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Testing the weak form of the Efficient Market Hypothesis and the impact of COVID-19 in LAC countries

Análisis de la Hipótesis de Mercados Eficientes y el impacto del COVID-19 en los países de América Latina y el Caribe

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ABSTRACT

This study analyses the impact of the pandemic on the poor performance of stock markets in Latin America and the Caribbean (LAC) by examining the COLCAP, BOVESPA, IPSA, MERVAL and MEXBOL indices between January 2018 and March 2021, with a particular focus on the first half of 2020. The proposed methodology is relatively new and consists of a sequential combination of statistical tests designed to determine whether index returns follow a random walk, and if so, what type this is. Empirical evidence shows that sharp price declines and increased volatility associated with the pandemic generally favoured weak-form efficiency in these markets. This reduced short-term return predictability and reinforced the role of prices in processing available information quickly. Additionally, the results imply that the impact of the pandemic on LAC markets was not uniform, but it did lead to a faster and more consistent incorporation of global and local news into stock prices, with significant implications for investor risk management and policymakers responsible for financial stability.

PALABRAS CLAVE

Hipótesis del Mercado Eficiente
Forma Débil
COVID-19
Mercados Financieros Latinoamericanos
Paseo Aleatorio

RESUMEN

Este estudio analiza el impacto de la pandemia en el bajo rendimiento de los mercados bursátiles de América Latina y el Caribe (ALC) mediante el examen de los índices COLCAP, BOVESPA, IPSA, MERVAL y MEXBOL entre enero de 2018 y marzo de 2021, con especial atención al primer semestre de 2020. La metodología propuesta es relativamente nueva y consiste en una combinación secuencial de pruebas estadísticas diseñadas para determinar si los rendimientos de los índices siguen un paseo aleatorio y, en caso afirmativo, de qué tipo es. La evidencia empírica muestra que las fuertes caídas de los precios y el aumento de la volatilidad asociados a la pandemia favorecieron en general la eficiencia débil en estos mercados. Esto redujo la previsibilidad de los rendimientos a corto plazo y reforzó el papel de los precios en el

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procesamiento rápido de la información disponible. Además, los resultados implican que el impacto de la pandemia en los mercados de América Latina y el Caribe no fue uniforme, pero sí condujo a una incorporación más rápida y consistente de las noticias globales y locales en los precios de las acciones, con importantes implicaciones para la gestión del riesgo de los inversores y los responsables políticos encargados de la estabilidad financiera.

1. INTRODUCTION

At the end of 2019, the SARS-Cov-2 virus and the disease caused by its infection, COVID-19, appeared in the Chinese city of Wuhan, and the World Health Organisation (WHO) declared it a global pandemic on 12 March 2020. World trade, social and cultural life, and structures of the most important sectors in all countries have been dramatically affected. The rapid transmission of the disease has also had a severe impact on financial markets, causing significant losses to investors in a very short time, slowing down the economies of the affected countries, delaying the growth of emerging countries, and accentuating the negative effects.

This systemic damage had a significant impact on the global economy and directly affected one of the fundamental components of the market system, the existence of an efficient capital market. Although Bachelier (1900) already characterised, in a certain way, the concept of an efficient market, Cowles (1933) was a later pioneer in the study of market efficiency with an empirical approach. He concluded that financial analysts' recommendations of his time did not regularly predict the market, thus demonstrating that the North American market was efficient at that time. Later, in the 1950s, Kendall (1953), Roberts (1959) and Osborne (1959) studied the behaviour of financial series and asset prices and detected random and seasonal patterns. However, it was not until the following decade that Mandelbrot (1963) and Samuelson (1965) used mathematical models to relate the stock series. Specifically, Samuelson challenged the idea that the competition of a speculative market was based on a random walk model, highlighting that this is not related particularly to perfect competition or market anticipation, and suggested replacing the random walk model with another stochastic process using Martingales. Thus, proposed the so-called mathematically excepted price formation (Samuelson, 1965). This axiom states that investors know and use the probability distribution defined by the relationship:

$$Yt,T = E[Pt_{+}T \mid It] \qquad (1)$$

Where the actual price, $Y_{t,T,}$ is conditioned on all information available at t, is the best predictor of future prices.

However, Fama (1965) compiled the empirical work conducted until then and laid the theoretical foundations, introducing one of the main theories of financial economics: the theory of capital market efficiency.

The term efficiency, when talking about financial markets, refers to the fact that a market is efficient when it comes to processing information; that is, the prices of the securities that make up that market, at any time, are based on a fair evaluation of all the information available at that precise moment. Thus, in an efficient market, asset prices fluctuate randomly around their fundamental values; therefore, on average, the current price is the best estimate of fundamental value, faithfully reflecting the information available to investors and agents that make up that market, and being precise signals for the placement of capital at that moment. With this assumption, in a general equilibrium context and in a market in which the agents that intervene are fully informed, Fama (1965) proposed three forms of efficiency that started the debate on efficiency:

- Weak form of efficiency: In this case, a technical analysis of the market is useless because it is impossible to increase performance using historical information on trends, indices, or prices. New information can affect only the market, and these changes are random because of their nature.

- Semi-strong form of efficiency: Fundamental investment analysis is useless, as the investor cannot obtain extra return using public information about a particular security or company because the prices of the shares already reflect all available public information.
- Strong form of efficiency: Privileged or private information is useless, as all public or private information is already reflected in current share prices, and investors cannot obtain any additional returns using this type of information.

In this context, previous literature has highlighted the relevance of analysing the Efficient Market Hypothesis, with the weak form having been widely studied. However, it should be noted that the COVID-19 crisis had a profound global impact that could have affected the efficiency of Latin American capital markets in several ways:

1. *Increased Volatility:* The COVID-19 pandemic led to heightened uncertainty and volatility in global financial markets, including those in Latin America. Sharp fluctuations in asset prices and trading volumes may have affected market efficiency by making it more difficult for prices to accurately reflect underlying fundamentals and information; this is the central research of El-Khatib & Samet, (2021) where the authors explore the impact of COVID-19 in 45 emerging countries (including Argentina, Brazil, Chile, Colombia and Mexico) and track the performance of each of the markets during the outbreak using its major stock index computing the volatilities.
2. *Disruptions to Information Flow:* The pandemic disrupted economic activity, supply chains, and financial reporting processes in Latin American countries. This disruption may have affected the flow of information to market participants, leading to delays or inaccuracies in the incorporation of new information into asset prices (Beirne *et al*., 2021).
3. *Policy Responses:* Governments and central banks in Latin American countries implemented various fiscal and monetary policy measures in response to the COVID-19 crisis, including stimulus packages, interest rate cuts, and liquidity injections (Solorza, 2021). These policy interventions may have influenced market dynamics and investor behavior, potentially impacting market efficiency.
4. *Sectoral and Regional Variations:* The impact of the COVID-19 crisis varied across sectors and regions within Latin American countries. Some sectors, such as healthcare, technology, and e-commerce, experienced in-creased demand and resilience, while others, such as tourism, hospitality, and energy, were severely affected. These sectoral and regional variations may have influenced the efficiency of capital allocation and asset pricing in Latin American markets (Benítez *et al*., 2020; Ahumada *et al*., 2022)
5. *Behavioural Factors:* The COVID-19 crisis-induced fear, uncertainty, and herding behavior among investors, which may have led to deviations from rational decision-making and affected market efficiency. Behavioral biases, such as overreaction or underreaction to news and events, could have distorted asset prices and hindered market efficiency (Huynh, 2021).

Taking all of the above into account, the aim of this empirical study is to analyse the impact of the pandemic on weak efficiency in the five major financial markets of Latin America and the Caribbean (LAC).

To this end, the study considers the markets of Brazil, Argentina, Colombia, Mexico, and Chile are considered, establishing two study periods. The first, 'the global period' (January 2018-March 2021), will enable analysis of structural efficiency behaviour over a complete economic cycle. The sub-period, comprising data from the first half of 2020, will capture market behaviour during a period of high uncertainty and volatility. This will allow us to integrate the motivations of investors, regulators and economic policymakers within the same empirical framework, which is heavily influenced by the situation.

Testing the weak from of the Efficient Market Hypothesis (EMH) in these countries, especially in the context of the COVID-19 pandemic, may therefore have several practical implications with a social impact on the various market participants.

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From an investment decision-making perspective, investors in Latin American countries may be interested in understanding the extent to which past price information can help predict future price movements, particularly during times of economic uncertainty like the COVID-19 pandemic. Testing the weak form of the EMH can provide insights into the efficiency of local financial markets and help investors make more informed decisions about asset allocation, portfolio diversification, and risk management.

On the other hand, policymakers and regulators in Latin American countries may be concerned about the efficiency and stability of their financial markets, especially in the face of external shocks like the COVID-19 pandemic. Testing the weak form of the EMH can help assess the degree to which market prices reflect all available information and identify potential inefficiencies or anomalies that may warrant regulatory intervention or market reforms. This is closely related to government policies as they may be interested in promoting financial market development and attracting foreign investment to support economic growth and development. Testing the weak form of the EMH can provide valuable insights into the transparency, integrity, and efficiency of local financial markets, which are important factors for both domestic and international investors.

Finally, financial institutions and market participants in Latin American countries may be concerned about the impact of the COVID-19 pandemic on market volatility, liquidity, and systemic risk. Testing the weak form of the EMH can help assess the degree to which market prices accurately reflect underlying fundamentals and information flows, which is crucial for effective risk management and maintaining financial stability.

The paper is organised as follows. The first section presents the paper, the main motivations for its completion, and its objective. Section 2 reviews the existing literature in two ways. First, it presents actual studies and analyses on capital market efficiency, with a special focus on Latin American countries. Next, the most relevant contributions on the impact of the pandemic on the financial markets of these countries are indicated. Section 3 addresses the methodology based on the theoretical foundations of capital market efficiency, which support the need to apply the proposed methodology in the HME testing process. Sections 4 and 5 present the empirical results and discussion, respectively. The final section presents the conclusions, highlighting the most relevant aspects of the research, the limitations of the study and future lines of research.

2. LITERATURE REVIEW

2.1. The Efficient Market Hypothesis

Since Fama (1965) introduced the notion of an 'efficient market', much controversy has arisen in discussions of finance and economics. Critics argue that there are many reasons to doubt that shareholders are always rational and that share prices are efficient at all times since share prices are influenced by investors psychological perceptions (optimism/pessimism) of the economic outlook. Lekovic (2018), presents evidence for and against the validity of the weak, semi-strong, and strong forms of the EMH, concluding that, even after more than half a century of research, the literature has not reached a consensus on the presence or absence of the validity of this hypothesis. However, the financial literature focused on testing this theory, especially in its weak form, is abundant, both in developed markets and emerging countries. According to Duarte & Mascareñas (2014), the United States and China are the most commonly analysed markets to verify this theory. However, in recent years the verification of EMH in other countries and with new methods also aroused interest among researchers. For example, Durusu *et al*. (2019) apply a new methodology based on panel unit root tests to determine whether equity markets are efficient by focusing on the role of cross-dependency and structural breaks. Hamid *et al*. (2017) provide empirical evidence of the weak form of the EMH in Asia-Pacific markets, concluding that monthly prices do not follow random walks in any country in that region.

