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TESTING INFORMATIONAL INEFFICIENCY OF STOCK PRICE FORMATION OF UKRAINIAN COMPANIES – COMPARISON BETWEEN UKRAINIAN AND WARSAW STOCK EXCHANGES

Bachelor thesis

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This paper conforms to the requirements for a research paper

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(signature of supervisor)

Admitted for defence " "…………… (date)

I have written this Research paper independently. Any ideas or data taken from other authors or other sources have been fully referenced

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(signature of the author and date)

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Introduction

There is an old joke about a finance student and his professor illustrating the improbability of beating the market returns. The student notices a $100 bill lying on the pavement and kneels to take it. The professor instead says "Don't bother. If it were really a $100 bill, it wouldn't be there."

In 2018 Ukraine became the best performing stock market globally with its PFTS index skyrocketing by shocking 80.39%. What this number does not describe are drastic declines in trading volumes happening since 2012. In just five years Ukrainian stock market's role degraded to just demonstrating that Ukraine has one, and not performing anymore its essential functions it "has turned into a pale shadow of itself" (Plastun, Makarenko & Balatskyi, 2018 p.29).

It is hard to name Ukraine market anything but underdeveloped and not liquid enough (Dovhal, 2015). Consider that total contract count (number of trades) in 2018 for all stocks traded on this exchange was less than 6000 (PFTS, n.a.). Naturally, under such conditions, local companies look for alternative stock exchanges for initial public offerings. Its close neighbour with the highest market capitalisation in sub-region is Warsaw Stock Exchange. For the past two years, equity market capitalisation of Ukraine ($4.4 billion in 2018) had been almost 40 times smaller than that of neighbouring Poland (World Federation of Exchanges, 2018). Poland is an advanced emerging market ranked 3rd of European emerging stock markets while Ukraine is classified as a frontier market and was on the last 15th place of the ranking by Smith (2012).

For a retail investor, it is hardly possible to participate in the Ukrainian Stock Exchange. Funds investors missed the top performing PFTS index mostly because Exchange Traded Funds representing only Ukrainian stocks did not exist. At the same time, there are no difficulties accessing the 5 Ukrainian companies listed on Warsaw Stock Exchange composing WIG-Ukraine index, that are reported to be undervalued and potentially growing (Parvi, 2017).

No matter how high the market returns are, it is natural for an investor to want to beat it if such an opportunity is possible. Market inefficiencies and anomalies offer such exploitable opportunities. Understanding the degree of market efficiency allows having more accurate expectations of the stock price movements behaviour as well as the suitability of technical and fundamental analysis. Lack of transparency, regulations, and healthy competition on an inefficient market is a repellent factor for investors. It is hence interesting to understand on which market the inefficiency of Ukrainian companies' price movements is lesser.

The paper aims to study the informational efficiency of individual stocks of listed Ukrainian companies listed and part of PFTS and WIG Ukraine indexes. The novelty of this approach is considering individual stocks alongside indices data to compare if Ukrainian companies listed on Kiev and Warsaw Stock Exchange participate in a more efficient market than the home one. Research tasks the author set for this paper are:

- Explaining the concept of stock market efficiency and its importance.
- Identifying ways to empirically test market efficiency.
- Giving an overview of works studying inefficiencies of the Ukrainian market.
- Processing data about Ukrainian listed companies and testing for inefficiencies.
- Analysing randomness of Ukrainian companies' stock price formation as a precondition of informational efficiency.
- Comparing Ukrainian companies listed domestically with those included in WIG Ukraine index.

Answering the question of where this study fits, there is a limited number of studies conducted about the Ukrainian stock market. Most researchers have studied calendar effects in general or, more specifically, weekend (Caporale, Gil-Alana & Plastun, 2016), month or end of the year (Tilica, 2014), etc. Another popular topic is understanding information (in)efficiency of Ukrainian stock market, by developing new assessment frameworks (Malyshenko, 2013), assessing insider information (Matsuk, 2015) or showing inefficiencies through proving short-term price overreaction based on daily returns (Mynhardt & Plastun, 2013). Finally, few studies exist specifically about the Ukrainian stock market during the ten months of political and territorial crisis with Russia in 2013-2014 (Plastun et al., 2018) and the impact of the conflict on returns of both countries (Hoffmann & Neuenkirch, 2017).

Speaking about the structure of the remainder of the paper, the first part will introduce readers to its key theoretical concept, market efficiency, briefly stating the forms of efficiency, the definition of the term and its importance to investors and economies. The author will continue by presenting the most common empirical methods to test market efficiency. It will be followed by an overview of the literature in the area of efficiency of the Ukrainian stock market within the last decade, and conclusions drawn by the scholars on its effectiveness.

The empirical part of the paper will focus on analysing daily returns from 2012 to mid 2018 of 13 selected Ukrainian companies that are included in PFTS and WIG Ukraine indexes. The author will describe the data chosen, justify the selection of methods, and statistically check for possible inefficiencies in price movements to eventually compare the two markets. The methods chosen for this purpose are used are variance ratio test, Augmented Dickey-Fuller test, and Hurst exponent estimation. Afterward, some limitations of the methods used will be highlighted. The final paragraph of the empirical part will also compare the conclusions of other works presented in the theoretical part to those obtained in this study.

Key Words: informational market efficiency, weak form market efficiency, Ukrainian stock market, random walk.

1. Literature Overview

1.1. Stock market efficiency and its importance

Since E.F. Fama developed the efficient market hypothesis (EMH) in 1970, informational market efficiency became a paradigm commonly studied by scholars both supporting and criticising it. Originally in Fama's work, it was defined as having only one condition that security prices at all times embody all available information. However, even the EMH author stated that with such a general definition full reflection of information cannot be empirically verified. In order to make the EMH more suitable to be empirically tested it was defined in the following three forms (Fama, 1970):

- **Strong form:** all public and insiders' information is reflected in the current price; there is no possible benefit in trading on insiders' information; a perfect market that covers all information.
- **Semi-strong form:** all publicly available information is reflected in the current price; there is no possible benefit from using fundamental analysis.
- **Weak form:** all past price movements information is reflected in the current price; there is no possible benefit from using technical analysis.

Grossman and Stiglitz (1980) paper claimed that informational efficiency is impossible to achieve. This is due to the non-zero cost of information acquisition that was not taken into consideration into EMH before by Fama (1970). In a current reality where full precise information is not practically possible to be obtained costless, all existing information cannot be reflected in the prices. Furthermore, in the real world assumptions about investors being rational cannot always hold. Not every trader is actually trading on information; some investors are uninformed and trade just due to liquidity (personal) reasons.

To reach the competitive equilibrium of security prices, it is enough that the information is inexpensive. On the one hand, the incentive of acquiring information comes into conflict with the efficiency of information spreading by markets. On the other hand, as markets evolve, price inefficiencies motivate more arbitrageurs to trade the wrongly priced assets. The latter phenomena by itself, so to say, forces markets to become more efficient and up-to-date in their securities pricing. In other words, an efficient market is a self-correcting mechanism. It appears that the degree of efficiency depends on a number of informed investors closely seeking opportunities to take advantage of inefficiencies and the original EMH needs to be rethought. (Grossman & Stiglitz, 1980)

Jensen (1978) had gathered some studies by multiple authors each being an individual scientific piece of evidence of anomaly cases from various markets as well as security types were brought up there in order to highlight the yet unsolved issues with the market efficiency theory as it was defined back at the time. One of the inconsistencies between the Jensen (1978) work and the preceding definitions was introducing a point until which the security prices would reflect available information.

