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Transformation of the Ukrainian Stock Market: A Data Properties View

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Abstract: This paper investigates the evolution of the Ukrainian stock market through an analysis of various data properties, including persistence, volatility, normality, and resistance to anomalies for the case of daily returns from the PFTS stock index spanning 1995–2022. Segmented into sub-periods, it aims to test the hypothesis that the market's efficiency has increased over time. To do this different statistical techniques and methods are used, including R/S analysis, ANOVA analysis, regression analysis with dummy variables, *t*-tests, and others. The findings present a mixed picture: while volatility and persistence demonstrate a general decreasing trend, indicating a potential shift towards a more efficient market, normality tests reveal no discernible differences between analyzed periods. Similarly, the analysis of anomalies shows no specific trends in the market's resilience to the day-of-the-week effect. Overall, the results suggest a lack of systematic changes in data properties in the Ukrainian stock market over time, possibly due to the country's volatile conditions, including two revolutions, economic crises, the annexation of territories, and a Russian invasion leading to the largest war in Europe since WWII. The limited impact of reforms and changes justifies the need for continued market reform and evolution post-war.

Keywords: stock market; persistence; anomalies; adaptive market hypothesis; R/S analysis; efficient market hypothesis



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1. Introduction

One of the fundamental academic theories describing and explaining the behavior of financial markets is the Efficient Market Hypothesis (EMH), developed by Fama (1965). According to this theory, at any given moment, the price of a financial asset equals its fundamental value, making it impossible to make economic decisions that would yield profits from operations with assets in the financial market (so-called “you cannot beat the market” rule).

This is explained by the random nature of price fluctuations in financial markets and by the fact that any discrepancy between the current market price of an asset and its fundamental value will be compensated by the corresponding actions of financial market participants, resulting in the almost instantaneous elimination of any deviation from the fair value (Samuelson 1965).

However, there is much empirical evidence against the EMH: persistence of returns and volatility (Caporale et al. 2019), the existence of price bubbles in the financial markets (Scherbina and Schlusche 2014), various types of market anomalies (Plastun et al. 2019), fat

tails in data, non-randomness of data (Lo and MacKinlay 1988), etc. Ball (2009) showed that during the global financial crisis (2007–2009) the most efficient markets suffered the most significant losses.

As a result, alternative concepts and theories emerged to explain the behavior of financial markets. Among the most commonly known are behavioral finance (Shiller 2003), adaptive market hypothesis (Lo 2004), fractal market hypothesis (Peters 1994), noisy market hypothesis (Black 1986), overreaction hypothesis (De Bondt and Thaler 1985), and many others.

These theories contradict each other; they are based on different assumptions and different methodologies of analysis and typically concentrate on a specific aspect of financial markets. Lo (2004) tried to put them all within a single concept, explaining existing differences with the instability of financial markets.

Evolutionarily, markets move from inefficient (when prices have a non-random nature of changes and there is a fundamental possibility of predicting price movements when information asymmetry is present, when there is an opportunity to make profits) to efficient, when prices are unpredictable, and their movements are random, information asymmetry is minimal, and financial markets are markets of perfect competition (Lo 2004).

This is a basic assumption of the Adaptive market hypothesis (AMH). The rationale for this includes the impact of competition, mutation, reproduction, and natural selections which cause changes in the behavior of financial institutions and market participants, with further transmission to the efficiency of markets.

Kim et al. (2011) showed that return predictability varies in time for the case of the Dow Jones Industrial Average index from 1900 to 2009.

The evolutionary nature of financial markets related to their efficiency was confirmed by Urquhart and Hudson (2013) who explored the persistence of returns in the US, UK, and Japanese stock markets and found evidence in favor of the adaptive market hypothesis. Contrary Hull and McGroarty (2014) could not find evidence of persistence trending down over time, suggesting no increase in market efficiency.

Exploring market anomalies provides an alternative perspective on evolutionary processes. Market anomalies should not exist in efficient markets (Jensen 1978). Kohers et al. (2004) and Plastun et al. (2019) observed the diminishing day-of-the-week effect, supporting market efficiency evolution. Xiong et al. (2019) found varying calendar effects in the Chinese stock market over time.

Lim and Brooks (2011) provide a summary of existing literature on market efficiency evolution. A general conclusion is in favor of the AMH: market efficiency varies over time.

However, the Ukrainian stock market remains relatively underexplored. Plastun et al. (2023) analyzed its efficiency, demonstrating predictability differences between traditional and ESG indices but leaving evolutionary aspects unexplored.

This paper fills this gap by analyzing the evolution of the Ukrainian stock market through data properties. Utilizing data from 1995 to 2022, it tests the hypothesis that market efficiency increases over time using regression analysis with dummy variables, normality tests, persistence analysis (R/S analysis), and various statistical tests, including examinations of anomalies such as the day-of-the-week effect.

The Ukrainian stock market presents a unique subject of analysis due to its tumultuous history, which includes two revolutions, economic crises, significant reforms, and the largest war in Europe since World War II. Examining its evolution may offer valuable insights into the behavior of stock markets in the aftermath of revolutions and during periods of conflict.

2. Materials and Methods

We analyse daily data for the leading Ukrainian stock market index PFTS (First Stock Trading System—Persha Fondova Torgova Systema) (<https://www.pfts.com.ua>, accessed on 10 October 2023). The sample period goes from 1995 to 2022.

In order to explore the evolution of the market overall data set is divided into the following sub-periods: 1995–1999, 2000–2004, 2005–2007, 2008–2009, 2010–2013, 2014–2015, 2016–2019, and 2020–2022. This division is based on key events in the development of

the Ukrainian stock market. For example, 2008–2009—the Global financial crisis and 2020–2022—pandemic period, etc.

We analyze returns computed as follows:

$$R_i = \left(\frac{Close_i}{Open_i} - 1 \right) \times 100\%, \quad (1)$$

where

R_i —returns on the i -th period in percentage terms;

$Open_i$ —open price on the i -th period;

$Close_i$ —close price on the i -th period.