Kim & Shamsuddin (2008) test the martingale hypothesis in the stock prices of a group of Asian markets, concluding that Hong Kong, Japan, Korea and Taiwan are weakly efficient, while those of Indonesia, Malaysia and the Philippines show no sign of market efficiency, despite the financial liberalisation measures implemented since the 1980s.

The weak form is also tested by Alexeev & Tapon (2021) using a model-based bootstrap to generate a series of simulated trials and applying a modified chart pattern recognition algorithm to stocks listed on the Toronto Stock Exchange, comparing the results from the actual and simulated series to draw inferences on weak-form efficiency in the overall Canadian market and its sectors. They conclude that the weak-form efficiency hypothesis is rejected when they find a significantly larger number of reversal patterns in a real price series than in a simulated series.

Rehman et. al. (2018) provide evidence that the stock prices of the Asian indices KSE 100, S&P BSE 500, and CSE All Share are not random processes, and therefore meet the weak efficiency hypothesis. Singh and Kumar (2018), on the other hand, examine whether the stock market in Kuala Lumpur, Malaysia, is efficient and whether equity returns follow a random walk model, concluding that equity prices in that market do not reflect all the above stock price information and that investors can earn abnormal returns by taking advantage of this market inefficiency. Malafeyev *et al*. (2019) test the efficiency of the market by studying the impact of the global financial crisis of 2008 and the Chinese crisis of 2015 on the efficiency of the securities market in the emerging markets of China and India. They conclude that the equity markets of these countries do not exhibit a weak form of efficiency and do not generally follow a random path, which implies that the recession did not affect the markets to a great extent. Sadat and Hasan, (2019) measure the efficiency of the market and the randomness of the Dhaka Stock Exchange (DSE) in its weak form during a five-year period from 2013 to 2018.

Recently, Das (2020) investigates whether the Indian market behaves like a random walk and shows a weak form of efficiency, while Gallo (2021) evaluated whether the efficiency of the Chinese market changed over time given the country's economic reforms.

Emerging markets in southeastern Europe were also analysed. For example, Filipovski & Tevdovski (2018) use the ratio of variance test to explore the hypothesis of the random walk in the daily returns of securities in ten Eastern European markets from 2007 to 2014. Atac & Tas (2019) investigate the weak form of market efficiency in the Istanbul Stock Exchange (ISE).

On the other hand, Mlambo & Biekpe (2007) and Mphoeng (2019) focus on the weak form of efficiency in African markets; the former show evidence from 10 African countries, while the latter focuses on the Botswana capital market. Other authors, such as Olubiyi & Olopade (2018) and Altin (2020), verified the efficient market hypothesis in Islamic capital markets. Also, García-Moreno *et al*. (2019), Dias *et al*., (2019), Zhu *et al*., (2019) and Sánchez-Granero *et al*., (2020), focused on Latin American markets.

2.2. The impact of COVID-19 on financial markets

The past pandemic caused chaos and fear, which resulted in business closures, curfews, temporary confinement of the population, reduction of practically all labour and commercial activity, lower purchases, except for basic supplies, and a fall in economic and financial returns. This made the scientific community question, once again, the operation of the efficiency of capital markets and generated interest in seeing the effects on the structures and dynamics of capital markets in many countries. For example, Senol & Zeren (2020) investigated the effect of the COVID-19 outbreak on global markets between January and April 2020 concluding that it affected the world economically. Dias *et al.* (2020) and Sansa (2020) tested the efficiency hypothesis in the context of COVID-19 in the capital markets of the US, China, and Europe, finding mixed confirmation about the EMH in the sense that prices do not fully reflect the information available and its changes are not independent and identically distributed (IID). Zeren & Hizarci, (2020) also verify the impact of the coronavirus in a selection of countries such as China, Italy, South Korea, France, Germany, and Spain and conclude that only in three countries, namely Italy, France and German, did not act according to the efficient market hypothesis. Liu *et al.* (2020) analyse the effect of the COVID- 19 outbreak in 21 of the main stock indexes of the most affected countries, including Japan, Singapore, Korea, the US, Germany, Italy, Spain, and the UK.

Their results suggest that COVID-19 had a significant negative effect on stock market returns across all affected countries. Khan *et al*., (2020) analyses the impact of the virus on the world's largest indices, and like He *et al*. (2020), reveal that investors in these countries did not react to media news of COVID-19 in the early stage of the pandemic. However, in the words of the authors, once human-to-human transmissibility had been confirmed, all stock market indices negatively reacted to the news in the short- and long-event window. Ali *et al*. (2020) also investigate the reaction of financial markets worldwide in terms of their decline and volatility as the epicentre of COVID-19 moved from China to Europe and then to the US.

Consistent with our proposal, Heliodoro *et al*. (2020a, 2020b), Alexandre *et al*. (2020), and Santos *et al*. (2020) verify the efficient market hypothesis in its weak form in the main markets of the Latin America. Recently, Okorie & Lin (2021) used martingale processes and conditional heteroscedasticity tests to evaluate the adaptive form of market efficiency for four stock indices of the first economies affected during the pandemic: the US, Brazil, India, and Russia. García-Moreno & Roldán, (2021) analyse the weak hypothesis in the Spanish, German, and Italian markets from January 2010 to March 2020, showing that the markets of those countries are efficient under the random walk in form 3.

Seeking the relationship between free trade and financial markets' efficiency, Baig *et al*. (2021), develop and test the hypothesis that trade restrictions can inhibit informational efficiency in financial markets. The multivariate tests used reveal that as the level of free trade increases, stocks become more informationally efficient, concluding that free trade improves the overall efficiency of financial markets.

On the other hand, Bassiouny *et al.* (2023) study the impact of COVID-19 from the *adaptive market hypothesis* (AMH) approach with calendar effect, since it has been shown that calendar anomalies used to examine violations of the EMH were not very conclusive their approach uses the rolling window analysis and estimate a T-GARCH (1,1) for a long time series that includes two years coinciding with the COVID-19 pandemic. The empirical findings validate the AMH paradigm by showing that calendar day anomalies in the sample markets used behave in a time-varying manner, changing over time according to patterns that move the markets between periods of efficiency and inefficiency.

Dos Santos (2023), in contrast, evaluates price efficiency dynamics and relates them to stock price predictability in the Brazilian equity market by using a novel approach based on multifractal analysis to examine stylized financial time series factors, such as long-memory dependence, asymmetry, and persistence, related to market inefficiency confirming multifractality before and after the pandemic and rejecting, therefore the random walk hypothesis.

Similarly, Aslam *et al*. (2023) examine the dynamic changes in the market efficiency of six major cryptocurrencies, using also the multifractal analysis confirming a varying degree of multifractal strength in the cryptocurrencies under consideration, which could be related to market inefficiency and fractal market hypothesis verification.

3. THEORETICAL FOUNDATIONS

From a methodological perspective, analysing the weak efficiency hypothesis in financial markets requires clearly specifying the stochastic process underlying price dynamics and how this can be empirically tested.

In fact, Fama (1991) reformulated a less stringent and more reasonable version of the efficiency hypothesis from an economic perspective. Specifically, he stated that market efficiency cannot be verified on its own and proposed examining it in conjunction with a price equilibrium model. Based on this approach, Bailey (2005) proposes a procedure in which he considers the existence of an underlying model in asset pricing, establishing a criterion that determines market efficiency based on a verifiable hypothesis. Of the three forms of efficiency proposed by Fama mentioned above, this study focuses on the weak form. This consists of evaluating sequence (1) in terms of a random process, where it is reduced to the historical price series; these must follow a random process of the type

$$p_t = \mu + p_{t-1} + \varepsilon_t \qquad (2)$$

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where, according to Campbell *et al*. (1997), μ is the expected change in price or drift and ε*t* is a structure of increments that implies that the random walk is a 'fair game' but in a stronger sense than the martingale. That is, traditionally, the martingale and the random walk are assumed to be pricing models *Pt* of a financial asset, whose continuous or logarithmic continuous return is given by the expression

$$rt = \ln Pt - \ln P_{t-1} = p_t - p_{t-1} \qquad (3)$$

The use of logarithmic continuous returns in financial modelling provides several advantages, for instance, they are *additive over time* which is particularly useful for analysing returns over long time horizons, and also for *normality assumptions*, due to logarithmic returns tend to be more normally distributed than simple returns. This is often observed empirically, and it facilitates the use of statistical techniques that assume normality, such as the Black-Scholes option pricing model because of the *statistical properties* of the logarithmic returns, for example, they have a constant variance over time, making them stationary. This simplifies many statistical analyses and modelling techniques, such as linear regression.

Therefore, based on the latter expression (3), we try to model the structure of increments, ε_t as r_t.

On this structure of increments, ε*t* *,* the author establish a series of conditions distinguishing three types of random walk:

- *Random Walk 1* (RW1): In this case, the structure of increments, εt, is IID, with mean 0 and variance σ^2.
- *Random Walk 2* (RW2): The assumption that ε_t is identically distributed is not feasible for returns on financial assets over long periods; in this case, the hypothesis that it is identically distributed is relaxed, and it is assumed to be independent.
- *Random Walk 3* (RW3): This is the least restrictive and most general process, as ε_t is neither independent nor identically distributed, however, it is uncorrelated.

However, the weak form of the EMH is difficult to analyse by applying the most common statistical tests alone, because most of them only contrast a necessary but not sufficient condition for a random walk-type assumption.

With this approach, the weak form of the EMH is difficult to test individually by applying most of the statistical tests that have traditionally been used in the literature, since most of them only test a necessary condition but not sufficient. Still, it is not enough to accept the existence of a random walk in any of its forms, or, in other cases, they only allow testing the randomness of returns, understood as Random Walk (García, 2016) Thus, the same authors propose a strategy of sequential application of different tests, which over- comes the limitation mentioned above for testing the hypothesis of weak efficiency in financial markets; the strategy which they validate through Monte Carlo simulation (Roldán & García-Moreno, 2022) and which will allow us to determine whether the returns of a market are a random walk and, if so, what type it is. The authors conclude that, from a financial perspective, random walks 2 and 3 are the ones that best fit reality, since they allow for the existence of heteroskedasticity[1] (conditional or not) in the structure of increments, $r_t(\varepsilon_t)$.