The definition of an efficient market in the paper was formulated with respect to an information set, simplified to stating the impossibility of making an economic profit by buying/selling on the basis of that information set. The contribution to the prevailing definition was a formula expressing price conditional on knowledge of the information set versus the costs associated. According to it, any rational, informed investor only acts on the information when the marginal cost of acting is below the marginal benefit of acting on it. In this situation the lower the cost at which marginal investors can acquire and process information sets, the better is their position to profit from it. (Jensen, 1978)

Finally, more recently Malkiel published a renowned paper on critics of the EMH. In it, an efficient market is defined as the one where investors cannot earn an above-average return unless they accept an above-average risk, and even an uninformed amateur investor will get a same high rate of return as a professional investor, eventually leaving the informed traders without the incentive to participate (Malkiel, 2003).

While the possibility of existence of a perfect efficiency is denied (in accordance with Grossman and Stiglitz (1980)), it is said that markets can still be considered as efficient even if they occasionally allow for random errors in pricing of securities (as likely to be overvalued as undervalued) or its participants are behaving irrationally (put it simply as selling security not because they are acting on information but rather because they need cash).

The definition used by the author of the paper is a combination of those mentioned above. It is most similar to the updated version by Fama (1991). This later work keeps the same definition presented in his original 1970 work but already accounts for the two primary preconditions brought out in the works of Jensen (1978) and Grossman and Stiglitz (1980). In this work it is thus defined in the following way:

> *An efficient market is the one where all available information is reflected in a current price of securities to the point where the marginal benefits of acting on this information exceed the costs of obtaining it plus marginal transaction costs.*

Multiple scholars discussed the importance of studying Market Efficiency. Timmermann and Granger (2004, p.15) named the EMH a "back-breaker for forecasters" as if returns would not follow the EMH, markets would resemble unlimited "money-machines." Such a statement implies that by knowing the efficiency level of a selected market, investors can set achievable, realistic expectations on what predictions and returns are realistic. To put it simply, if trading on an efficient market (self-correcting mechanism) investor would not “waste” time on performing technical and fundamental analyses, as all the extractable information from those is already reflected in the price.

Market efficiency is one of the top factors that attract investors. In a very inefficient market even when a mispriced security is discovered, there can be no certainty that its price will be adjusted in future and bring an additional return. In contrast, on a market with some degree of efficiency, a currently undervalued stock will be later adjusted to its real value. Now consider that more traders result in more liquidity in the market. Chordia, Roll, and Subrahmanyam (2008) mentioned a loop effect where more liquidity encourages more arbitrageurs’ activity on mispriced assets which in turn leads to higher market efficiency.

On the government level, Formosa (2008) pointed out a trend to encourage market efficiency by creating respectful country-wide economic reforms. Improving the availability of public free information from the listed companies by forcing them to provide it is among the first steps the legislators can take to boost informational efficiency. Overall, efficient and effective stock markets are a crucial part of the national economy that facilitates integration into the global economy (Dovhal, 2015) and development of the financial system through intensified competition for investable assets.

All things considered, the efficient market hypothesis (in its not extreme version) is supported both by the majority of scholars and evidence from the world markets. Nonreaction to negative news announcements on developed markets could be explained from the strong form of EMH perspective with the claim that the stock price at the moment of the announcement had already been correctly reflecting the actual value. It is though difficult to believe in such ambitious reasoning, where correct pricing preceding public release.

Ultimately, the author thinks that studying market efficiency is relevant especially for developing markets where inefficiencies give hints on some technical analysis could result in beating the market. In more efficient markets it is rather essential to understand what EMH is and what it is not stating. The main issue for investors picking a market with a high efficiency assessment is not to fall into the logical fallacy of concluding that it is impossible to beat, or (what is worse for beginner investor) underperform on an efficient market. While inefficiency suggests that most traders will make excess returns or losses, efficiency is not yet a guarantee of performance on the market level.

Traders do not all interpret and act identically on the same information about listed companies, no matter how detailed and easy to access it is. Accurately choosing the individual stocks that will beat the market in future as a matter of luck or as a result of speculations on ideas that could succeed in future does not contradict the premises of Fama's hypothesis. That is how Warren Buffett and John Templeton can outperform a market in the long term without necessarily discrediting its efficiency.

1.2. Methods of testing market efficiency

Testing market efficiency usually requires setting a joint hypothesis test of market efficiency and efficacy of the investment scheme returns. In general, most of the methods used to prove or disprove market efficiency (mainly its weak form) include parametric or non-parametric statistics. It is intuitive to think that the empirical methods to fall into two categories – price randomness check and invalidity of predictability. In the figure 1 below the author offers a brief classification of the most used methods to test for the weak form market efficiency, followed by some additional explanations below. Note, that while testing strategies include some brief examples as well, randomness tests as the more frequently used group were allocated more attention in this study.

Test randomness

parametric + **non-parametric**

- Standard Variance ratio test
- Serial correlation tests
- Spectral analysis
- Dickey-Fuller unit root test
- ARMA model (auto-regression & moving average)

- Phillips-Perron unit root test
- Runs test (Wald–Wolfowitz)
- Time series autocorrelation tests (e.g. Ljung Box Q-test)
- Neural network
- Hurst exponent

Test strategies

- Event study & market reactions
- Seasonal patterns
- Day-of-the-week effect
- Portfolio study (winner / loser)
- Filter rules / technical trading simulation
- Firm characteristics anomalies

Figure 1. Methods of testing weak form stock market efficiency
Source. Compiled by the author

Random Walk hypothesis was among the earliest approaches to testing for weak-form market efficiency. The theory behind Random Walk (or in other words “fair game) model was elaborated by Samuelson (1965) who showed the absence of correlation between past and next period price differences. It implies the ideal image of the impossibility of exploiting trading systems for consistent gains, hence zero serial covariance.

Testing for the Random Walk is a common method applicable to individual stocks as well as to large indexes. As for its usage, Fama (1970) suggested that it would be desirable to test directly trading rules profitability, due to hardly justifiable serial correlation and filter tests. Being a non-parametric test it could also give better results in the serial price dependence than the similar parametric tests.

Wald-Wolfowitz runs test evaluated the randomness of a two-valued (binary) dataset. In the time series, run-tests can analyse serial independence of returns, though only taking into account the sign of the change. Succeeding prices are considered autonomous if it is not possible to predict the positive or negative sign of future price movement. The test set up identifies sequences of identical symbols (called runs), as the number and length of those can be used to reject randomness. Nevertheless, it is important to understand that run tests simplify the observations to only include the sign of each, and thus reflect only limited information about ths studied sequence. (Wald &Wolfowitz, 1940)

To address the magnitude difference, later works (Lo & MacKinlay, 1988; Poterba & Summers, 1988) had developed and used modifications of standard variance ratio, based on the fact that if dividends adjusted security's price follows a random walk hypothesis, its return variance is a linear function, increasing proportionally to the horizon length. Lo and MacKinlay (1989) in their variance tests decided to check for two separate null hypotheses – Gaussian (normal distribution) and the heteroscedastic hypothesis; they also suggested the standard variance test to be more powerful than the Dickey-Fuller test of non-stationarity.