Hypothesis to be tested: The efficiency of the Ukrainian stock market increases over time.

To test this hypothesis the following methods and techniques are used:

- Descriptive statistics (to explore differences between key quantitative characteristics of data sets belonging to different sub-periods);
- Parametric tests (t -tests, ANOVA-analysis) to identify statistically significant differences between data sets belonging to different periods;
- Non-parametric tests (Mann–Whitney, Kruskal–Wallis) to identify statistically significant differences between data sets belonging to different periods;
- Data normality tests (Kolmogorov–Smirnov test) in order to check the random nature of data with further conclusions about the efficiency/inefficiency of the market during the analyzed period;
- Methods to analyze price anomalies (the effect of the day of the week) as signs of market inefficiency;
- R/S analysis to explore data persistence with further conclusions regarding the level of market efficiency during the analyzed period.

In this paper, various statistical tests are employed to assess the statistical significance of differences between specific periods and the overall data set. Depending on the distribution of the data (whether it adheres to a normal distribution or not), both parametric and non-parametric tests are used. Given the diverse nature of the data periods under examination, differences in normality distribution are highly probable. To account for this variability and circumvent the need for extensive preliminary checks (such as data normality tests), a combination of parametric tests (t -test and ANOVA analysis) and non-parametric tests (including the Mann–Whitney test for two groups and the Kruskal–Wallis test for datasets with more than two groups) are applied.

The null hypothesis (H_0) in each case is that the data belong to the same general population, and rejecting this hypothesis suggests that the data originate from different populations. This serves as evidence supporting the presence of statistically significant differences between specific period data and the overall dataset.

To measure the degree of persistence R/S analysis is applied. R/S analysis is one of the most commonly used methodologies to calculate the Hurst exponent for financial data over the last 30–40 years. It was used to analyze persistence in FOREX (Corazza and Malliaris 2002), commodities (Barkoulas et al. 1997; Crato and Ray 2000), cryptocurrency (Caporale et al. 2018), stock markets of different countries: the US stock market (Greene and Fielitz 1977), Chinese (Hja and Lin 2003), Japanese (Batten et al. 2003), Swedish (Lennart and Lyhagen 1998), etc.

There is evidence (Taqqu et al. 1995; Lo 1991) that R/S analysis might be biased. As a result, additional techniques to calculate the Hurst exponent can be applied: modified R/S analysis (Lo 1991), DFA and DMA (Jiang et al. 2019), etc. Still, for the case of financial data standard R/S analysis is actively used even in the most recent studies (Raimundo and Okamoto 2018; Danylchuk et al. 2020; Metescu 2022).

Standard R/S analysis is based on the following algorithm (see Caporale and Plastun 2024 for additional details):

1. A time series of length M is transformed into one of length $N = M - 1$ using logs and converting prices into returns:

$$N_i = \log\left(\frac{Y_{t+1}}{Y_t}\right), t = 1, 2, 3, \dots (M - 1). \tag{2}$$

2. This period is divided into contiguous A sub-periods with length n , such that $A_n = N$, then each sub-period is identified as I_a , given the fact that $a = 1, 2, 3 \dots, A$. Each element I_a is represented as N_k with $k = 1, 2, 3 \dots, N$. For each I_a with length n the average e_a is defined as:

$$e_a = \frac{1}{n} \sum_{k=1}^n N_{k,a}, k = 1, 2, 3, \dots N, a = 1, 2, 3 \dots, A. \tag{3}$$

3. Accumulated deviations $X_{k,a}$ from the average e_a for each sub-period, I_a is defined as:

$$X_{k,a} = \sum_{i=1}^k (N_{i,a} - e_a). \tag{4}$$

The range is defined as the maximum index $X_{k,a}$ minus the minimum $X_{k,a}$, within each sub-period (I_a):

$$R_{Ia} = \max(X_{k,a}) - \min(X_{k,a}), 1 \leq k \leq n. \tag{5}$$

4. The standard deviation S_{Ia} is calculated for each sub-period I_a :

$$S_{Ia} = \left(\left(\frac{1}{n} \right) \sum_{k=1}^n (N_{k,a} - e_a)^2 \right)^{0.5}. \tag{6}$$

5. Each range R_{Ia} is normalized by dividing by the corresponding S_{Ia} . Therefore, the re-normalized scale during each sub-period I_a is R_{Ia}/S_{Ia} . In step 2 above, adjacent sub-periods of length n are obtained. Thus, the average R/S for length n is defined as:

$$(R/S)_n = (1/A) \sum_{i=1}^A (R_{Ia}/S_{Ia}). \tag{7}$$

6. The length n is increased to the next higher level, $(M - 1)/n$, and must be an integer number. In this case, n -indices that include the start and end points of the time series are used, and Steps 1–6 are repeated until $n = (M - 1)/2$.
7. The least square method is used to estimate the equation $\log(R/S) = \log(c) + H \cdot \log(n)$. The slope of the regression line is an estimate of the Hurst exponent H . (Hurst 1951).

The Hurst exponent lies in the interval $[0, 1]$. On the basis of the H values three categories can be identified: the series are anti-persistent, and returns are negatively correlated ($0 \leq H < 0.5$); the series are random, returns are uncorrelated, and there is no memory in the series ($H = 0.5$); the series are persistent, returns are highly correlated, and there is memory in price dynamics ($0.5 < H \leq 1$).

However, the Hurst exponent often hovers around 0.5, complicating the interpretation of results. Additionally, the question of the statistical significance of the obtained results remains open, i.e., whether the Hurst exponent value obtained can be considered reliable.

To address these shortcomings of standard R/S analysis, we propose evaluating the statistical significance of the estimated Hurst exponent. This involves calculating p -values for the Hurst exponent using procedures within the framework of regression analysis. Additionally, confidence intervals are estimated to gain insight into the behavior of the Hurst exponent within its typical range of fluctuations with a certain level of confidence (default set at 95%).