Thus, the test combination strategy for testing the random walk hypothesis shown in Fig.1 can be started in two different ways. The first is by applying tests that only check a necessary but not sufficient condition for determining that the series of returns follows a random walk. Specifically, the uncorrelatedness of the series is analysed using the Ljung-Box and Ratio-Variance tests (in the form that does not admit heteroskedasticity); so that if the uncorrelatedness hypothesis is rejected, we could not admit the existence of a random walk in any of its forms, and the market in question could not be said to be efficient. On the other hand, if the hypothesis of uncorrelation is accepted, despite knowing that we are dealing with a random walk, we would also have to determine whether or not there are non-linear relationships between the returns, since only then would we be able to decide what type of relationship it is. To this end, we analyse the ARCH effects,

1. In financial return series such as those analysed in this study, volatility is measured by the variance or standard deviation of those returns; when this variance is not constant, it is said that there is heteroscedasticity, a characteristic behaviour of return series.

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whose non-existence would corroborate that we are dealing with a RW1 (corresponding to weak efficiency in its strictest form); while their existence would indicate that we are dealing with a RW3 (corresponding to the loosest form of weak efficiency in financial markets).

The second way to apply the procedure, on the other hand, is using methods that directly test for a form of random walk. Thus, we begin by applying the Runs test (Bradley, 1968) and the BDS test (Broock *et al*., 1996) which allows us to determine directly whether the returns follow a RW1 when the null hypothesis is not rejected in each of the cases. On the other hand, if the null hypothesis is rejected, it only determines that we are not dealing with a series of returns following an RW1, but does not influence the other types of random walk. In these cases, we proceed to apply the Ratio Variance test that considers the existence of heteroscedasticity in the series of returns to determine whether, at least, weak efficiency can be accepted in the form established by RW3; thus, if the null hypothesis is accepted, we would be facing an RW3, while if it is rejected, it is determined that we would not be facing a random walk type 3 or 1.

Based on this methodological framework, we examine HME both for the period from 1 January 2018 to 23 March 2021 (overall period) and for the period from 1 January 2020 to 30 June 2020 in the financial markets of Colombia, Chile, Brazil, Argentina and Mexico. To do so, we use the daily closing values of their respective stock market indices (COLCAP, IPSA, BOVESPA, MERVAL, and MEXBOL), obtained from a Bloomberg© terminal at the official closing time of their corresponding stock markets. The selected stock markets represent more than 90% of the total capitalisation of the countries of Latin America and the Caribbean, reaching US$1.1 billion.

As a preliminary step to verifying the weak form of the efficiency hypothesis in the five indicated stock markets, we require a prior analysis to contextualise the behaviour of each one during the sample period, considering the graphs of the evolution of each price series and the returns associated with each index; in the latter case reflecting market volatility.

To determine the evidence of some form of the random walk hypothesis, and implicitly, the weak efficiency hypothesis, we apply the test procedure specified below to the series of returns associated with each index. Thus, this approach, which allows for the testing of the random walk hypothesis, focuses more on the strategic combination of the methods proposed for the evaluation of the efficiency hypothesis.

This process starts with **a)** considering a methodology that tests only a necessary but not sufficient condition or **b)** considering a method that directly discriminates between types 1 and 3[2]. The methodology, as previously indicated, was validated by Roldán &García-Moreno (2022).

In this sense, if the first part of the process shows an uncorrelated return series with a methodology concerning the first group, the ARCH effects test is appropriate to identify whether the random walk is of 1 or 3. In contrast, the existence of correlation means that the series does not fit into any type of random walk.

On the other hand, regarding the methods that directly test a type of random walk, it is suggested to start the procedure with the one that can contrast a type-1 random walk such that, when the null hypothesis is rejected, with the proposed criterion, it is not possible to discard the fact that the series is of type 3. Therefore, as a preliminary step to declare that we are not facing any kind of random walk, it is proposed to carry out the verification of such an extreme using a method that enables its detection.

The entire process is schematically in figure 1.

2. Considering that testing a type 2 random walk is not based on inference formal procedure, the proposed process is oriented to types 1 and 3 of the random walk.

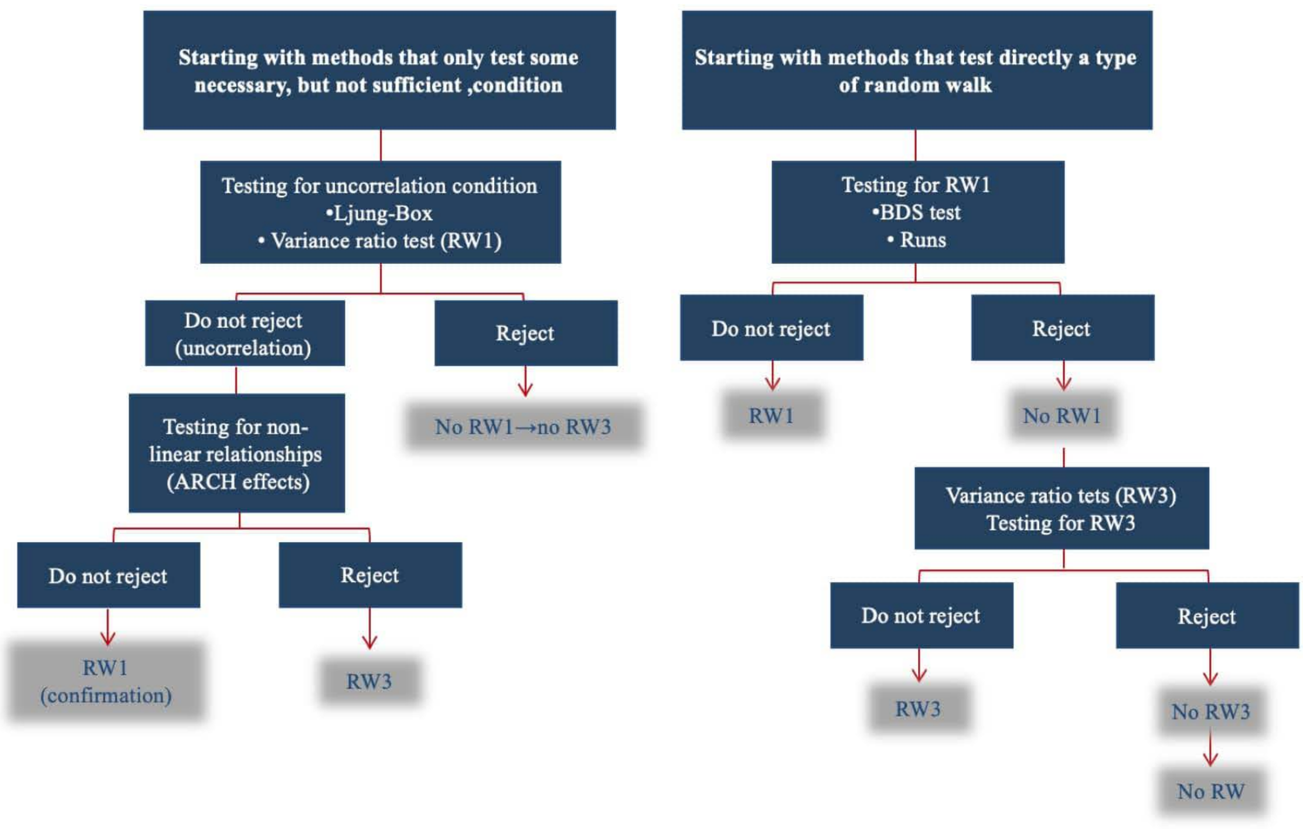

Figure 1. Strategies to test the random walk hypothesis. Source: own elaboration.

In the present analysis, the ratio-variance and the Ljung-Box test are considered from amongst the methodologies that only contrast some necessary conditions but not all of the conditions for the random walk hypothesis, in addition to the BDS test and the streak test (randomness), when starting from methods that proceed to contrast the referred hypothesis directly. If the procedure requires the use of ARCH effects tests to decide between types 1 and 3 of random walks, ARCH models will be used up to order 4.

4. RESULTS

This section presents the results obtained after applying the methodology outlined in the previous section to the daily price data of the COLCAP, BOVESPA, IPSA, MERVAL, and MEXBOL stock indices for the period from January 1 2018 to March 31 2021, including a sub-period limited to the first half of 2020, where the effects of volatility are more pronounced as a result of the official declaration of the COVID-19 pandemic by the WHO.

4.1. Graphical and descriptive analysis

As a starting point, a graphical representation of the indices and their associated returns allows an analysis of the global evolution of each time interval considered, as well as the fluctuations caused by the different facts and events that occurred in the treated period, which may have affected each market.

It is particularly relevant to highlight the effects and consequences of the WHO's declaration of the COVID pandemic in March 2020. Therefore, to facilitate the interpretation of this global reality, we include the series of returns of each index for the first half of 2020.

Starting with the Colombian market and its benchmark index (COLCAP), which reflects the variations in the prices of the most liquid shares on the Colombian Stock Exchange (figure 2a), a recovery trend can be seen from the end of 2019. It peaks in the first trading session of 2020 and repeats after a slight adjustment at the end of February. Since then, the index has pierced the entire series of previous rising lows and plunged by 52% from the highs just one week after the declaration of the pandemic. Up to the most recent date of our analysis, the index managed to recover to just over half of its previous drop to 1,318 trading points. The volatility mean in the series of returns of the index (figure 2b) peaks greater than ±10%. In greater detail, as figure 2c shows, which collects the returns of COLCAP in the pre- and post-COVID-19 period, closest to the date of the declaration. The negative part of performance even exceeds -15%, and despite a certain subsequent relaxation of the instability, volatility has never returned to its previous average, with peaks rather close to ±5%.

The BOVESPA Index, which represents the São Paulo Stock Exchange in Brazil (the seventh largest and most important stock market in the world), showed clear and vigorous growth, reaching high values in the series of prices studied in January 2020. From this point, and after the declaration of the pandemic, it reached a minimum in mid-March 2020, with a drop of 52% very similar to the previous index, although it comes from a different situation: COLCAP index reached 9% since 2018, compared to 53% for BOVESPA.

Since then, it managed to surpass the previous highs just one year later, that is, in January 2021, being immersed on the date of our analysis in a shockwave that should take it to all-time highs. Regarding the average volatility, if we first look at the details extended to the first half of 2020 (figure 3c), a considerable increase is observed, with peaks around ±15% and a greater post-COVID-19 range compared to previous dates. For example, on 3 March 2020, the return reached -14,7%, and the next day, recovered ±13,7% and after the weekend, it lost the previous day's gains. News reported significant global economic setbacks, the absence of public events, and ongoing supply chain disruptions. The complete series (figure 3b) shows that the average returns do not differ much from each other, regardless of the specific moment indicated, and the range of their fluctuations was normalised around ±5%.