Dickey-Fuller test of unit root in an autoregressive model is a classic test developed in 1979 to test for stationarity (Dickey & Fuller, 1979). Its later adaptation to fit more complex and greater in size models – Augmented Dicky-Fuller (ADF) test checks if the series is stationary or, in other words, mean reverting. If yes, then the next move sign can be predicted using the current price level. A core practical concern around ADF test is selecting the lag length within which security's price should return to the origin. While ADF is a parametric test, Philips & Perron (1988) non parametric test had corrected some shortcomings of ADF test in handling serial correlation and heteroscedasticity. (Hamid, Suleman, Shah & Akash, 2010; Onour, 2009)

Currently one of the most common measures to show the violation of weak form market efficiency is proving long-range dependence in time series. Long-term memory of a market means that past shocks affect current price behaviour, or in other words are autocorrelated. One of the ways to detect it is by calculating the Hurst exponent. As an index of dependence, it can detect the cases where the long-term memory is positive or negative, since both give exploitable arbitrage opportunities.

While the Hurst exponent was initially developed for hydrological measurements, the oldest and best known due to its simplicity way to estimate it had always been the rescaled range analysis (Mandelbrot & Wallis, 1969). Some alternative ways include detrended fluctuation (based on scaling of variances), detrended moving average (based on moving average filtering), and height-height correlation (based on scaling of height correlation function) analysis (Kristoufek & Vosvrda, 2013).

An event study can be used to evaluate reactions such as abnormal price movements to selected information events (both market-wide and firm-specific announcements). Security prices in the period around the event date are collected and analysed to identify any excess returns using t-statistics. For that matter, events taken into account do not have to be necessarily associated only with the stock market, like earnings or dividends announcements. A more complex approach to event study when applicable can take the longer horizon of announcements, as in the example of Hoffmann and Neuenkirch (2017) analysing a 10-month period of returns based on selected keywords frequency in global news.

Some common methods are based on building a regression model that would forecast securities prices, assessing excess yields obtained in event studies, or calculating returns from following selected investment strategies. Cross-sectional (multiple firms/markets at one point of time) and time-series (one firm/market across long time period) regressions can be used to check how stock returns could be possibly related to selected variables from a strategy tested. As for the variables, anything from days of the week to firm's size and its P/E ratio can serve as one. The main issue around using regressions is not to fall into common mistakes, such as choosing a shred of anecdotal evidence to come to the desired conclusion, or not accounting for market-wide performance and risk.

Finally, in order to claim the market inefficient, it is enough to show that a selected investment strategy can consistently beat the market. Note that it is not same as an investor beating the market without a single strategy. Some scholars choose to check the profitability of their technical trading filtering rules strategies, including but not limited to moving averages, triangle and other chart patterns, momentum indicators, trend lines to name but a few. Others check for the presence of already proposed seasonal and calendar effects, like January or weekend effects.

The issue with strategy testing is that these studies seldom take into account the transaction costs, though some markets have high execution fees and large bid-ask spreads. The applicability of strategies that involve a lot of costly transactions is dubious. As an example from one of the works presented in the next chapter, Caporale, Gil-Alana and Plastun (2016) reported that the weekend effect could bring up to 25% yearly profit, though their result was not adjusted for the transaction costs.

To conclude, this overview of methods is not exhaustive, as alternatives to set up tests of inefficiencies are unlimited. Selection of methods takes into account specific market characteristics, data availability and goals posed by the researchers. Among factors that influence methods choice one of the most intuitive ones is the trading frequency. In the markets with a high frequency of trades the methods are chosen to account for autocorrelations in price movements during each trading session and two consecutive days. Meanwhile, with only a few trades happening (e.g., in the case of Ukraine, some days no trades happen at all) the selection of methods has to focus on those suitable for extended periods of limited data. Again, with the choice of methods depending heavily on market and study specifics, it is not possible to point out selected methods as the globally prevailing ones.

1.3. Results of earlier works

The topic of testing the stock market efficiency of Ukrainian and Warsaw stock Exchanges especially from the perspective of Ukrainian companies listed there was barely studied before. Some works tangent to the topic of efficiency on this markets exist, but the field is yet underexplored in this region. In the few cases when these neighbouring markets were compared, the tests were performed on the data from main indices, not individual companies.

Even in the international perspective, to the author's best knowledge, there are no works on the efficiency of stock price movement that would compare individual companies listed in their local versus neighbouring markets. This may be due to the fact that comparisons are usually done with the most developed markets, like the New York or London stock exchanges.

From the companies' perspective, the questions posed in this paper can be also associated with the firms' choice between foreign and domestic listing. While this topic is more studied then the stock price informational efficiency as a standalone phenomenon, the listing choices include other more ambiguous factors, like entrepreneurial signalling or infrastructure demands. Most examples of juxtaposing domestic and foreign listing tangible to this paper are describing Chinese-based companies choosing between mainland and Hong Kong markets (Ding, Nowak & Zhang, 2010; Yang & Lau, 2006). The author has to point out that these factors will not be studies and the comparison will be only based on the price efficiency listed companies.

Coming back to the markets chosen in this paper, regardless of the fact that Ukrainian companies compose one of the biggest groups of international IPOs on the Warsaw Stock Exchange, no thought study of their efficiency was ever conducted. While Polish market, in general, is considered to have the weak form of efficiency with some exceptions regarding the small- and medium-size companies (Kilon & Jamroz, 2015), the Ukrainian companies' index was not researched separately. To the author's best knowledge, there is only one related work dedicated to the WIG-Ukraine index. Parvi (2017) studied the fair value of share prices of WIG-Ukraine companies, discovering that those were undervalued.

Recent Polish works tend to describe the performance of stocks based on industry companies operate within mixing local and foreign companies, rather than understand the price movement tendencies. Others write on the trends, regulations, and possible reasons of Ukrainian companies choosing Warsaw for their IPOs, such as legislation barriers, lack of clear available information, and fears connected to the domestic currency (Perz et al. 2011). This research hence attempts to bridge the gap in understanding the efficiency level and dynamics of returns of Ukrainian companies listed on Ukrainian and Warsaw stock exchanges.

From the Ukrainian side, academics' articles published in national journals typically bear only descriptive nature. For the purpose of this paper, though, the conclusions presented without any accompanying empirical models/calculations cannot be taken seriously even if topics were closely related to this bachelor thesis. For instance, Starostenko and Torshyn (2011) explain the nature of IPO focusing on regulations and advantages of Warsaw stock exchange if compared to the Ukrainian one, based on the information about similar already listed companies. Other researches done on the topic include focusing on problems and outlooks of IPOs in Poland faced by companies from the Ukrainian banking sector (Lerner, Kuropatenko, Momot & Skrypka,

2016) or comparing both Warsaw Stock Exchanges and alternative NewConnect platform (Pozniakova & Wilgard, 2016).

Speaking of the stock market efficiency, there are no works combining Ukrainian and Polish markets. It is more popular among scholars to write separately about one of the markets, do tests for the whole Central-Eastern / Eastern European region (Tilica, 2014), or to compare it to the USA market as a benchmark (Depenchuk, Compton & Kunkel, 2010). The most relevant for this paper would be an overview of studies written about the Ukrainian market during the last decade. Conclusions reached in some of the most substantial studies recently conducted are briefly summarised in Table 1.