Consequently, the improved version of the Hurst exponent calculation appears as follows: $H = 0.63, p = 0.00; CI = 0.62-0.64$.

In this scenario, the data exhibit persistence, the Hurst exponent is statistically significant, and the entire confidence range is above 0.5.

Regression analysis with dummy variables serves as an additional method to scrutinize data for statistically significant differences across various periods. Within this methodology, data from two sub-periods are consolidated into a unified data set, distinguishing data assignments to specific subsets through the incorporation of dummy variables.

The model is as follows:

$$R_i = a_0 + a_1 D_{1i} + \varepsilon_i \tag{8}$$

where R_i —is the average value of the overall data set for period i , a_0 —is the average value of the first data set (first sub-period); a_1 —is a coefficient for a dummy variable characterizing its influence on the average value of the overall data set for period i ; D_i —is a dummy variable equal to 0 for the first data sub-period and 1 for the second data sub-period for period i .

3. Results

We start with descriptive statistics (see Table 1).

Table 1. Descriptive statistics for all data and sub-period: the case of the Ukrainian stock market.

Parameter	All Data	1995–1999	2000–2004	2005–2007	2008–2009	2010–2013	2014–2015	2016–2019	2020–2022
Average	0.05%	−0.13%	0.18%	0.21%	−0.09%	−0.02%	−0.04%	0.10%	−0.02%
Standard error	0.03%	0.14%	0.06%	0.05%	0.13%	0.07%	0.09%	0.04%	0.07%
Median	0.06%	0.10%	0.10%	0.19%	−0.10%	−0.04%	−0.05%	0.06%	0.03%
Standard deviation	2.06%	3.12%	2.03%	1.47%	2.96%	2.13%	1.90%	1.24%	1.59%
Sample variance	0.04%	0.10%	0.04%	0.02%	0.09%	0.05%	0.04%	0.02%	0.03%
Excess	10.54	4.13	17.16	3.79	3.48	9.60	12.90	6.13	5.37
Asymmetry	0.00	−0.64	1.01	−0.26	−0.05	0.32	0.66	−0.09	−0.27
Interval	38.05%	26.57%	37.25%	13.40%	24.76%	29.83%	26.94%	15.68%	18.37%
Minimum	−15.90%	−15.90%	−15.11%	−6.94%	−12.37%	−11.62%	−11.73%	−7.99%	−8.45%
Maximum	22.15%	10.67%	22.15%	6.46%	12.38%	18.21%	15.21%	7.69%	9.92%
Count	5895	526	1231	736	494	992	492	860	570

Key data characteristics vary across different periods. Particularly, average returns tend to be negative during crisis periods and positive during non-crisis periods, consistent with evidence from other countries and economic logic: stock markets grow during economic expansions and decline during crises. Regarding volatility (measured in Table 1 by the parameter “standard deviation”), there is a general trend of decreasing volatility, indicating a transition to a more efficient market state. With a greater number of professional participants, the market reacts more appropriately to events without excessive price fluctuations. However, volatility increases during times of crisis, a typical reaction of the stock market.

Figure 1 visually confirms these conclusions, depicting the dynamics of average values and standard deviations.

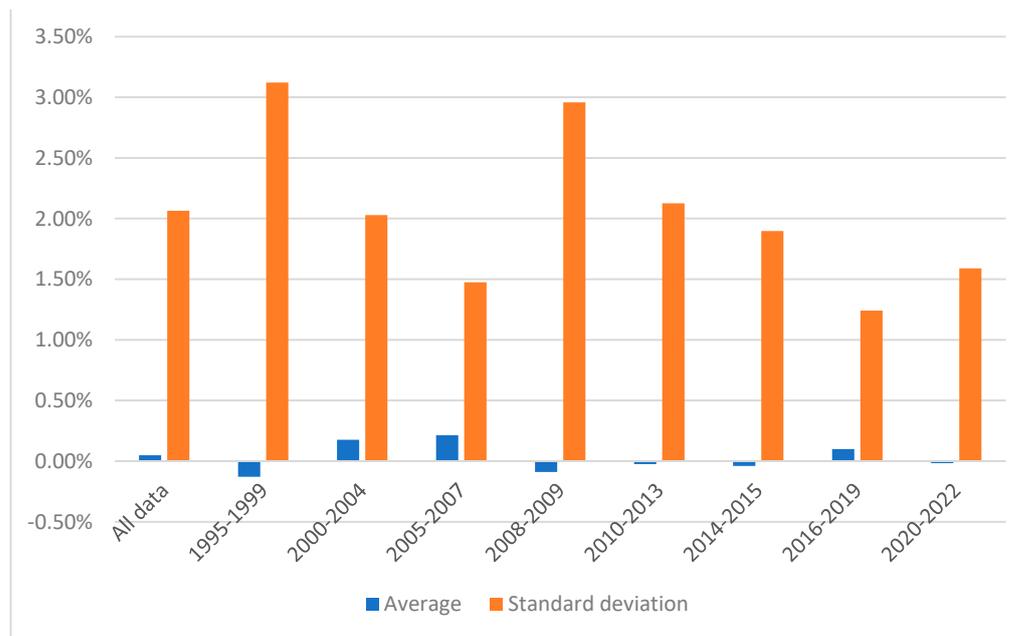


Figure 1. Dynamics of average returns and their standard deviations in the Ukrainian stock market by sub-periods.

Absolute differences, while visually evident, only imply potential distinctions among the data across different periods, as they may lack statistical significance for drawing conclusions about the belonging of the data to different populations. To ascertain the statistical significance of these differences, a series of statistical tests are conducted, encompassing both parametric and non-parametric methods to accommodate possible deviations of data from the normal distribution. The results of the ANOVA analysis (parametric test) and the Kruskal–Wallis tests (non-parametric) are presented in Table 2.