Unlike the Colombian index, the IPSA or Selective Stock Price Index of Chile (figure 4a), shows a marked downward trend, with successive decreasing highs and lows since the beginning of 2018, reaching a temporary price floor on dates close to the declaration of the pandemic. Therefore, if we consider this milestone, the index only loses an additional 25%, although considering the maximums in January 2018, the minimum reached at the end of March 2020 also represents a fall of more than 50%. Thus, until the most recent date of our analysis, the index not only recovered to the levels before the great pandemic fell but also exceeded them, reaching approximately 4,800 trading points. The average volatility showed by the series of returns of the index (figure 4b) increases significantly and higher peaks are reached, in the range (+10%, -15%). Figure 4c shows the IPSA yields in the pre- and post- COVID-19 period closest to the date of the declaration, also showing much higher volatility than the pre-pandemic series with peaks around ±4%.

Continuing with the Argentinian market and its reference index (MERVAL), which includes the shares of leading companies listed on the Buenos Aires Stock Exchange (figure 5a), a lateral market with increasing bias can be seen until the current date, although it is marked by two significant milestones. First, in August 2019, a historical collapse occurred as an un- expected reaction to the final results of the presidential elections, scoring a loss of 50% of capitalisation above the maximum. After recovering and repeating with almost the same pattern, we see a similar collapse after the declaration of the pandemic. However, when updated to the last day of our date range, the index exceeded previous highs by more than 5%. The mean volatility, as shown in the series of returns of the index (figure 5b), shows different extremes around ±10%, which are exceeded in the negative end (-15%) due to the pandemic (figure 5c), but far from the -50% milestone during in the 2019 elections. In this sense, the post-COVID-19 volatility has been developing a decreasing wedge structure to dates, in line with the achievement of new price highs.

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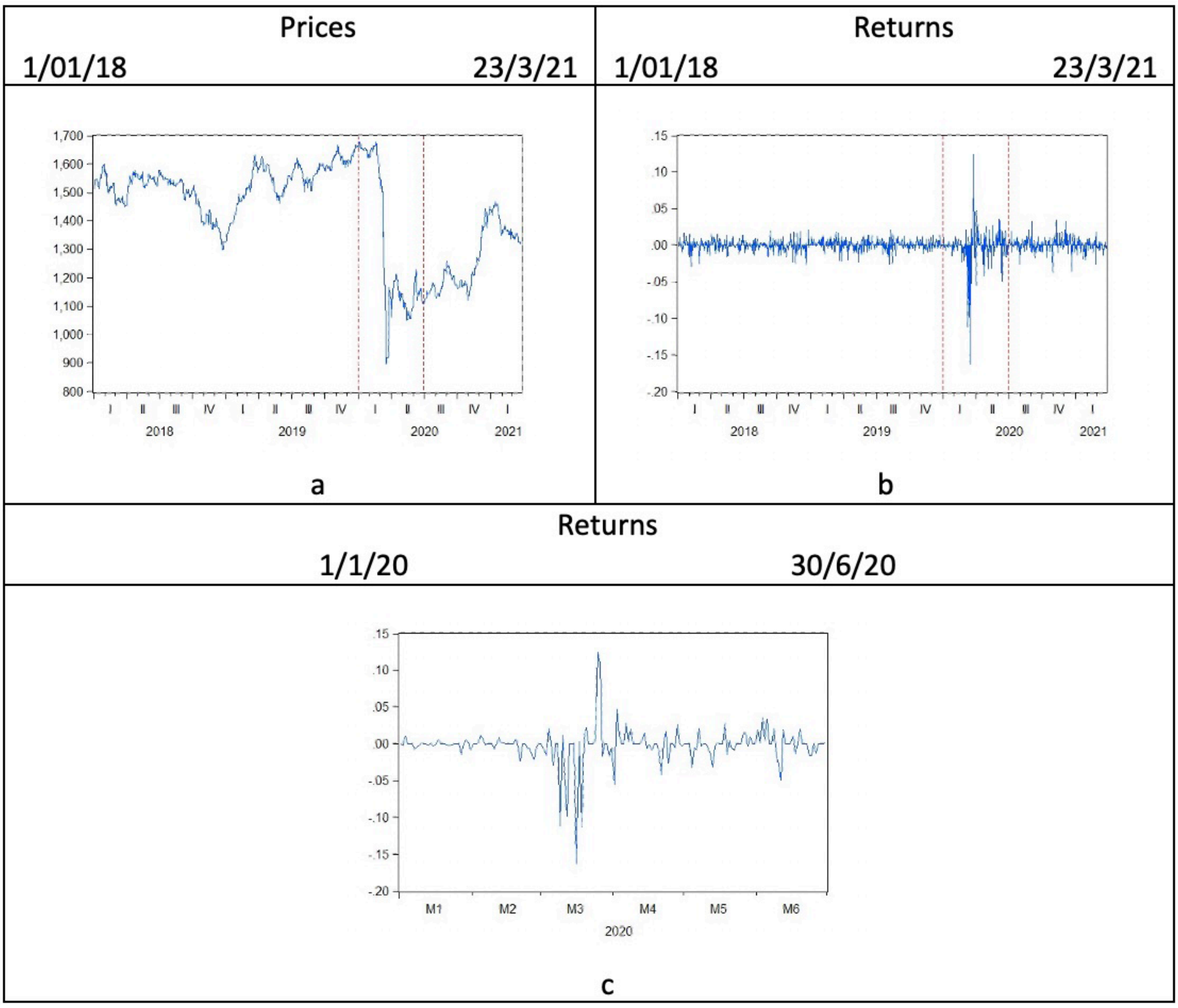

Figure 2. Colcap (Colombian capitalisation) prices and returns. Source: own elaboration with Bloomberg© data.

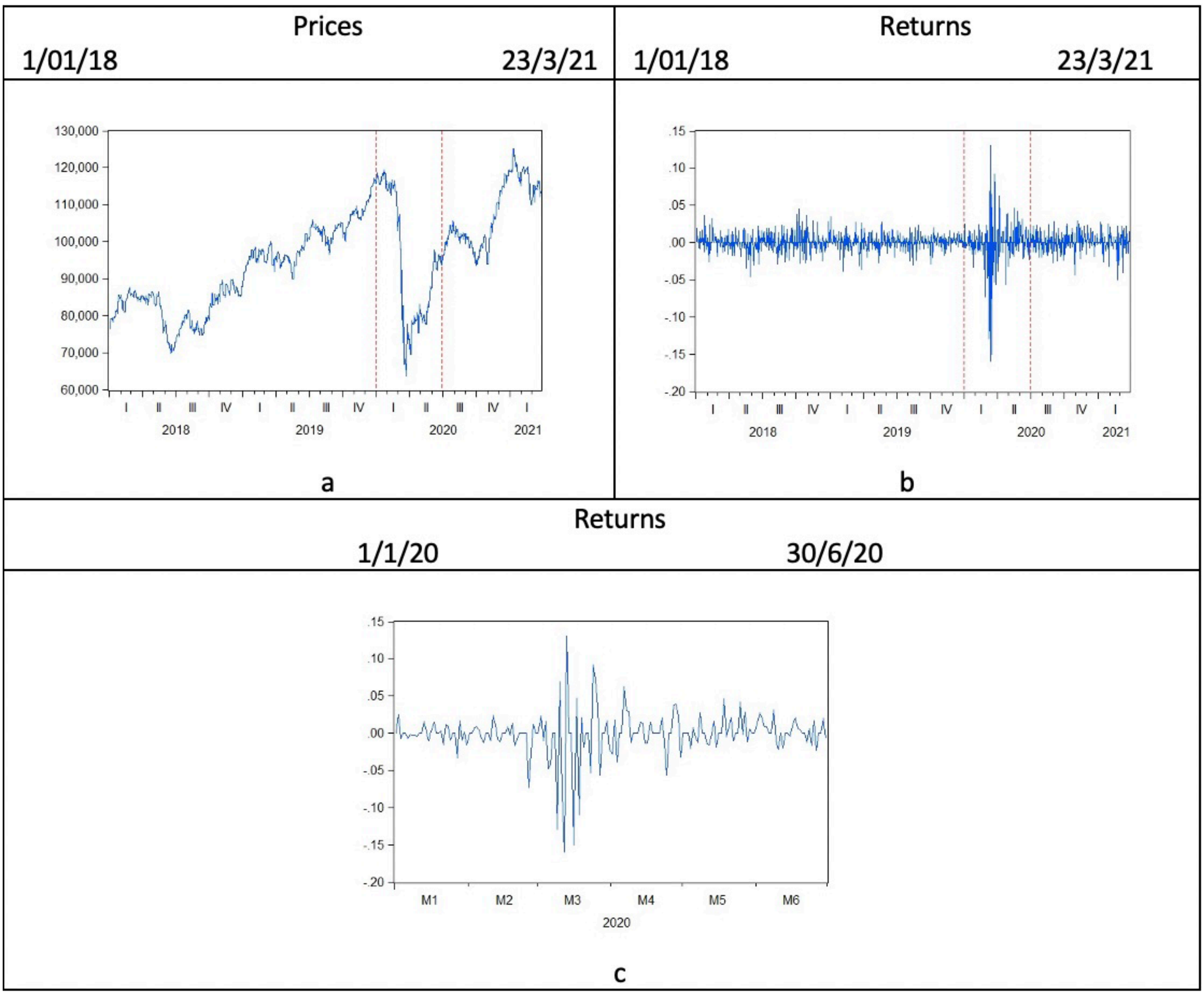

Figure 3. Bovespa (Bolsa de Valores de Sao Paulo) prices and returns. Source: own elaboration with Bloomberg© data.