Table 1

Studies on Ukrainian stock market informational efficiency

Authors, year	What was tested	Period tested	Methods Used	Conclusion
Depenchuk, Compton & Kunkel,2010	*Calendar anomalies* on Ukrainian financial markets	2003-2007	parametric OLS regression, t-tests	Turn-Of-Month effect is present
Khrapko, 2013	*Weak form efficiency* of the Ukrainian stock market	2008-2011	evaluating intertemporal equation for randomness	5 out of 13 tests do not reject weak form efficiency; supported random walk hypothesis
Mynhardt & Plastun, 2013	*Overreaction* on the Ukrainian vs. US and commodities markets	2008-2012	t-tests difference of counter-reactions from typical counter-movements	Low level of market efficiency, significant overreaction
Caporale, Gil-Alana & Plastun,2016	*Weekend effect* on Ukrainian stock market	2010-2014	Average analysis, trading simulation, regression analysis, Student’s t-tests	Abnormal returns present on Fridays
Zakorko, 2013	*Information efficiency* of the Ukrainian stock market	2012-2013	Regression, Froot & Obstfeld model	Rejected strong and semi-strong efficiency

Source: compiled by the author

The papers presented in the table showed a few methods of testing for efficiency. As the predictability of price movement patterns signals the possibility of arbitrage and inefficiencies multiple authors attempted to prove or reject those patterns. Smith (2012) chose to test the martingale hypothesis that showed Ukraine as one of the lowest efficiency results among emerging European stock markets. Zakorko (2013) was assessing excess yields and attempted to use the Froot & Obstfeld's model that proved not to be applicable for the Ukrainian market.

The approach chosen by Khrapko (2013) was to test random walk of prices, which was supported by Kendall and I.I.D. tests for the 2008-2011 period. However, the opposite result was achieved in the study of Dragota and Tilica (2014) that rejected random walk hypothesis for Ukraine for the period of 2008-2010, and even claimed that for a one-day lag it is possible to build a return forecasting model. One-third of tests done in a study by Dragota and Ţilică (2014) also rejected the EMH for Ukrainian PFTS index.

A separate stream of research on informational market efficiency is dedicated to testing the presence of possible calendar effects on selected markets. Theoretically, efficient markets cannot have any systematical differences in returns based solemnly on the date in a calendar. These type of anomalies was widely researched during the past decade on the Ukrainian stock market. Abnormal positive returns on Fridays were proved that taking advantage of the present weekend effect an investor can earn up to 25% annually in extra profit (Caporale, Gil-Alana & Plastun, 2016).

Interestingly, among varying evidence Khrapko (2013) discovered that the test results on Ukrainian market weak form efficiency could be more similar to the USA market than to the neighbouring Poland and Russian ones. It was not the only work elaborating on possible correlations with this oversees market. Depenchuk, Compton & Kunkel (2010) had found the turn-of-month (TOM) effect in Ukrainian stocks and bonds markets; the suggested reason for that is a dependence of the Ukrainian stock indexes on the USA market. For a reader it could translate that since a calendar effect is present in the price movements of the two Ukrainian Stock Indexes, the market is in general not efficient in the weak form.

At the same time, information availability was addressed with critics. A study by Malyshenko (2013) claims that the Ukrainian market is impossible to be considered efficient since it is insiders: there is a high level of informational asymmetry that turned into a normal state of affairs. What is more, act there is an extremely high level of short-term overreaction on the market as well as high speculative potential (Mynhardt & Plastun, 2013). In general, the way in which information is presented in media if compared to other countries with more developed markets is not carrying the same value. It appears that the transparency of disclosed information and speed with which it is communicated to the market are inferior.

Continuing with issues that further inefficiencies, the composition of the Ukrainian securities market is not corresponding to what is considered a competitive market; even though the number of players on the market is relatively sufficient, very few of those are “big players” that have a real effect on the stock market or could even manipulate it (Malyshenko, 2013). An illustration by Zakorko (2013) gives the example of 1^{st} to 6^{th} February 2013, when Ukrnafta’s stock (UNAF) more than doubled due to access to insiders’ information by big players, while no news whatsoever was released to the public. Another study by Matsuk (2015) revealed the practice of speculatively trading based on insiders’ information with the idea of achieving greater profit from speculations.

One of the most recent thorough studies covering a longer period of returns of Ukrainian stock indexes daily returns 2001-2013 checked for the long memory of prices. The Ukrainian stock market was found to be inefficient and persistent. It is curious, that during the recent crisis, the inefficiency was at a higher degree of persistence. Clearly, depending on the economic circumstances the conclusion on the extent to which the Ukrainian stock market could be considered efficient varies. (Caporale, Gil-Alana, Plastun, & Makarenko, 2016)

To sum up, previous studies came to the conclusion that even weak form efficiency was never distinct on the Ukrainian stock market. The exact sentiment about how close to informational efficiency this market is varies depending on the tests conducted and the period of data chosen. Addressing the lack of consistency in market assessment in existing literature, figure 2 below shows the author's summary of the relative grade of efficiency as established in the studies presented in table 1.

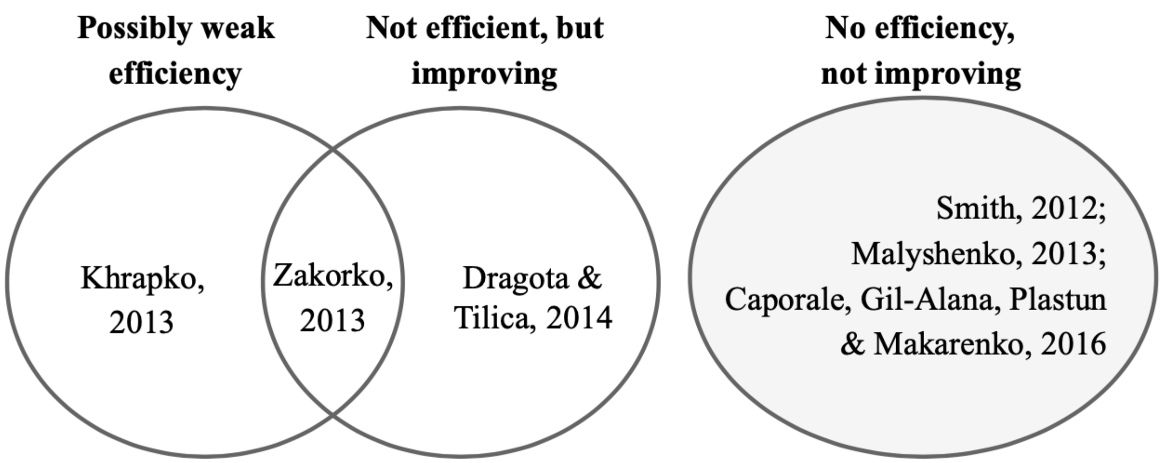

Figure 2. Ukrainian market efficiency evaluations

Source: compiled by the author

Multiple anomalies were revealed that make it impossible to name the Ukrainian market efficient. Some of the noted problems of this market were exploitation of insiders' information and trading manipulations by few big players that allowed for speculations along with the low quality of communicated information, consistent calendar anomalies of returns and trading strategies outperforming the market over time.