Table 2. Results of ANOVA analysis and Kruskal–Wallis Tests for statistical differences between periods in the Ukrainian Stock Market.

Method	Value	p-Value	Difference Is Statistically Significant
ANOVA analysis	2.67	0.01	Yes
Kruskal-Wallis Tests	25.22	0.00	Yes

As indicated, differences are statistically significant, meaning that not all of the analyzed periods belong to the same population. In other words, some periods demonstrated price behavior that was not typical compared to other periods.

However, based on the results from Table 2, it is not possible to conclude which periods were typical and which were not. To address this question, additional analysis is conducted. Each individual sub-period is explored for differences from the general population (the population, in this case, consisted of all data except for the period being examined). To do this parametric *t*-tests and ANOVA analysis as well as non-parametric Mann–Whitney tests are used. Results are provided in Tables 3–5, respectively.

The results of *t*-tests show that statistically significant differences are observed only during 2005–2007, and in all other periods the data behaved within the framework of the general population.

The data in Table 4 confirm the results of the *t*-tests: the only period that was statistically different from the general population was the period from 2005 to 2007.

ANOVA analysis and *t*-tests are parametric tests, so to avoid potential methodological biases associated with the normality/non-normality of data, a non-parametric Mann–Whitney test is used.

Table 3. Results of *t*-tests for statistical differences between periods in the Ukrainian stock market.

Period	t-Criterion	t-Critical (0.95)	Null Hypothesis	Difference
1995–1999	1.24	1.96	Not rejected	absent
2000–2004	0.87	1.96	Not rejected	absent
2005–2007	3.53	1.96	Rejected	present
2008–2009	0.82	1.96	Not rejected	absent
2010–2013	0.99	1.96	Not rejected	absent
2014–2015	0.54	1.96	Not rejected	absent
2016–2019	1.50	1.96	Not rejected	absent
2020–2022	0.97	1.96	Not rejected	absent

Table 4. Results of ANOVA analysis for statistical differences between periods in the Ukrainian stock market.

Period	F	<i>p</i> -Value	F Critical	Null Hypothesis	Difference
1995–1999	1.55	0.21	3.85	Not rejected	absent
2000–2004	0.75	0.39	3.85	Not rejected	absent
2005–2007	12.50	0.00	3.85	Rejected	present
2008–2009	0.68	0.41	3.85	Not rejected	absent
2010–2013	0.99	0.32	3.85	Not rejected	absent
2014–2015	0.29	0.59	3.85	Not rejected	absent
2016–2019	2.26	0.13	3.85	Not rejected	absent
2020–2022	0.95	0.33	3.85	Not rejected	absent

Table 5. Results of the Mann–Whitney tests for statistical differences between different periods for the case of the Ukrainian stock market.

Period	Adjusted H	d.f.	<i>p</i> -Value	Critical Value	Null Hypothesis	Difference
1995–1999	0.09	1	0.77	3.84	Not rejected	absent
2000–2004	0.27	1	0.60	3.84	Not rejected	absent
2005–2007	18.90	1	0.00	3.84	Rejected	present
2008–2009	1.63	1	0.20	3.84	Not rejected	absent
2010–2013	2.05	1	0.15	3.84	Not rejected	absent
2014–2015	0.45	1	0.50	3.84	Not rejected	absent
2016–2019	3.05	1	0.08	3.84	Not rejected	absent
2020–2022	0.35	1	0.56	3.84	Not rejected	absent

The results of the Mann–Whitney tests confirm the previous findings of parametric tests.

As an additional method to validate the obtained results, regression analysis with dummy variables is employed. In the regression model, Variable X1 represents the coefficient of a dummy variable. The dummy variable takes the value of 1 when the data belongs to a certain period (e.g., 1995–1999, 2000–2004, etc., as indicated in column 1), and 0 otherwise. A *p*-value below 0.05 indicates statistical differences between a specific period from column 1 and the overall data set. The results are presented in Table 6.

Table 6. Results of the regression analysis with dummy variables for statistical differences between periods in the Ukrainian stock market.

Period	F	<i>p</i> -Value	Variable X1	<i>p</i> -Value X1	Difference
1995–1999	1.55	0.21	−0.0017	0.21	absent
2000–2004	0.75	0.38	0.0006	0.38	absent
2005–2007	12.50	0.00	0.0022	0.00	present
2008–2009	0.67	0.41	−0.0011	0.41	absent
2010–2013	0.98	0.32	−0.0008	0.32	absent
2014–2015	0.29	0.59	−0.0005	0.59	absent
2016–2019	2.25	0.13	0.0008	0.13	absent
2020–2022	0.94	0.33	−0.0007	0.33	absent

The results of the regression analysis with dummy variables align with those obtained from the statistical tests: the only period that statistically differs from the overall data set is the period from 2005 to 2007.

Based on the statistical tests and regression analysis with dummy variables, it can be concluded that the only period exhibiting different data properties from the general population is the period from 2005 to 2007. Despite various crises, regulatory changes, and economic shifts, the behavior of prices in the Ukrainian stock market remained relatively consistent across other periods. Apart from the period 2005–2007, there is a lack of evidence indicating qualitative transformations or evolution in the specificity of price fluctuations within the Ukrainian stock market.

A distinct approach to analyzing market efficiency involves examining data persistence. The results of the R/S analysis for the entire data set and sub-periods are presented in Table 7.

Table 7. Results of the persistence analysis for the case of the Ukrainian stock market in different periods.