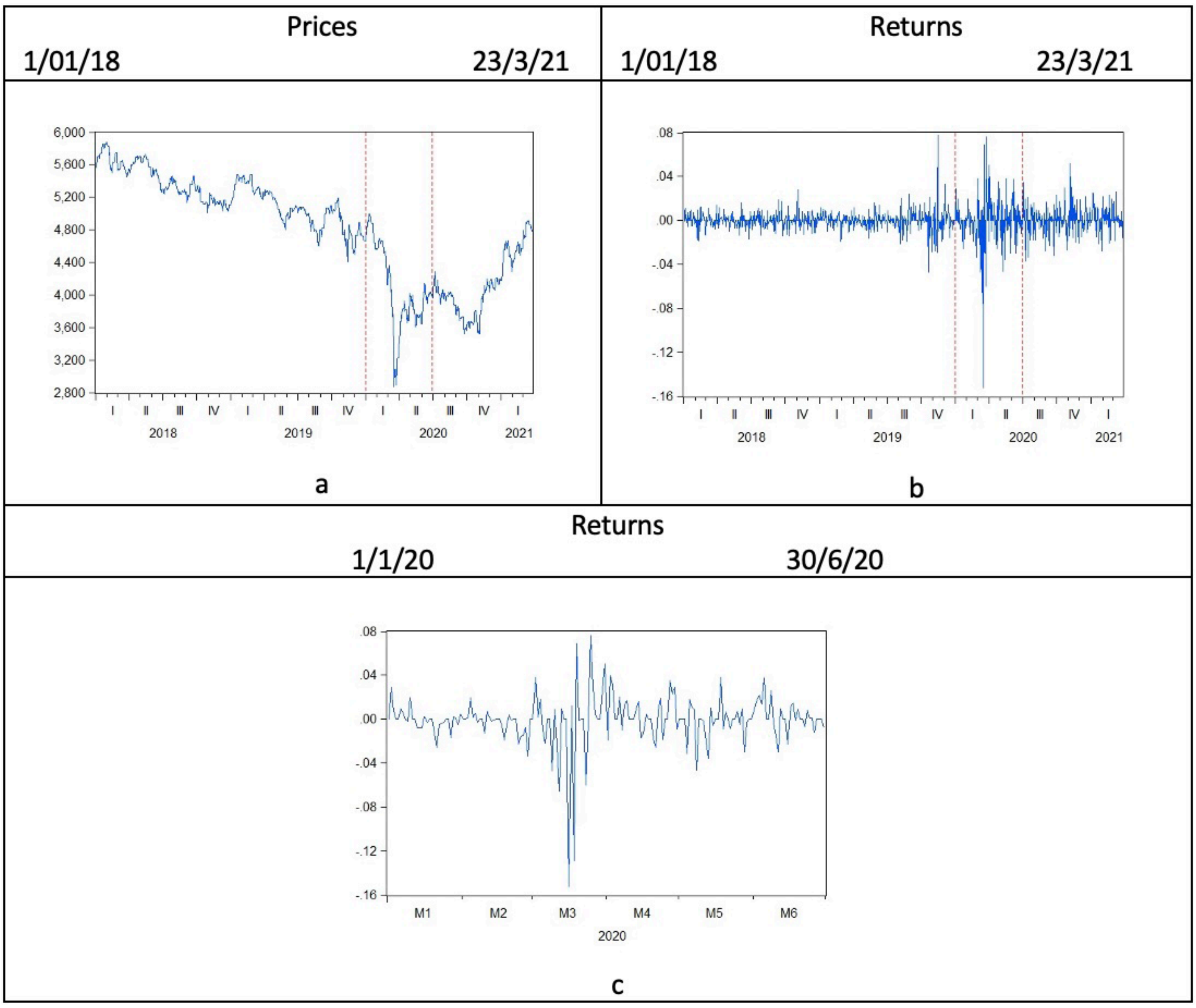

Figure 4. Ipsa (Selective Stock Price Index) prices and returns. Source: own elaboration with Bloomberg© data.

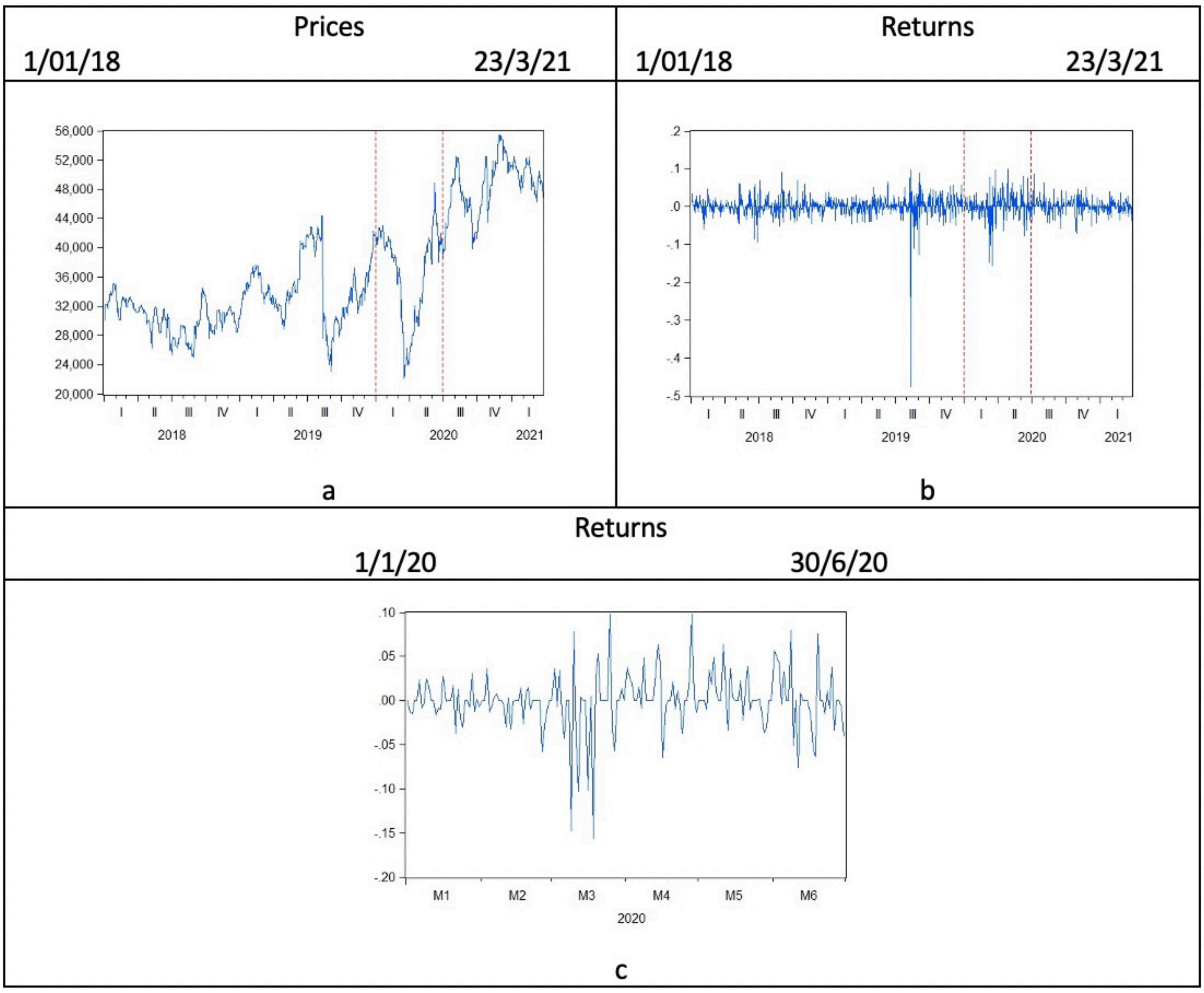

Figure 5. Merval (Stock Exchange) prices and returns. Source: own elaboration with Bloomberg© data.

Finally, similar to the Chilean index, the MEXBOL or Mexican Stock Market Index, which is the largest stock index in Mexico (figure 6a), shows a significant downward trend since the beginning of 2018, developing a typical impulse and correction structure with successive decreasing highs and lows, with a floor of prices around 39.000 points was also pierced after the declaration of the pandemic. However, the correction from the highs represented 36%, of which only 17% could be attributed to the COVID-19 effect. Of the five indices analysed, it is the one with the lowest loss after the pandemic, as is also reflected in the volatilities (figure 6b) with more limited peaks in the range (+4%, -6%), slightly higher than the average of the full period. Figure 6c specifically shows the MEXBOL yields in the pre- and post-COVID-19 period closest to the date of the declaration, showing lower variability than the rest of the previous indices.

Table 1 below presents the main descriptive statistics for returns for the entire period and for the first half of 2020, in order to quantify changes in volatility and distribution shape during the health crisis.

The results show that, in the first half of 2020, the standard deviation of returns increased significantly across all indices compared to the 2018–2021 period, indicating a higher volatility regime consistent with an environment of high information uncertainty, as described above. In this context, the greater dispersion of returns and the persistence of fat tails and negative skewness reflect intense episodes of price adjustment in response to new information, making it more difficult to take advantage of predictable patterns and thus suggesting an improvement in the degree of weak efficiency, insofar as consistently beating the market becomes more complex even for informed investors.

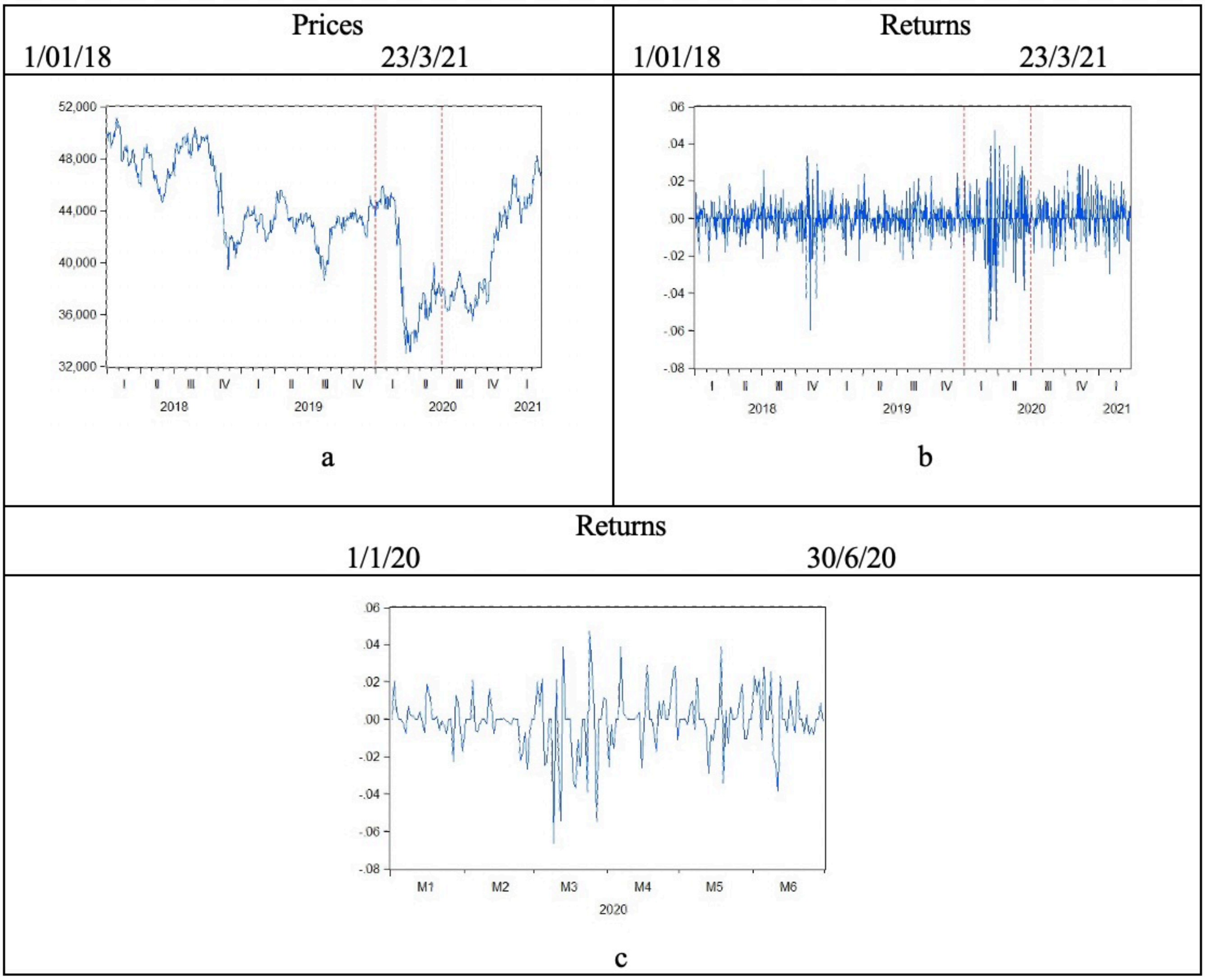

Figure 6. Mexbol (Mexican Stock Exchange) prices and returns. Source: own elaboration with Bloomberg© data.