Being underdeveloped compared to its neighbours both in terms of infrastructure and trading volumes, the Ukrainian stock market remains unattractive to investors who wish to receive updated information from companies. Informational inefficiency of price movements is an outcome of a more significant issue of insufficient policies and regulations. These concern lack of legislation in the areas ranging from activities disclosure to dividends distribution, to protection of investors' rights and online access to trading financial instruments. The stock market needs critical improvements to reach the transparency, accessibility, and objectivity of information required to achieve weak and semi-strong efficiency.

The author of the thesis would not expect this situation to change unless stricter legislation is adopted primarily in the area of transparency of information disclosure resolving some of the problems as mentioned earlier. With the legislation in place and accessible real-time information more international investors would be interested in the Ukrainian stock market, and the liquidity would increase. As for the local investors, an average market participant has a weak awareness of the country's stock exchange, with one of the possible reasons being the lack of flawlessly functioning online trading platforms.

2. Empirical Analysis

2.1. Data and Methodology

Data. In order to test stock efficiency, the author uses daily stock prices of eight Ukrainian companies listed on the Ukrainian stock exchange and five companies listed on the Warsaw Stock Exchange, as well as the PFTS, UX and WIG-Ukraine indices that they compose. PFTS index was calculated since 1 Oct 1997, starting from 100 base points; it has always been the official Ukraine index in S&P500 (PFTS, n.d.). PFTS currently represents six most liquid Ukrainian stocks. UX is an alternative index based in Kiev, consisting of 5 repetitive with PFTS stocks. Both indices price movement is presented in figure 3.

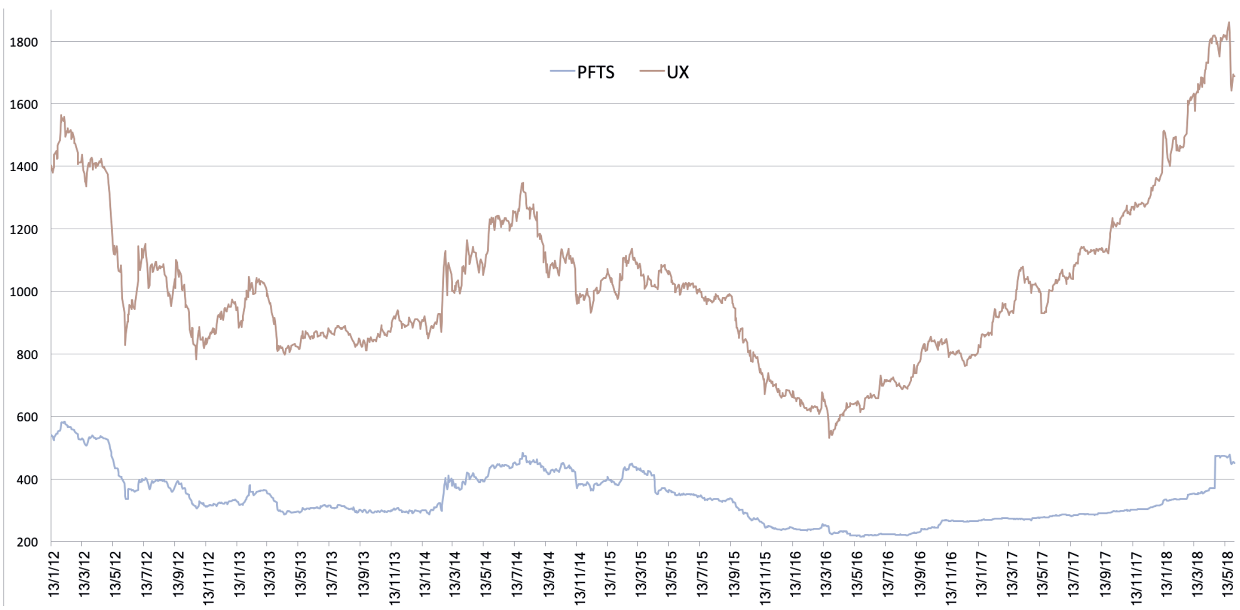

Figure 3. PFTS and UX indices: Jan 2012 – Aug 2018

Source: compiled by the author

The period of returns studied in this paper is from 2012 to mid-2018 (depending on stocks' lifetime). Since peaking at above 1100 base points early in 2011, PFTS - kept plunging till reaching 215 points in May 2016. UX though being more volatile followed a similar pattern.

Since late 2016 both indices have shown upwards trend, recovering from the historically low plunge and showed record returns in 2017-18.

Such significant variations were naturally related to political and economic events in the country. The first half of the chosen period is the time of the most dramatic political happenings like mass protests in the country, Crimea annexation, sudden Ukrainian currency plunge, and EU sanctions in support of Ukraine. The years that followed are characterised by economy shrinkage due to the ban of access to the Russian market, UAN currency historical low, and booming level of bad loans.

Considering the Warsaw stock exchange, WIG-Ukraine is calculated since 31.12.2010 and is the only index outside Ukraine that is composed of exclusively Ukrainian-based companies (headquarters and (or) majority of operations and (or) the company itself located in Ukraine). All the companies in it are traded on the Main Market. The historical data for WIG-Ukraine index is presented in figure 4; the period covered is limited to 2015 – mid 2018 due to earlier data unavailability from Inversting.com (n.a.) database.

Figure 4. WIG Ukraine index: Jan 2015 – Aug 2018

Source: compiled by the author

The data consists of available sets of daily stock prices of Ukrainian based companies for 2012 – August 2018 retrieved from Investing.com (n.a.). The total number of work days in this period is approximately 1680 (different between the two countries.) The market data was processed for PFTS, UX, and WIG-UA indices and separately all six listed companies currently composing the index:

- Donbasenergo (DOEN),
- Centrenergo (CEEN),
- Krukivsky Carriage Works (KVBZ),
- Ukrnafta (UNAF),
- Ukrtelekom (UTLM),
- Raiffeisen Bank Aval (BAVL),

plus two recently excluded from PFTS ones:

- Motor Sich (MSICH),
- Turboatom (TATM),

along with the five companies currently comprising WIG-UA index:

- Kernel Holding (KER),
- Ovostar Union (OVO),
- Industrial Milk Company,
- Astarta Holding (ASTH),
- Agroton (AGTP).

As for the companies' selection in Ukraine, considering the existence of "miniature" regional stock exchanges outside the central one, the total number of listed companies is larger than the PFTS index components. According to Investing.com, as of 2019, there are 11 companies listed in Ukraine. A few of those were excluded due to very low liquidity. For instance, Interpipe Ntz Pat (NITR) during the six years of being listed had had less than 150 days in which trades happened.

The companies that are included in this study range from circa 1700 to 22000 employees (Investing.com, n.a.). The sectors Ukrainian-listed ones are operating within are utilities, energy, transportation, capital goods, communication, and financial services. The five companies of WIG-Ukraine index are the population of Ukrainian companies on the Warsaw stock exchange. The sectors of these companies are relatively similar, namely agriculture, livestock and food-processing.

Finally, the author would like to point out, that this approach to selecting data adds to the novelty of the thesis. It may seem that the sectors of the companies on Warsaw and Ukrainian stock exchanges are not similar enough to be compared, nonetheless those are the only companies existing on the market that could be studied. While almost all existing studies of these markets limit the data used to UX and PFTS indices, this work includes the individual companies price movements to better study the population of stocks.