Period	Hurst Exponent	<i>p</i> -Value	Confidence Interval (95%)	Type of Data
All data	0.65	0.00	0.63–0.66	persistent
1995–1999	0.56	0.00	0.44–0.69	persistent
2000–2004	0.66	0.00	0.64–0.68	persistent
2005–2007	0.63	0.00	0.60–0.66	persistent
2008–2009	0.67	0.00	0.63–0.71	persistent
2010–2013	0.61	0.00	0.58–0.63	persistent
2014–2015	0.56	0.00	0.54–0.58	persistent
2016–2019	0.62	0.00	0.61–0.63	persistent
2020–2022	0.53	0.00	0.49–0.57	random

Overall, the Ukrainian stock market is characterized by the presence of persistence (long-term memory), meaning that past prices contain information about future prices, thus prices in such a market are fundamentally predictable. The visualization of the Hurst exponent dynamics with a trend line is provided in Figure 2.

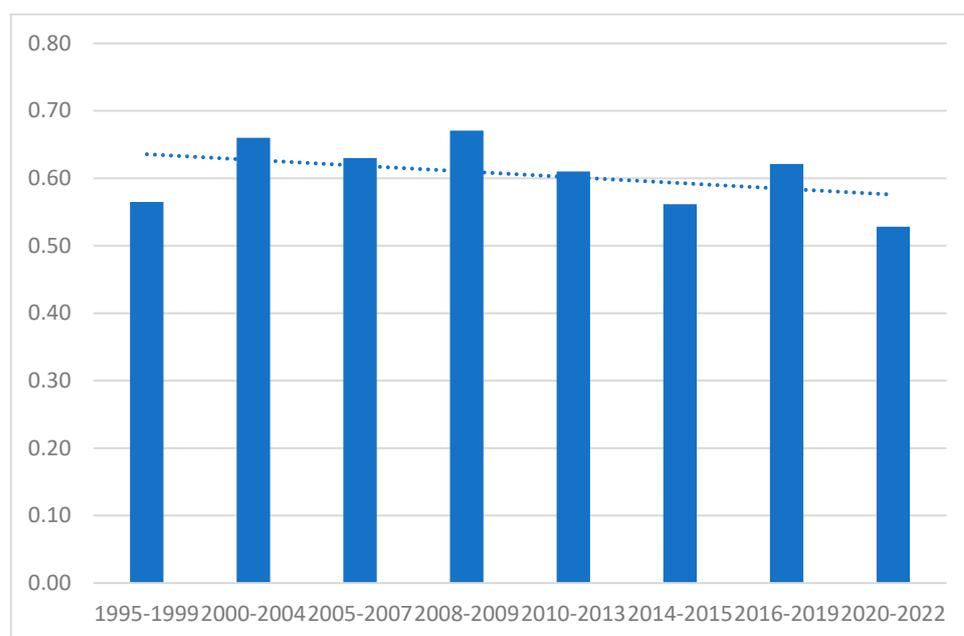


Figure 2. Transformation of persistence in the Ukrainian stock market in time.

As can be seen, there is a certain trend in the dynamics of persistence in the Ukrainian stock market: a decrease in the Hurst exponent values. Essentially, this represents a shift in the specificity of price fluctuations from their fundamental predictability due to the presence of long-term memory to the random nature of price movements, which is typical for an efficient market. Therefore, we have confirmation in favor of certain evolutionary processes in the Ukrainian stock market: it transforms from a less efficient state to a more efficient one.

However, there is only one period (from 2020 to 2022) that can be classified as non-persistent.

An important data property is the type of data distribution (normal/not normal). The normality of data is one of the indicators of an efficient market. Accordingly, the “non-normality” of data is evidence in favor of market inefficiency. Changes in the behavior of this data property can be used as one of the signs of market evolution.

Preliminary conclusions about data normality can be made based on the analysis of descriptive statistics parameters kurtosis and skewness. For a perfectly symmetrical distribution (i.e., normal distribution), the skewness is zero. While there is no strict threshold, skewness values between -1 and 1 (in some sources -0.5 to 0.5) are often considered acceptable for assuming normality. For a normal distribution, the kurtosis is typically around 3 . Commonly, excess kurtosis values between -2 and 2 are considered acceptable for assuming normality (George and Mallery 2010; Field 2009). Going beyond these ranges raises doubts about the normality of data distribution.

In Table 8 the values of kurtosis and skewness parameters for each of the analyzed sub-periods are provided.

Table 8. Kurtosis and skewness of data for different periods in the Ukrainian stock market.

Period	Kurtosis	Skewness
All data	10.54	0.00
1995–1999	4.13	−0.64
2000–2004	17.16	1.01
2005–2007	3.79	−0.26
2008–2009	3.48	−0.05
2010–2013	9.60	0.32
2014–2015	12.90	0.66
2016–2019	6.13	−0.09
2020–2022	5.37	−0.27

Skewness across all periods is within the range $[-1..1]$, which is an indication of data normality. However, kurtosis significantly exceeds $[-2..2]$ range in all cases, which, in turn, is a sign of data non-normality.

To eliminate this uncertainty, there are numerous statistical tests for assessing the conformity of data to a normal distribution. One of the most popular ones is the Kolmogorov–Smirnov test. Results are presented in Table 9.

Table 9. Kolmogorov-Smirnov test for different periods in the Ukrainian stock market.

Period	Statistic	d.f.	p-Value
1995–1999	0.123	492	0.000
2000–2004	0.082	492	0.000
2005–2007	0.071	492	0.000
2008–2009	0.094	492	0.000
2010–2013	0.100	492	0.000
2014–2015	0.089	492	0.000
2016–2019	0.086	492	0.000
2020–2022	0.060	492	0.000

Results from Table 9 confirm the normal distribution of the data. Normal distribution was typical for all periods, implying that there were no radical changes in the behavior of this data property in the Ukrainian stock market from 1999 to 2022.

One of the main criticisms against the Efficient Market Hypothesis is the presence of anomalies—typical patterns in price behavior that should not exist in an efficient market but have been empirically identified by researchers. Anomalies range from calendar anomalies (month-of-the-year effect, day-of-the-week effect, Halloween effect, holiday effect, etc.) to anomalies related to small firms and price patterns emerging after abnormal price fluctuations, etc.