Table 1. Descriptive statistics of the returns of the indices analysed.

Descriptive Stats	Period 1/01/18 to 26/03/21				
	COLCAP (Colombia)	BOVESPA (Brazil)	IPSA (Chile)	MERVAL (Argentina)	MEXBOL (Mexico)
Mean	-0.000116	0.000337	-0.000131	0.000376	43245.71
Median	0.000000	0.000000	0.000000	0.000000	43538.12
Maximun	0.124697	0.130228	0.077586	0.097732	51065.49
Minimun	-0.162903	-0.159938	-0.152155	-0.476922	32964.22
Std.Dev.	0.011977	0.015870	0.012039	0.027046	4125.803
Skewness	-2.553078	-1.807947	-2.303010	-4.945256	-0.346087
Kurtosis	63.92242	29.90521	40.79683	87.49060	2.420051
Descriptive Stats	Period 1/01/20 to 30/06/20				
	COLCAP (Colombia)	BOVESPA (Brazil)	IPSA (Chile)	MERVAL (Argentina)	MEXBOL (Mexico)
Mean	-0.002210	-0.001077	-0.000907	-0.000408	39225.63
Median	0.000000	0.000000	0.000000	0.000000	37821.05
Maximun	0.124697	0.130228	0.075940	0.097732	45902.68
Minimun	-0.162903	-0.159938	-0.152155	-0.156288	32964.22
Std.Dev.	0.025578	0.031345	0.023093	0.033177	4192.552
Skewness	-1.448665	-1.354604	-2.254569	-0.918038	0.303373
Kurtosis	19.38185	12.18204	17.97567	8.245708	1.540917

Source: own elaboration with Bloomberg© data.

4.2. Testing the EMH

Table 2 reports the results of applying the methodology described in Section 4 to the series of returns of each index to contrast the weak EMH in our sample markets. As observed, for each test of the procedure in each sample period, we combine the results to draw conclusions on the random walk hypothesis. Where appropriate, we establish what type of random walk is accepted. Similarly, the results corresponding to the tests carried out individually, which are required in the application of the procedure, in all the series of returns for the two periods analysed, are shown in Tables 2 to 7.

Thus, starting with the Ljung-Box test, we conclude that the Colombian, Brazilian, and Chilean markets were inefficient after detecting correlation in the corresponding yield series (table 3). On the other hand, in the Argentinean and Mexican markets, the non-correlation of yields makes it necessary to corroborate whether or not there are non-linear relationships to determine whether efficiency corresponds to the form established by random walk 1 or 3. For this purpose, we apply the ARCH effects tests (table 5), and find that for Argentina, the market shows a type 1 random walk as we do not detect non-linear relationships. We find a type-3 random walk in Mexico, where we find non-linear relationships. In addition to that, if the process is repeated, focusing on the analysis of the first half of 2020, it is observed that all markets except for the

Chilean market are efficient; specifically, the analysis of the indices of Colombia and Argentina leads us to accept the efficiency of these markets in the most restrictive sense of random walk 1, whereas in Brazil and Mexico, we find type-3 random walk.

On the other hand, if the procedure starts from the ratio-variance test, it again leads to correlation, and, therefore, inefficiency in the Colombian, Brazilian, and Chilean markets when considering the entire period, while both Argentina and Mexico show no correlation (table 4) without non-linear relationships (table 5), so they are efficient in the sense of random walk 1. However, when analysing the sub-period of the first semester of 2020, the only correlation is detected in the returns of the Colombian market (table 4), thus revealing inefficiency. After applying the remaining the ARCH effects tests (table 5) we find non-linear relationships in the yield series and thus accept efficiency in the loosest sense of a type-3 random walk.

Table 2. Test of the weak efficiency hypothesis: RW1 or RW3 against no RW.

Period/Procedure 1/1/18 to 3/26/21 1/1/20 to 6/1/20	Ljung-Box + (ARCH effects)	RV (RW1) + (ARCH effects)	Runs + (RV (rw3))	BDS + (RV (rw3))
COLCAP (Colombia)	Correlation ↓ *No RW*	Correlation ↓ *No RW*	No randomness + Uncorrelation and no independence ↓ *RW3*	No IID + Uncorrelation and no independence ↓ *RW3*
	Uncorrelation + no ARCH ↓ *RW1*	Correlation ↓ *No RW*	Randomness ↓ *RW1*	IID ↓ *RW1*
BOVESPA (Brazil)	Correlation ↓ *No RW*	Correlation ↓ *No RW*	Randomness ↓ *RW1*	No IID + Uncorrelation and no independence ↓ *RW3*
	Uncorrelation + ARCH ↓ *RW3*	Uncorrelation + ARCH ↓ *RW3*	Randomness ↓ *RW1*	No IID + Uncorrelation and no independence *RW3*
IPSA (Chile)	Correlation ↓ *No RW*	Correlation ↓ *No RW*	No randomness + Uncorrelation and no independence ↓ *RW3*	No IID + Uncorrelation and no independence ↓ *RW3*
	Correlation ↓ *No RW*	Uncorrelation + ARCH ↓ *RW3*	Randomness ↓ *RW1*	IID ↓ *RW1*

Period/Procedure 1/1/18 to 3/26/21 1/1/20 to 6/1/20	Ljung-Box + (ARCH effects)	RV (RW1) + (ARCH effects)	Runs + (RV (rw3))	BDS + (RV (rw3))
MERVAL (Argentina)	Uncorrelation + no ARCH ↓ *RW1*	Uncorrelation no ARCH ↓ *RW1*	No randomness + Uncorrelation and no independence ↓ *RW3*	No IID + Uncorrelation and no independence ↓ *RW3*
	Uncorrelation + no ARCH ↓ *RW1*	Uncorrelation + no ARCH ↓ *RW3*	Randomness ↓ *RW1*	IID ↓ *RW1*
MEXBOL (Mexico)	Uncorrelation + ARCH ↓ *RW3*	Uncorrelation + no ARCH ↓ *RW1*	No randomness + Uncorrelation and no independence ↓ *RW3*	No IID + Uncorrelation and no independence ↓ *RW3*
	Uncorrelation + ARCH ↓ *RW3*	Uncorrelation + ARCH ↓ *RW3*	No randomness + Correlation ↓ *No RW*	No IID + Uncorrelation and no independence ↓ *RW3*

Source: own elaboration.

Table 3. Ljung-Box test on returns.

Period 1/1/18 to 3/26/21	LJUNG-BOX test*						
	Autocorrelation order (k)						
	1	2	3	4	5	6	7
COLCAP (Colombia)	8.8358 (0.003)	27.796 (0.000)	39.009 (0.000)	45.709 (0.000)	48.661 (0.000)	50.773 (0.000)	52.856 (0.000)
BOVESPA (Brazil)	21.333 (0.000)	21.658 (0.000)	21.918 (0.000)	25.499 (0.000)	25.610 (0.000)	26.315 (0.000)	33.917 (0.000)
IPSA (Chile)	1.2996 (0.254)	10.215 (0.006)	18.024 (0.000)	25.237 (0.000)	30.908 (0.000)	37.982 (0.000)	38.004 (0.000)
MERVAL (Argentina)	5.1962 (0.023)	5.3266 (0.070)	6.4828 (0.090)	6.4832 (0.166)	7.1733 (0.208)	7.6568 (0.264)	8.2551 (0.311)
MEXBOL (Mexico)	2.9906 (0.084)	3.1606 (0.206)	4.6745 (0.197)	4.9251 (0.295)	4.9274 (0.425)	6.9459 (0.326)	7.7147 (0.358)
Period 1/1/20 to 6/30/20	LJUNG-BOX test*						
	Autocorrelation order (k)						
	1	2	3	4	5	6	7

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Period 1/1/18 to 3/26/21	LJUNG-BOX test*						
	Autocorrelation order (k)						
	1	2	3	4	5	6	7
COLCAP (Colombia)	2.2530 (0.133)	6.8637 (0.032)	9.1881 (0.027)	10.885 (0.028)	11.251 (0.047)	11.902 (0.064)	12.162 (0.095)
BOVESPA (Brazil)	5.7960 (0.016)	5.9041 (0.052)	5.9337 (0.115)	7.7072 (0.103)	8.1819 (0.146)	8.7223 (0.190)	12.875 (0.075)
IPSA (Chile)	0.6026 (0.438)	7.6575 (0.022)	8.9941 (0.029)	12.353 (0.015)	14.398 (0.013)	19.718 (0.003)	19.718 (0.006)
MERVAL (Argentina)	0.5487 (0.459)	0.6305 (0.730)	1.3036 (0.728)	1.3378 (0.855)	1.3689 (0.928)	4.7697 (0.574)	4.8379 (0.680)
MEXBOL (Mexico)	0.1069 (0.744)	0.2519 (0.882)	0.3699 (0.946)	1.0615 (0.900)	1.5314 (0.909)	2.8907 (0.822)	2.8981 (0.894)

*For each statistic its *p*-value for different values of *k* is recorded.
Source: own elaboration with Bloomberg© data.

Table 4. Ratio-Variance test for RW1 on returns data.