Methods. One of the most challenging tasks in testing market efficiency is to decide on a relevant method to set up the test that would fit the data available for particular market. There is no unique proven method to check if the market is efficient in a weak form. Multiple methods that could be used, as described in section 1.2. of this work. Still, any possible method would require the author to work with the financial time series.

In this work, the author focused on the methods of testing the randomness of price movements. Coming from the idea that weak form efficiency requires time series to follow a random walk, the tests were chosen so that they reject (or not) the random walk of prices.

Considering the ambiguity of results interpretations while testing efficiency (Kilon & Jamroz, 2015), multiple tests should be conducted before reaching any conclusion. The author will thus work with variance ratio test, unit root test, and Hurst exponent.

As some of the most intuitive violations of random walk are the magnitude differences (variance of returns is not a linear function), stationarity (mean and variance remain constant over time), and long-range memory/dependence - the methods were chosen to address each of three respectively. Additionally, such methods selection offers a balance between choosing the simplest methods like run test, that would only take into account weather the price is above or below the mean/median, and focusing on a single complex method like artificial neural networks.

Variance Ratio Test

This study chose to start with conducting a variance ratio test. This method introduced by Lo and MacKinlay (1988) enables to conduct the initial diagnostic check of potential deviations from the random walk conditions robust for both homoscedastic and heteroscedastic financial time series. The short and long-horizon variance tests should display if the relationship between the price variance and the horizon length is indeed linear as it is assumed for efficient markets. While studies like Chordia, Roll and Subrahmanyam (2008) on NYSE companies could use the five-minutes versus hourly variance, the markets chosen for this study are not liquid enough to record such frequent changes.

The null hypothesis is that the univariate time series process is random. As the returns are not correlated over time, an estimator of VR (variance) of k-period return should be:

$$VR(k) = \frac{\hat{\sigma}^2(k)}{\hat{\sigma}^2(1)}$$

where $\hat{\sigma}^2(1)$ estimates one-period return variance. The result expected from the weak form efficient market is the VR(k) that equals to the unity of k horizons. In case of time series not following the random walk, VR will be higher than unity when the autocorrelation with past movements is positive, and vice versa with lover unity suggesting negative autocorrelation of returns. (Charles & Darne, 2009)

Considering the low number of trades of Ukrainian stocks, it is possible that taking only daily prices will bias the results towards random walk rejection. The author of this thesis hence decided to perform this test in two modifications. The first run will be done with daily logarithmic returns using the formula

$$r_t = \ln\left(\frac{P_t}{P_{t-1}}\right)$$

– classical for liquid markets. The second test run will consider the adaptation of weekly logarithmic returns – logarithmic returns for the past five trading sessions calculated as

$$r_t = \ln\left(\frac{P_t}{P_{t-5}}\right).$$

Unit root test

The next test to focus on is the non-parametric unit root test. It is conducted to check if the financial time series are nonstationary (random). To put it simple, unit root test calculates if the price movement can be predicted based on the preceding days and time series could be claimed mean-reverting. Both predictability and mean-reversion are clear signs of lack of autonomy in price formation and thus inefficiencies on a market.

The Augmented Dickey-Fuller test used gives the result of negative range – with the more negative results signalling the stronger rejection of stationarity.

$$\Delta r_t = y_0 + y_1 r_{t\quad 1} + y_2 T + \sum_{i=1}^{n} y_i \Delta r_{t-i} + \varepsilon_t$$

Under the null hypothesis, the statistical properties of time series variable (r_t) - including but not limited to mean, autocorrelation, and variance - are not changing over time, and thus the unit root is present (y_1=0). In the equation above ε_t is a 0-mean error term, and *t* is the time index.

Hurst Exponent

Finally, calculating the Hurst exponent (*H*), otherwise called "index of a long-range dependence", of PFTS and WIG-Ukraine indexes would cast light on possible long-term correlations of returns and long-memory as an inefficiency indicator of the market. A genuinely uncorrelated series should have the $H = 0.5$. However, as claimed by McCauley, Gunaratne and Bassler (2007) even with Hurst exponent other than 0.5 it is inadequate to say that there are some long-term correlations from scaling without further testing.

Since the Hurst exponent calculation is not included in the Matlab econometrics package, the script with formulas used were written based on the formulas below. Estimation of Hurst exponent thorough the R/S (rescaled range) uses daily stock prices. It starts with calculation of the time series mean and creation of new mean-adjusted series Y_t , then calculating the cumulative deviate series

$$Z_t = \sum_{i=1}^{t} Y_t \ ,$$

range series R

$$R_t \ = \ max(Z^1, Z^2, \ldots, Z^t) - \ min(Z^1, Z^2, \ldots, Z^t); \quad t \ = \ 1, 2, \ldots, n,$$

and standard deviation series S

$$S_t = \sqrt{\frac{1}{t}\sum_{i=t}^{t}(X_i - u)^2}\ ; \quad t \ = \ 1, 2, \ldots, n$$

where u is a mean from X_1 to X_t. Hurst exponent is then calculated from

$$(R/S)_t = const \times t^H$$

as a slope of regression line (Qian & Rasheed, 2004).

2.2. Results and Discussion

For the Ukrainian companies and their indices, the degree of informational efficiency tested was limited to its weak form efficiency, that rejects the possibility of predicting future price movements based on historical data and technical analysis. Repeating the conclusions of previous chapters, weak form was chosen because no previously done researches on data for the past two decades claimed that Ukrainian stock market could possibly have semi-strong or strong efficiency.

Before presenting the test results, in order to better understand the data characteristics, the summary statistics for daily prices are provided in table 2. The total of 13 individual stocks (ticker along with company name) and 3 indices (in bold) were sorted by market of listing.

Table 2

Summary of descriptive statistics for 13 Ukrainian companies and 3 indices

Variable	Observ	Mean	Std. Dev.	Min	Max
UNAF Ukrnafta	1,583	171.8383	74.1622	74	400
TATM Turboatom PAT	453	10839.69	2422.06	1000	17035
MSICH Motor Sich	1,561	2314.153	635.274	1448	5695
UTLM Ukrtelecom	1,217	0.155935	0.03568	0.08	0.33
KVBZ Krukov Vag Zav	1,312	13.18104	5.34838	3.72	25.99
DOEN Donbasenergo	1,631	21.90782	8.18258	9.85	47.63
CEEN Tsentrenergo	1,601	8.081886	3.46747	2.7	23.7
BAVL Raiff Bank Aval	1,585	0.141343	0.07695	0.06	0.372
PFTS	1,492	334.9009	81.9443	215.27	584.29
UX	1,801	1137.367	440.037	532.13	2889.93
KER Kernel Holding SA	1,684	51.35503	13.9114	22	80
OVO Ovostar Union N.V.	1,228	87.39871	12.3296	59.4	130
IMC Industrial Milk Company SA	1,616	10.21087	3.31786	4.38	17.29
ASTH Astarta Holding NV	1,676	49.20448	14.7638	14.5	77.4
AGTP Agroton	1,682	4.900065	4.81274	0.8	24.2
WIGUA	941	464.633	107.446	264.96	660.78

Source: author’s calculations

The statistics above are useful to understand the range spread between minimum and maximum values, and how far are those extremes from within two standard deviations from mean point. These three columns are later used in the rescaled range for Hurst exponent calculations. To see how the quantiles of individual stocks price distribution compare with those of a standardised theoretical one please see the Appendix A. It graphically presents the Q-Q scatterplots, so deviations from normality can be seen at-a-glance.