Therefore, studying price anomalies can provide additional information about market efficiency. The presence of anomalies is evidence in favor of market inefficiency, while the absence supports market efficiency.

Plastun et al. (2019) explored calendar anomalies in the U.S. stock market and showed that anomalies lost their strength with the development of the U.S. stock market and almost completely disappeared at the beginning of the 21st century. Thus, investigating price anomalies over different periods can offer valuable insights into the evolution and current state of the market in terms of efficiency.

Considering the specifics of the data used in this study (daily data over 2–5-year periods), it is impossible to analyze most anomalies due to their requiring a different data periodicity (monthly, for example) or a larger data set. However, some anomalies can be explored with statistically significant results. One such anomaly is the day-of-the-week effect—one of the most well-known calendar anomalies studied on various markets (stock, currency, commodity, cryptocurrency) in different countries (U.S., Japan, China, etc.) and groups of countries (developed, emerging).

The first step in the analysis for the presence of this anomaly is the visual inspection of average daily returns for specific days of the week (Figure 3).

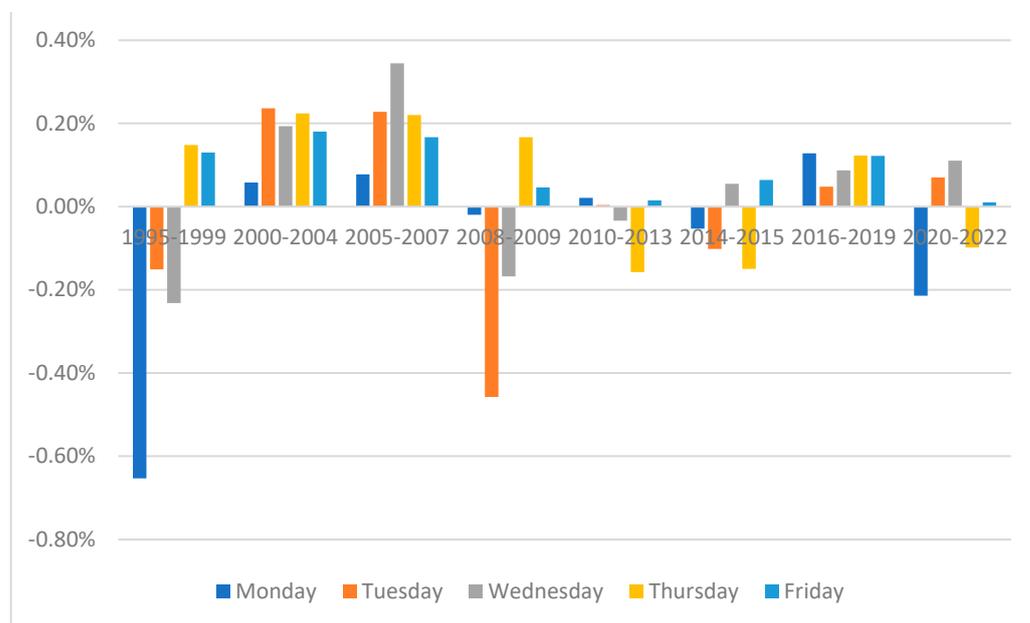


Figure 3. Average Daily Price Fluctuations in the Ukrainian Stock Market by Day of the Week.

As can be seen, the only day when price dynamics were consistently positive (prices increased) was Friday, aligning perfectly with the classical day-of-the-week effect. Regarding another classical feature of the day-of-the-week effect—price declines on Mondays—this effect was vividly observed only in the first and last of the analyzed periods (1995–1999 and 2020–2022, respectively). For the rest of the days, the data were mixed. In certain periods, the dynamics on specific days appeared anomalously strong compared to other days. For

instance, the price decline on Tuesdays during the 2008–2009 period, in absolute terms, was several times greater than the average dynamics on any other day of the week.

Based on visual analysis it cannot be concluded whether the observed differences are statistically significant. Therefore, the next stage of the analysis involves the use of statistical tests to answer the question of whether the differences are statistically significant. For these purposes, both parametric and non-parametric tests are employed.

The results of the *t*-test are presented in Table 10.

Table 10. Testing the statistical significance of day-of-the-week effects: *t*-tests.

Period	t-Criterion (t-Critical (0.95) = 1.96)					Null Hypothesis	Difference
	Monday	Tuesday	Wednesday	Thursday	Friday		
1995–1999	−1.66	−0.04	−0.32	1.17	1.02	Not rejected	absent
2000–2004	−1.17	0.47	0.12	0.37	0.00	Not rejected	absent
2005–2007	−1.17	0.17	1.27	0.11	−0.37	Not rejected	absent
2008–2009	0.22	−1.21	−0.35	0.98	0.58	Not rejected	absent
2010–2013	0.35	0.26	−0.02	−0.98	0.37	Not rejected	absent
2014–2015	−0.06	−0.37	0.63	−0.75	0.74	Not rejected	absent
2016–2019	0.33	−0.62	−0.17	0.22	0.28	Not rejected	absent
2020–2022	−1.21	0.70	0.96	−0.66	0.22	Not rejected	absent

Null hypothesis status is provided for the case of 95% confidence level.

The *t*-test results provide evidence in favor of the absence of statistically significant differences in the price dynamics on different days of the week. All days belong to the same population, indicating that the day-of-the-week effect in the Ukrainian stock market is not confirmed for any of the analyzed periods.

The next parametric test used for additional verification is the ANOVA analysis. The results are presented in Table 11.

Table 11. Testing the statistical significance of day-of-the-week effects: ANOVA analysis.

Period	F	<i>p</i> -Value	F Critical	Null Hypothesis	Difference
1995–1999	1.12	0.35	2.39	Not rejected	absent
2000–2004	0.29	0.89	2.38	Not rejected	absent
2005–2007	0.64	0.64	2.38	Not rejected	absent
2008–2009	0.66	0.62	2.39	Not rejected	absent
2010–2013	0.24	0.91	2.38	Not rejected	absent
2014–2015	0.25	0.91	2.39	Not rejected	absent
2016–2019	0.13	0.97	2.38	Not rejected	absent
2020–2022	0.76	0.55	2.39	Not rejected	absent

Null hypothesis status is provided for the case of 95% confidence level.