	RATIO-VARIANCE test (RW1)*								
	k	*VR(k)*	*z-Statistic*	*p*	*Global test***	*VR(k)*	*z-Statistic*	*p*	*Global test***
Period		1/01/18 to 26/03/21				1/01/20 to 30/06/20			
COLCAP (Colombia)	2	1.0864	2.9682	0.0030	7.028582 (0.0000)	1.1102	1.4878	0.1368	3.342447 (0.0033)
	4	1.3045	5.5922	0.0000		1.3779	2.7256	0.0064	
	8	1.6052	7.0285	0.0000		1.7328	3.3424	0.0008	
	16	1.7014	5.4741	0.0000		1.7708	2.3626	0.0181	
BOVESPA (Brazil)	2	0.8651	-4.6336	0.0000	4.633646 (0.000)	0.8228	-2.3892	0.0169	2.389221 (0.0658)
	4	0.8062	-3.5574	0.0004		0.7499	-1.8032	0.0713	
	8	0.8478	-1.7670	0.0772		0.8310	-0.7705	0.4410	
	16	0.9448	-0.4302	0.6670		1.0002	0.0007	0.9994	
IPSA (Chile)	2	1.0328	1.1288	0.2590	2.940247 (0.0131)	0.9426	-0.7735	0.4392	1.669091 (0.3295)
	4	1.0949	1.7438	0.0812		1.0603	0.4352	0.6634	
	8	1.2531	2.9402	0.0033		1.3659	1.6690	0.0951	
	16	1.2677	2.0892	0.0367		1.4318	1.3235	0.1857	
MERVAL (Argentina)	2	0.9330	-2.2982	0.0215	2.298224 (0.0834)	0.9413	-0.7906	0.4292	0.791468 (0.8935)
	4	0.8927	-1.9701	0.0488		0.9605	-0.2847	0.7758	
	8	0.8885	-1.2938	0.1957		1.0654	0.2983	0.7654	
	16	0.9389	-0.4762	0.6339		1.2582	0.7914	0.4287	

	RATIO-VARIANCE test (RW1)*								
	k	*VR(k)*	*z-Statistic*	*p*	*Global test***	*VR(k)*	*z-Statistic*	*p*	*Global test***
MEXBOL (Mexico)	2	1.0494	1.6985	0.0894	1.698570 (0.3124)	0.9759	-0.3244	0.7456	0.553846 (0.9688)
	4	1.0446	0.8191	0.4127		0.9409	-0.4256	0.6704	
	8	1.0229	0.2661	0.7901		0.8785	-0.5538	0.5797	
	16	1.0865	0.6750	0.4996		1.0110	0.0339	0.9729	

*For each market, the ratio-variance and the Z-statistics are recorded, with their corresponding p-value and for each k.
**For each market, the Chow-Deming statistics are recorded with their corresponding p-values.
Source: own elaboration with Bloomberg© data.

Table 5. Arch test on returns series.

Period 1/01/18 to 26/03/21	ARCH test*			
	Order of heterocedasticity (q)			
	1	2	3	4
COLCAP (Colombia)	21.50821 (0.000)	78.10297 (0.000)	78.52178 (0.000)	24.81890 (0.000)
BOVESPA (Brazil)	174.2224 (0.0000)	198.7738 (0.0000)	307.3006 (0.0000)	352.4535 (0.0000)
IPSA (Chile)	9.737605 (0.0018)	198.8077 (0.000)	204.1976 (0.000)	209.3947 (0.000)
MERVAL (Argentina)	2.000021 (0.1573)	2.012704 (0.3656)	2.936561 (0.4015)	0.4015 (0.5649)
MEXBOL (Mexico)	35.00277 (0.000)	38.88175 (0.000)	121.4599 (0.000)	128.8778 (0.000)
Period 1/01/20 to 30/06/20	ARCH test *****			
	Order of heterocedasticity (q)			
	1	2	3	4
COLCAP (Colombia)	2.374405 (0.1233)	8.649133 (0.0132)	8.592508 (0.0352)	9.995356 (0.0405)
BOVESPA (Brazil)	24.60953 (0.0000)	27.02183 (0.0000)	44.05600 (0.0000)	50.03015 (0.0000)
IPSA (Chile)	0.673000 (0.4120)	30.38216 (30.38216)	30.96714 (0.0000)	32.55966 (0.0000)
MERVAL (Argentina)	0.491063 (0.4835)	7.395845 (0.0248)	8.001389 (0.0460)	8.483891 (0.0754)
MEXBOL (Mexico)	5.649691 (0.0175)	5.692106 (0.0581)	21.22910 (0.0001)	21.49044 (0.0003)

* For each market the statistics and their *p*-values are recorded for each *q*.
Source: own elaboration with Bloomberg© data
*For each market, the statistics and their p-values are recorded for each *q*.
Source: own elaboration with Bloomberg© data.

Starting the analysis procedure with the run test for the entire period, for a significance level of $p < 0.05$, the efficiency hypothesis could only be accepted in the form established by random walk 1 in the Brazilian market, as the BOVESPA yield series is random (table 6). For the rest of the markets, the application of the variance-ratio test, which admits the existence of heteroscedasticity in the returns (Table 8), leads to the acceptance of the efficiency in the form of random walk 3 (table 2). However, if the analysis focuses on the first semester of 2020, the application of the test of streaks (table 6) leads us to accept the randomness of the returns in all markets except Mexico, so that the efficiency is set to random walk 1 for them. In the Mexican market, after applying the ratio-variance test (RW3) (table 8), we find a correlation, so the market was inefficient.

Table 6. Runs test on the randomness of returns' series.

	Runs test			
	*Number of runs**	*p*	*Number of runs **	*p*
Period	1/01/18 to 26/03/21		1/01/20 to 30/06/20	
COLCAP (Colombia)	451	0.000127	63	0.035148
BOVESPA (Brazil)	522	0.326893	88	0.325575
IPSA (Chile)	455	1.33E-07	76	0.359939
MERVAL (Argentina)	488	0.001784	80	0.808564
MEXBOL (Mexico)	453	1.37E-07	68	0.011480

*Runs are obtained using the series means.
Source: own elaboration with Bloomberg© data.

Finally, if the procedure begins with the BDS test considering the entire period, we find for all markets that the yield series are not IID (table 7). Therefore, the ratio-variance (RW3) test was applied (table 8), which detects dependence driving the acceptance of efficiency, but only in the looser way established by the random walk 3. However, focusing on the first semester of 2020, the BDS test allows direct acceptance of efficiency in the strictest form established by random walk 1 in the Colombian, Chilean, and Argentine markets (table 7). In the Brazilian and Mexican markets, the rejection of the IID returns hypothesis leads to the application of the ratio-variance (RW3) test (table 8). We therefore conclude that both markets are efficient according to walk 3 as we find no correlation but dependency.

Table 7. BDS test on returns' series.

	BDS TEST*						
	m	*BDS Statistic*	*z-Statistic*	*p*	*BDS Statistic*	*z-Statistic*	*p*
Period		1/1/18 a 3/26/21			1/1/20 a 6/30/20		
COLCAP (Colombia)	2	0.0126	3.4085	0.0007	0.0048	0.4468	0.6550
	3	0.0147	2.7349	0.0062	0.0237	1.4015	0.1610
	4	0.0153	2.6115	0.0090	0.0348	1.7376	0.0823
	5	0.0135	2.4172	0.0156	0.0420	2.0233	0.0430

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	BDS TEST*						
	m	*BDS Statistic*	*z-Statistic*	*p*	*BDS Statistic*	*z-Statistic*	*p*
Period		1/1/18 a 3/26/21			1/1/20 a 6/30/20		
BOVESPA (Brazil)	2	0.0198	5.8912	0.0000	0.0514	5.2464	0.0000
	3	0.0183	4.3786	0.0000	0.0622	4.5628	0.0000
	4	0.0135	3.4521	0.0006	0.0704	4.9473	0.0000
	5	0.0082	2.5823	0.0098	0.0678	5.2119	0.0000
IPSA (Chile)	2	0.0358	9.2065	0.0000	0.0082	0.8408	0.4005
	3	0.0425	8.1505	0.0000	0.0108	0.8511	0.3947
	4	0.0397	7.5696	0.0000	0.0120	0.9623	0.3359
	5	0.0364	7.8554	0.0000	0.0155	1.4433	0.1489
MERVAL (Argentina)	2	0.0358	9.2065	0.0000	0.0082	0.8408	0.4005
	3	0.0425	8.1505	0.0000	0.0108	0.8511	0.3947
	4	0.0397	7.5696	0.0000	0.0120	0.9623	0.3359
	5	0.0364	7.8554	0.0000	0.0155	1.4433	0.1489
MEXBOL (Mexico)	2	0.0234	6.7364	0.0000	0.0248	2.6011	0.0093
	3	0.0230	5.6943	0.0000	0.0289	2.5888	0.0096
	4	0.0160	4.5609	0.0000	0.0290	2.9569	0.0031
	5	0.0104	3.8773	0.0001	0.0238	3.1662	0.0015

*For each market the BDS and *Z* statistics and their *p*-values are recorded for each *m*.
Source: own elaboration with Bloomberg© data.

Table 8. Ratio-Variance test for RW3 with the returns series.

	RATIO-VARIANZA test (RW3)*								
	k	VR(k)	z-Statistic	p	Global test**	VR(k)	z-Statistic	p	Global test**
Period		1/1/18 to 3/26/21				1/1/20 to 6/30/20			
COLCAP (Colombia)	2	1.0882	0.9840	0.3251	2.253562 (0.0934)	1.1226	0.9380	0.3482	2.245120 (0.0954)
	4	1.3112	1.7212	0.0852		1.4246	1.6492	0.0991	
	8	1.6244	2.2535	0.0242		1.8746	2.2451	0.0248	
	16	1.7455	1.7552	0.0792		2.1043	1.8522	0.0640	
BOVESPA (Brazil)	2	0.8665	-1.3175	0.1877	1.317508 (0.5646)	0.8320	-1.0007	0.3170	1.000744 (0.7823)
	4	0.8103	-1.0338	0.3012		0.7753	-0.7416	0.4583	
	8	0.8579	-0.4916	0.6229		0.8990	-0.2121	0.8320	
	16	0.9693	-0.0759	0.9394		1.1886	0.2848	0.7757	

	RATIO-VARIANZA test (RW3)*								
	k	VR(k)	z-Statistic	p	Global test**	VR(k)	z-Statistic	p	Global test**
IPSA (Chile)	2	1.0346	0.5535	0.5799	1.089025 (0.7255)	0.9531	-0.4426	0.6580	1.191239 (0.6549)
	4	1.1005	0.6411	0.5214		1.0963	0.3574	0.7207	
	8	1.2681	1.0890	0.2761		1.4777	1.1284	0.2591	
	16	1.3005	0.8754	0.3813		1.7014	1.1912	0.2336	
MERVAL (Argentina)	2	0.9346	-1.0805	0.2933	1.089025 (0.7255)	0.9518	-0.5540	0.5796	1.173273 (0.6676)
	4	0.8972	-0.9957	0.3194		0.9930	-0.0383	0.9694	
	8	0.8992	-0.7073	0.4816		1.1526	0.5482	0.5835	
	16	0.9633	-0.1874	0.8513		1.4951	1,7332	0.2407	
MEXBOL (Mexico)	2	1.0512	1.1065	0.2685	1.106594 (0.7136)	0.9867	-0.1305	0.8961	0.481893 (0.9812)
	4	1.0499	0.5942	0.5524		0.9728	-0.1504	0.8804	
	8	1.0351	0.2605	0.7945		0.9504	-0.1724	0.8631	
	16	1.1146	0.5772	0.5638		1.2014	0.4818	0.6299	

*For each market the ratio-variance and Z statistics and their p-values are recorded for each m.
**For each market the Chow-Deming statistics and their p-values are recorded.
Source: own elaboration with Bloomberg© data.