Additionally, it is worth noting, that due to the low market-wide liquidity some business days no trades happened and/or information may be unavailable for selected stocks. Furthermore, the starting date of stock trading is different for each studied company, resulting in a smaller number of observations (see TATM, UTLM and KVBZ).

Since the beginning, there have been two hypothesis posed by the author to be tested in this paper. The first one is that the Ukrainian stock market does not have a weak-form informational efficiency. The second is that price formation of Ukrainian companies on the Warsaw Stock Exchange are more informationally efficient then on the Ukrainian one. Supportive results of the second hypothesis would also be in line with the common believe that even if operating on the same country's market, companies listed on more developed foreign stock exchanges with greater supervision tend to be characterised as more informationally efficient than those traded on domestic exchanges.

Coming down to the specific test results, all of the tests on 16 sets of stocks and indices daily data were conducted in Matlab (script available in Appendix B). For variance ratio test logarithmic returns were used as input data; Augmented Dickey-Fuller test checked the random walk of daily prices. This is not the first study to test the randomness both raw prices and logarithmic returns, but for the efficiency of Ukrainian companies it was not used before.

The results for the variance ratio test (vratiotest) and Augmented Dickey-Fuller (ADF) tests are presented in Table 3. As explained in the methods description, the former are calculated for both 1-day and 5-days returns. The results are sorted according to the market of listing, with the stocks and indices above being listed on Ukrainian, and those at the bottom – on the Warsaw stock exchange. The first column shows the ticker symbol –of stock or index (in bold). Columns 2, 4 and 6 state which hypothesis to accept – H_0 or H_1. Columns 3, 5 and 7 show the p-values for the conducted tests.

Table 3

Results of variance ratio test, Augmented Dickey-Fuller (ADF) test, and their p-values

Ticker	Vratiotest*, weekly returns	p-value	Vratiotest*, Daily returns	p-value	ADF**,	p-value
UNAF	1	0.0000	1	0.0000	0	0.3100
TATM	1	0.0254	1	0.0344	0	0.2007
MSICH	1	0.0000	1	0.0000	1	0.0449
UTLM	1	0.0000	1	0.0000	0	0.3237
KVBZ	1	0.0000	1	0.0000	0	0.4214
DOEN	1	0.0000	1	0.0000	0	0.3353
CEEN	1	0.0000	1	0.0000	1	0.0381
BAVL	1	0.0000	1	0.0000	1	0.0495
PFTS	1	0.0000	1	0.0000	0	0.9602
UX	1	0.0000	1	0.0000	0	0.9910
KER	0	0.2057	1	0.0000	0	0.6529
OVO	1	0.0479	1	0.0000	0	0.3437
IMC	1	0.0044	1	0.0000	0	0.3311
ASTH	1	0.0457	1	0.0000	0	0.6119
AGTP	0	0.3690	1	0.0000	0	0.9679
WIG UA	0	0.7459	1	0.0000	0	0.3229

Notes. *H1: reject random walk **H1: reject unit root presence

Source: author's calculations

The variance ratio test null hypothesis of the time-series following a random walk is accepted when the test result is 0, and p-value is ≤0.05 at 95% confidence level. Hence, for the tested markets, it can be said with certainty that none of Ukrainian 8 stocks and 2 indices satisfies the criteria of test. The variance being a linear function as a condition of weak form efficiency is not met on Ukrainian stock market. The daily returns are therefore mean reverting or averting during long horizons.

From the stocks listed on the Warsaw stock exchange, the results are more interesting. While for the daily returns random walk was rejected, the five-day returns exhibit more promising results. Only for IMC the random walk was strongly rejected. For the OVO and ASTH stocks slightly changing the confidence level from 95% to 96% would result in acceptance of the null hypothesis that does not reject random walk. Subsequently, taking into account this test only, the companies listed in Poland are more likely to follow the random walk.

The Augmented Dickey-Fuller test results denote either rejection (1) or a failure to reject (0) the presence of unit root. An efficient time series expected result is H_1. It can be noted, though, that out of all tested variables, unit root and thus stationarity were not discovered only in three stocks listed in Ukraine, specifically MSICH, CEEN, and BAVL. This result is nonetheless not exactly comparable with the previous variance ratio test. Interestingly, changing confidence level to 97% or higher, unit root would not be rejected in all of these time series. As for the rest of variables, the Augmented Dickey-Fuller test had failed to reject the stationarity of time series. Ultimately, with both markets showing signs of stationarity they cannot be considered efficient.

The final test conducted was the estimation of Hurst exponent of as an index of long-term dependence. In the process of calculation of Hurst exponent, rescaled ranges (R/S) were calculated. R/S reflects value range divided by the standard deviation for each variable, and increases along with the number of observations. Complete results of Hurst exponent calculated through the R/S statistics at 95% confidence intervals for the R/S columns 3 and 4 are presented in table 4.

Table 4

Hurst exponent and rescaled range at 95% confidence interval

Ticker	Hurst exponent	Conf_lower	Conf_higher
UNAF	0.9657	0.3767	0.6164
TATM	1.0389	0.2746	0.7104
MSICH	0.9828	0.3762	0.6168
UTLM	0.9674	0.3621	0.6299
KVBZ	0.6299	0.3661	0.6262
DOEN	1.0323	0.3781	0.6150
CEEN	1.0229	0.3770	0.6161
BAVL	1.0071	0.3770	0.6161
PFTS	0.9835	0.3737	0.6191
UX	0.9835	0.3833	0.6102
KER	1.0254	0.3800	0.6133
OVO	0.9471	0.3625	0.6295
IMC	1.0260	0.3775	0.6156
ASTH	0.9715	0.3798	0.6135
AGTP	1.0103	0.3800	0.6133
WIG UA	1.0485	0.3446	0.6460

Source: author's calculations

All of the results were far from the anticipated value of 0.5 for a time series without a long memory of returns. Persistent results above 0.5 are distinctive for most of financial time series such as stock price movements, and indicate the presence of positive long memory (Qian & Rasheed, 2004). As for algorithmic traders, growth investors would purchase stocks with $H>0.5$ as a sign of their persistence. Nevertheless, the fact that only one stock (KVBZ) has $H<0.9$ may be a signal to the reconsideration of the usage of this method for the purpose of comparison of efficiency in these markets setting.

Proceeding with the limitations, the results of testing the random walk and its preconditions using daily prices naturally have some. General limitations are the magnitude of inefficiency that the tests can identify without bias. Similarly, the choice of setting the confidence intervals can be challenging: too lose confidence intervals do not guarantee true randomness, while setting them too high would result in almost no real life time series meeting these theoretical demands.

Switching to the methods that test strategies does not eliminate the concern either. It is doubtful that any statistical test would be able to identify a constant option to beat the market returns by a relatively low rate (e.g. 0,5-1% monthly). Furthermore, in the portfolio strategies testing linking risk to returns poses further complications. While EMH says that investors cannot gain returns above market it assumes that investor is not taking additional risk. Eventually, as it was previously addressed in chapter 1.2., the presence of consistently outperforming investors can be called a “lucky event issue” that does not reject weak form efficiency of the market in question (Rizkianto & Surya, 2014).