The results of the ANOVA analysis are in line with those obtained from the *t*-tests, confirming that no statistically significant differences are detected and providing no evidence of the existence of a day-of-the-week effect in the Ukrainian stock market.

The next step is the use of non-parametrical Kruskal–Wallis Tests (Table 12).

The results of the Kruskal–Wallis tests in general confirmed the conclusions of parametric tests with one exception: during the period 2020–2022, statistically significant differences were observed between different days of the week. However, this conclusion does not specify which days of the week differ from the others.

To clarify this point additional research for this period is provided. Visual analysis (see Figure 4) indicates that Monday is characterized by an anomalously strong price movement compared to other periods, namely a decline in prices.

Table 12. Testing the statistical significance of day-of-the-week effects: Kruskal–Wallis Tests.

Period	Adjusted H	d.f.	p-Value	Critical Value	Null Hypothesis	Difference
1995–1999	5.95	4	0.20	9.49	Not rejected	absent
2000–2004	3.97	4	0.41	9.49	Not rejected	absent
2005–2007	2.88	4	0.58	9.49	Not rejected	absent
2008–2009	1.74	4	0.78	9.49	Not rejected	absent
2010–2013	1.63	4	0.80	9.49	Not rejected	absent
2014–2015	1.36	4	0.85	9.49	Not rejected	absent
2016–2019	0.98	4	0.91	9.49	Not rejected	absent
2020–2022	9.76	4	0.04	9.49	rejected	present

Null hypothesis status is provided for the case of 95% confidence level.

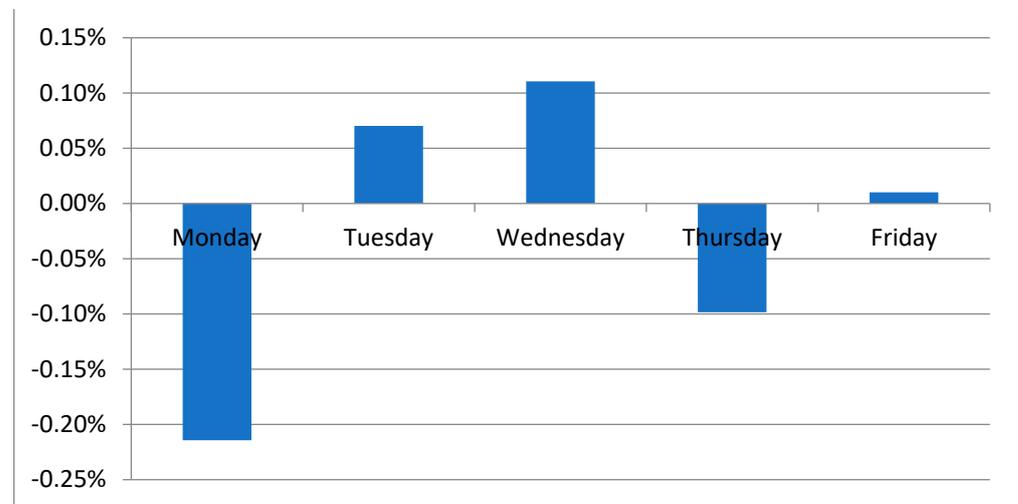


Figure 4. Average daily returns in the Ukrainian stock market for the period 2020–2022: the case of days of the week.

As can be seen, returns on Monday were much lower compared with the other days of the week. To see whether this difference is statistically significant parametric ANOVA analysis and non-parametric Mann–Whitney tests are applied. The results of the ANOVA analysis are presented in Table 13.

Table 13. ANOVA analysis for the case of the day-of-the-week effects in the Ukrainian stock market during the period 2020–2022.

Day	F	p-Value	F Critical	Null Hypothesis	Difference
Monday	2.59	0.11	3.89	Not rejected	absent
Tuesday	1.92	0.17	3.89	Not rejected	absent
Wednesday	1.06	0.30	3.89	Not rejected	absent
Thursday	0.36	0.55	3.89	Not rejected	absent
Friday	0.03	0.86	3.89	Not rejected	absent

Null hypothesis status is provided for the case of 95% confidence level.

The results of Table 13 confirm the conclusions of the ANOVA analysis for all days provided in Table 11—there are no statistically significant differences between individual days of the week.

As for the non-parametric Mann–Whitney tests, they are presented in Table 14.

Table 14. Mann–Whitney tests for the case of the day-of-the-week effects in the Ukrainian stock market during the period 2020–2022.

Day	Adjusted H	d.f.	p-Value	Critical Value	Null Hypothesis	Difference
Monday	6.27	1	0.01	3.84	rejected	present
Tuesday	2.39	1	0.12	3.84	Not rejected	absent
Wednesday	5.04	1	0.02	3.84	rejected	present
Thursday	0.22	1	0.64	3.84	Not rejected	absent
Friday	0.00	1	0.98	3.84	Not rejected	absent

Null hypothesis status is provided for the case of 95% confidence level.

Non-parametric tests, unlike parametric ones, indicate that returns on Mondays and Wednesdays differ from the typical price behavior throughout the week. Therefore, there is evidence supporting a day-of-the-week effect during the period 2020–2022, characterized by a presence of negative returns in prices on Mondays and a tendency for the market to demonstrate positive dynamics on Wednesdays.

Considering that throughout all other periods, starting from 1995–1999, anomalies were entirely absent, it can be argued that there is a certain degradation of the Ukrainian stock market from the point of its efficiency.

In general, the analysis of anomalies has shown that the Ukrainian stock market was immune to the day-of-the-week effect. There are no specific trends in their development depending on the period. Thus, the hypothesis that the evolution of the stock market led to an increase in its efficiency in terms of the presence of fewer anomalies has not been confirmed.

