefits from these insights. By recognising differences in asset price behaviour, investors can allocate resources more effectively, distributing them between assets that show persistent returns during periods of turbulence and assets that offer above-average earnings potential during periods of stability. Additionally, the patterns identified in asset prices can be used to identify investment opportunities. During periods of persistent returns, investors can look for assets that show a continuing trend, while periods of anti-persistence can indicate buying or selling opportunities based on the expectation of a trend reversal. Finally, the importance of continuous market monitoring is emphasised. Given the dynamics of financial markets, investors and financial market professionals must constantly monitor changes in asset price behaviour patterns and adjust their investment strategies in response to new information and market conditions.

5.2 LIMITATIONS AND SUGGESTIONS FOR FUTURE RESEARCH

The limitations of this study include the lack of consideration of other variables that could influence asset prices, such as macroeconomic conditions, government policies and industry-specific events. For future research, it would be interesting to incorporate a more holistic approach, considering multiple factors that influence asset prices and comparing
different time series analysis methods to verify the robustness of the results. Furthermore, additional research could explore the impact of specific events, such as economic or political shocks, on market efficiency and asset price patterns during periods of crisis and stability.

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across clean energy indices and grain commodity markets around COVID-19 crisis. 