Thus, it can be said that the pandemic had a positive influence on the efficiency of the financial markets analysed. In most cases, the analysis on the first half of 2020 revealed that in each method of applying the procedure, efficiency improved for the full period. Horta *et al.* (2014) and Gomes *et al.* (2018) provide evidence of this. Specifically, with a few exceptions where we find that efficiency was maintained, in most cases, efficiency increased, the yields going from not being RW to being RW3 or RW1, or from RW3 to RW1; the latter form corresponds, as explained previously, to the one that can be considered stricter within the weak efficiency of a market. 261

5. DISCUSSION

As mentioned previously, the methodology employed in this study yields inconsistent results across various markets and sub-periods. However, one consistent finding is that many series aling with a more flexible random walk (RW3) following the initial impact of the pandemic. Additionally, some markets exhibit an RW1 (strict) or remain inefficient according to some of the analysed results.

Several recent studies using alternative methods and samples arrive at superficially different results, but when considered together, they offer a consistent picture of market efficiency depending on scale and time. Applying a sequential econometric decision framework to five Latin American indices, this paper find that the short.term serial dependence was reduced by the COVID-19 crisis, in many cases, producing behaviour closer to a random walk (RW3) in the post-crisis periods. In contrast, multifractal analyses reveal a persistent multiscale structure that refutes the notion a strict random walk.

The approach taken by Aslam *et al*. (2023) is based in the purest tradition of econophysics, which emphasises multiscale structure. The authors apply multifractal non-trending fluctuation analysis (MFDFA) and associated multifractal indices (H(q), Δα, MLM efficiency index) using moving window analysis to cryptocurrencies. They focus on scaling, multifractal strength and time-varying efficiency, and link multifractality with predictability. These indices differ between assets and increase during crisis phases, indicating horizon-dependent inefficiency and a predictable structure.

Dos Santos (2023) also applies MFDFA applied to 135 Brazilian market stocks (with daily data from 2015 to 2022) in order to estimate generalised Hurst exponents, and the markets deficiency measure (MDM). The author then relates multifractality (i.e., inefficiency) to out-of-sample predictability (evalueated using ARIMA/ETS, evaluated with MASE). MFDFA thus focuses on long-term multiscale dependence and fractal structure, rather than short-term correlations. The authors found multifractality both before and after the pandemic, which accentuated multifractal behaviour. According to their measurements, stock efficiency declined after the pandemic. Furthermore, they demonstrate that less efficient (i.e. more multifractal) stocks exhibit greater predictability in out-of-sample tests (lower MASE relative to the weak random walk).

Finally, Bassiouny *et al.* (2022) demonstrates that calendar anomalies themselves vary over time and may reappear during crises. This pattern is consistent with the adaptive market hypothesis (AMH), which suggests that markets move between periods of relative efficiency and inefficiency. Therefore, these differences are both methodological and substantive rather than contradictory. Standard econometric tests mainly detect short-term linear/non-linear structures. MF-DFA captures long-term dependence that depends on scale, and moving window AMH analyses reveal temporal adaptation. Taken together, these tests imply that market efficiency depends on the time horizon and evolves through crises. Therefore, empirical claims about market efficiency must specify the time scale, the aspect of dependence analysed, and the asset class studied.

It is important to note that the empirical findings of the above cited studies cited above converge and differ from those of this research in the following assumptions:

1. The different null hypotheses or different characteristics tested: while the econometric tests used in this research focus on short-term linear/non-linear dependence and conditional heteroscedasticity, whereas MFDFA focuses on multiscale, long-range scaling and multifractality. A series may not be correlated in conventional lags (i.e., exceed the Ljung-Box/VR), but may exhibit a long-range multifractal structure, which is detected by MFDFA. Therefore, our conclusion of that daily behaviour is more efficient daily behaviour (similar to RW3) can coexist with Dos Santos Maciel's conclusion that increased multifractality (inefficiency at different scales) increased after the pandemic.
2. Temporal variation is fundamental, and significant divergence is evident in the results of Bassiouny's moving window and Aslam's moving MFDFA, which show that market characteristics undergo through different phases. Their analysis of sub-periods (the first half of 2020 versus the full sample) also reveals changing behaviour. Taken together, these studies emphasise that market efficiency is not static, but depends on time and the horizon.
3. Finally, the asset class and market microstructure are important considerations. Cryptocurrencies are structurally different from equities, and single-country equity samples may behave differently from a panel of five Latin American indices, as we have seen in this paper (Dos Santos Maciel for Brazil). Liquidity, market depth, retail participation, and political interventions can differ across markets, which partly explains the empirical divergence.

6. CONCLUSIONS

The main contribution of this study is that it analyses the weak form of efficiency considering different approaches to each type of random walk (1, 2 and 3) in five of the most influential financial markets in South America through their stock indices: Colombia (COLCAP index), Brazil (BOVESPA index), Chile (IPSA index), Argentina (MERVAL index), and Mexico (MEXBOL index). We used a mixture of tests to determine whether the market is efficient. The sample period is from 1 January 2018 to 23 March 2021, with special attention paid to the first half of 2020 to assess the impact of COVID-19 on financial markets.

A graphical analysis of the evolution of the indices allows us to conclude the different levels of maturity in different markets and sometimes show opposing trends, although with the same turning point around the declaration of the COVID-19 pandemic in March 2020. Thus, in the range considered, the market trend before this historical moment was bullish or laterally bullish for Colombia, Brazil, and Argentina, and bearish for Chile or Mexico. After the stock market crash in March 2020, all countries experienced greater or lesser recovery. Weighting this, the return series for each market's price index shows volatility peaks recorded in the period following the WHO's declaration.

Through a combined process of methods that define a necessary but not sufficient condition for random walk testing and methods that provide a direct contrast of a specific type of random walk, it is possible to define a strategy to detect and classify random walk behaviour for returns obtained from the market indices. In those cases and periods in which the random walk hypothesis cannot be rejected, the type-3 random walk emerges as the specification that best describes the behaviour of the markets analysed, as it allows for uncorrelated returns with possible non-linear dependence and, therefore, the use of volatility models. This evidence is, however, partial and period-dependent, since in several indices and for the full sample the assumptions of a random walk are rejected, revealing mixed results in terms of weak-form efficiency.

For the entire period analysed, the variance-ratio test and the Ljung-Box test show that for the MERVAL and MEXBOL indices, the markets are efficient, accepting the behaviour as a random walk type 1 for Argentina and type 3 for the Mexican stock market. However, for the COLCAP, BOVESPA, and IPSA indices, the stock market is inefficient. That is, there is no succession in incorporating all available information into a true reflection of a stocks fair price, which is important because it creates opportunities for arbitrage and abnormal returns. Thus, some assets may be over-or undervalued in the market, creating opportunities for excess profits.

However, for the first half of 2020, all the indices except for the Chilean stock market proved to be efficient. In particular, Colombia and Argentina were efficient in Form 1, while Brazil and Mexico were efficient in Form 3. Using the runs test for the entire period reveals that the markets tended to be efficient of type 1 for Brazil; therefore, changes in prices are i.i.d., and of type 3 for Colombia, Argentina, Chile, and Mexico, assuming that the return structure is not i.i.d. but uncorrelated and thus better adjusted to reality.

The general results carried out with econometric models are mixed, which means that because we have total and partial rejection of the random walk and the EMH. The results reported by Abakah *et al*. (2018) and Aggarwal (2018) imply that market efficiency results depend on the approach used. Here, we employ multiple tests of efficiency, and a sub-sample is used to validate the random walk hypothesis when the pandemic hit harder. This study shows evidence that global pandemic had a significant impact on the stock market indices in Latin America.

Our previous conclusions highlighted the main contributions of this study. Market inefficiencies occur because of information asymmetry, transaction costs, market psychology, and human emotions. In our study, although we expected that the pandemic would cause a contagion effect in all Latin American countries, affecting efficiency in their respective markets, we showed that this contagion only occurred in some of these countries, while the markets were efficient in the remaining countries. In fact, with other markets not following a random walk, the scope of the work can be ex- tended to several approaches, for instance, to assess whether such inefficiencies persist as long as the markets are still recovering, as we understand that persistent volatility weakens investor confidence in the markets. The adaptive market hypothesis (AMH) approach, which proposes the coexistence of weak forms of market efficiency and time-varying conditionality, can also be explored.

The results obtained in this study have important economic implications. The improvement in the efficiency of Latin American financial markets during the pandemic suggests a greater capacity to adapt to disruptive events, which strengthens the resilience of the regional financial system. This greater efficiency can facilitate a more optimal allocation of capital, reduce systematic arbitrage opportunities, and improve market transparency. Furthermore, for economic policymakers, these findings indicate that the measures adopted during the crisis (such as fiscal or monetary stimuli) may have helped to stabilise investor expectations, favouring the faster incorporation of available information into prices. Consequently, this opens up a line of research on how emerging markets can strengthen their structural efficiency in contexts of high uncertainty and volatility.

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This study has some limitations that should be considered. First, the analysis is based exclusively on stock market index data, without incorporating macroeconomic or micro variables that could influence market efficiency. Furthermore, although robust, the methodology employed focuses on traditional statistical tests and does not consider alternative approaches such as multifractal analysis or the adaptive market hypothesis (AMH), which could better capture the temporal dynamics of efficiency. On the other hand, although relevant, the period analysed could be extended to assess the persistence of the observed effects. In terms of future lines of research, it would be relevant to compare the results with developed markets to identify common or divergent patterns in crisis contexts, and to analyse the role of government policies (fiscal policy measures) and central banks (monetary policy measures) in Latin American countries in the evolution of efficiency.

Responsabilities and conflicts of interests

The authors undertakes to disclose any existing or potential conflict of interest in relation to the publication of his article.

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- Manuel Adolfo Pérez Priego: Conceptualization, Methodology, Validation, Investigation, Data curation, Writing-Original Draft, Writing-Reviewing and Editing.
- María de los Baños García-Moreno García: Conceptualization, Methodology, Validation, Formal Analysis, Investigation, Writing-Original Draft, Writing-Reviewing and Editing, Supervision, Visualization.
- Lorena Caridad y López del Río: Conceptualization, Data curation, Resources, Visualization.
- José Rafael Caro-Barrera: Validation, Software, Writing-Original Draft, Visualization.

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