4. Discussion

Summarizing the results of the evolution of the Ukrainian stock market, it can be concluded that the level of its efficiency did not demonstrate a clear trend of growth. Existing evidence is mixed, ranging from certain signs of movement towards greater efficiency (R/S analysis and volatility analysis) to clear signs of the degradation of the Ukrainian stock market (movement towards greater inefficiency observed for the case of day-of-the-week effect). Based on these results it is hard to call the last 30 years a development of the Ukrainian stock market.

Partially, this can be attributed to the extremely unstable situation in Ukraine, both economically and politically. The 1990s witnessed a transition from the Soviet economic model to a market-oriented one, during which neither citizens nor companies were familiar with the stock market. The early 2000s saw rapid development in the Ukrainian stock market, but the 2004 revolution marked a significant shift in mentality and development trajectory, impacting the stock market as well. Subsequently, the global financial crisis of 2007–2009, with some time lags, further disrupted the Ukrainian stock market, which has yet to fully recover. Additionally, the revolution of 2013–2014, accompanied by the annexation of Crimea and the onset of war with Russia, led to the physical loss of many industrial companies, plunging the Ukrainian stock market into a new phase of degradation and depression. The full-scale invasion of Russia in 2022 caused the largest war in Europe since WWII, resulting in a one-third loss of Ukrainian GDP and the actual disappearance of the Ukrainian stock market. In 2024, it was only nominally present. Given this tumultuous history, the results of this paper may not be as confusing as they initially appear, and it cannot be conclusively argued that they contradict the AMH.

No wonder the reforms and legislative as well as regulatory changes that took place had little or no impact on the nature of price behavior and the properties of prices as data series. This, in turn, justifies the relevance and necessity of further reforming the Ukrainian stock market and its evolution needs more time.

An additional argument in this favor is that Ukraine's asset price transmission channel is not working. The National Bank of Ukraine primarily operates through other trans-

mission channels, notably the Exchange Rate and Credit Channel. This is mainly because the Ukrainian stock market wields minimal influence over the country's financial system. Hence, it is imperative to prioritize the development of the Ukrainian stock market.

Factors influencing the development of the Ukrainian stock market encompass various aspects, including the end of the war and post-war economic recovery. Additionally, security guarantees and the alignment of Ukrainian legislation with European standards play pivotal roles. Furthermore, the influx of foreign funds is significant, but the establishment of proper stock market infrastructure and business processes is equally crucial. Moreover, the growth of financial literacy among the population and the fostering of an investment culture are essential for market development. Addressing information asymmetry and transparency issues within the Ukrainian stock market are other vital factors. Lastly, introducing new financial products such as futures, options, ETFs (Exchange Traded Funds), and ESG indices contributes to market diversification and growth.

In conclusion, following the war, the Ukrainian stock market is poised to embark on a new trajectory, indicating that the market is still far from achieving efficiency, as evidenced by the findings of this paper.

5. Conclusions

This paper explores the transformation of the Ukrainian stock market through an analysis of various data properties. Daily returns from the leading Ukrainian stock market index PFTS spanning 1997–2022 are examined, with the data set divided into sub-periods to identify differences in data properties. The following hypothesis is tested in this paper: efficiency of the Ukrainian stock market increases over time.

To test this hypothesis a number of data properties are explored: persistence, volatility, normality, and resistance to anomalies. To do these different methods and techniques are used: descriptive statistics, parametric tests (*t*-tests, ANOVA-analysis), non-parametric tests (Mann–Whitney test, Kruskal–Wallis test), data normality tests (Kolmogorov–Smirnov test), R/S analysis, regression analysis with dummy variables.

Volatility (measured by the standard deviation) shows a general decreasing trend, suggesting a shift towards a more efficient market. However, there are no statistically significant differences in returns for different sub-periods, except for the period from 2005 to 2007, which contradicts conclusions from volatility analysis.

The R/S analysis indicates the presence of persistence in the Ukrainian stock market, suggesting that past prices contain information about future prices. Despite this, there is a decreasing trend in Hurst exponent values, indicating a transformation towards a more efficient market and less predictable prices.

Normality tests reveal a normal distribution of daily returns in the Ukrainian stock market across all analyzed sub-periods, with no significant shifts in data properties over time. Similarly, the market shows immunity to the day-of-the-week effect, although there are signs of degradation during the period from 2020 to 2022. Thus, the hypothesis that the evolution of the stock market led to an increase in its efficiency in terms of the presence of fewer anomalies has not been confirmed.

Overall, the results suggest a lack of systematic changes in data properties in the Ukrainian stock market over time, which can be attributed to the country's unstable economic and political situation. Over the past 30 years in Ukraine, there have been two revolutions, numerous economic crises, territorial annexations, and a full-scale Russian invasion, resulting in the largest war in Europe since WWII.

Policymakers can leverage the findings of this paper as a roadmap for their regulatory endeavors. Their primary focus should revolve around post-war economic recovery and ensuring security guarantees. Subsequent efforts should entail harmonizing Ukrainian legislation with European standards, attracting foreign investment, bolstering stock market infrastructure, promoting financial literacy, and introducing innovative financial products such as futures, options, ETFs, and ESG indices.

Furthermore, the results of this paper hold implications for investors, particularly in exploiting abnormal negative returns observed on Mondays in the Ukrainian stock market over recent years. Implementing a straightforward trading strategy of selling on Mondays could yield additional profits, albeit subject to further verification through trading simulations. This avenue presents a promising area for future research, along with exploring other potential price anomalies such as momentum and contrarian effects following abnormal returns, the Month of the Year effect, the Halloween effect, and the Holiday effect.

Moreover, future research directions could include the use of more sophisticated methodologies to investigate data properties. For example, instead of R/S analysis fractional integration methodology can be applied.

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