More test-specific limitations concern the critics of methods chosen. Since the variance ratio and Augmented Dickey-Fuller tests usually do not normally pose complications in interpreting results, these are commonly used tests that do not face much criticism. The only debatable point could be guessing the relevant length of tested periods. The concerns exist around the Hurst exponent on whether values other than 0.5 necessarily imply long-run correlation of the market. McCauley, Gunaratne and Bassler, (2007) and Couillard and Davison (2005) were among the main works denying the idea that an exponent of >0.5 should be always interpreted as long-memory evidence. The later work went even further to claim that Brownian motion data sets always result in H>0.5.

Summarizing the results of the tests conducted in this bachelor thesis, it cannot be said that the price formation of Ukrainian companies and indices comprising them are random, which is a clear sign of informational inefficiency. The one-day returns based variance ratio test results can be compared to those previously achieved by Khrapko (2013), who also rejected the null-hypothesis of random walk for both Ukrainian and Polish stock markets based on their indices data. The results for the latter market contradict each other taking the five-day returns. As for the two other tests, those were not appearing in recent published papers on the topic, hence there is little space for comparison.

Confirming the first hypothesis, the weak form efficiency is rejected for both Ukrainian and Warsaw stock exchange from the perspective of Ukrainian based companies. The second hypothesis tested cannot be answered, as only variance ratio test of five-day returns showed more randomness in WIG-Ukraine index companies. The overall results are insufficient to claim that the share price movements of Ukrainian companies on Warsaw stock exchange is inefficient to a lesser degree then on their domestic market.

Conclusions

Market efficiency hypothesis (EMH) is among the most renown theories on how global capital markets functions. It represents an ideal fair game setting, where strong form efficiency claims the market to be a self-correcting mechanism. Market efficiency development depends on investors ability to access relevant up-to-date information, and their incentives to trade on it if any asset was mispriced. Ultimately, the price of assets that are equally likely to be undervalued as overvalued is adjusted to reflect all available information.

As for the Ukrainian stock market, existing studies do not evaluate it as obeying weak-form of EMH. Instead, this market is considered underdeveloped and illiquid. Furthermore, having such small number of listed companies in one of the biggest European countries is a striking exception. For Ukrainian market to exhibit higher efficiency in future low transaction costs and even existence of accessible online trading platform would not be enough. Investors rights protection, transparent contract settlement, and attainable up-to-date information from companies are the conditions that need to be addressed first.

While the conclusions of existing literature about Ukrainian stock market divide in their assessments of its possible efficiency, none of the existing studies worked with the data from individual companies, thus relying solemnly on country's PFTS and UX indices. The five Ukrainian companies listed on the Warsaw Stock Exchange and their index had never been investigated on the issue of market efficiency as a separate group. The author hence attempted to bridge the research gap by comparing the efficiency of individual companies and indices on these two markets. This was achieved by taking daily prices of companies during the 2012-2018 period and testing for linearity of variance function, unit root presence, and long-range memory.

Since there is no universally agreed method to test market efficiency the most common methods are joint hypothesis tests grounded on understanding that on an efficient market the prices of securities are random and should not be predictable by any technical analysis. This work had divided the existing methods into two larger groups: the random walk testing and portfolio study. The author proceeded to focus on methods testing the price randomness, specifically – the variance ratio test, Augmented Dickey-Fuller unit root test, and the Hurst exponent estimation through rescaled range analysis.

In the empirical part of the paper, both domestic and Polish markets were found inefficient in its weak form for Ukrainian companies listed there. The results of tests conducted by the author revealed and the presence of unit root and long-range dependence on both stock exchanges, and additionally not linear variance function of the Ukrainian one. Such an evaluation is consistent with the main body of work on the Ukrainian stock market. It is impossible, however, to say that the selected Warsaw-listed stocks are efficient to a greater extent than the Ukrainian-listed ones.

To sum up, it is hard to deny and even harder to confirm the weak-form market efficiency with complete certainty. Doing multiple tests is beneficial to provide a more comprehensive evaluation of the market, but it can at the same time provide all kinds of contradictory results. Efficiency is a multisided phenomenon, that cannot be narrowed down to a selection of tests.

The future recommendations for further exploration of the topic would be to include into the efficiency comparison the “Ukrainian portfolio” of companies listed on the London Stock exchange. Additional steps could add into the analysis the cases of listing on the Frankfurt Stock Exchange and American Depositary receipts traded on the USA exchanges. By doing so it would be possible to further understand if potential inefficiencies are the result of Ukraine being the company’s country of origin or the market they chose for listing.

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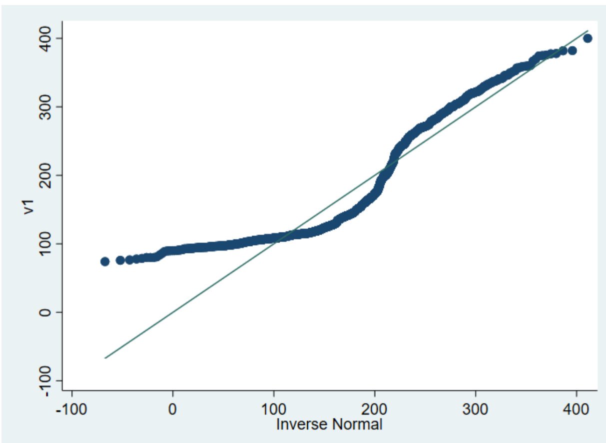
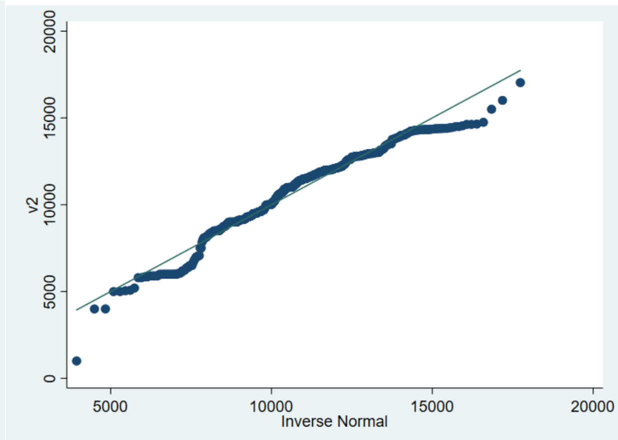
Appendices

Appendix A

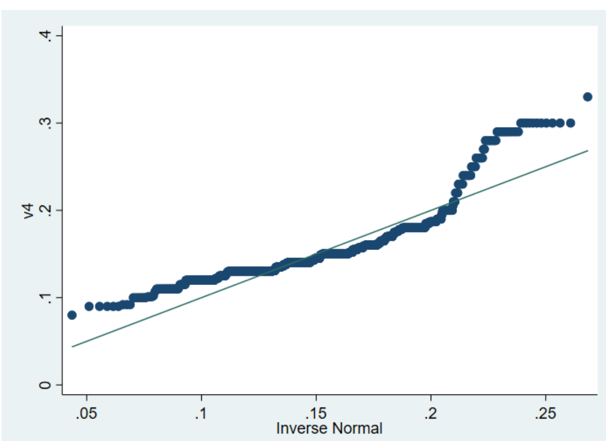
Q-Q scatter plots



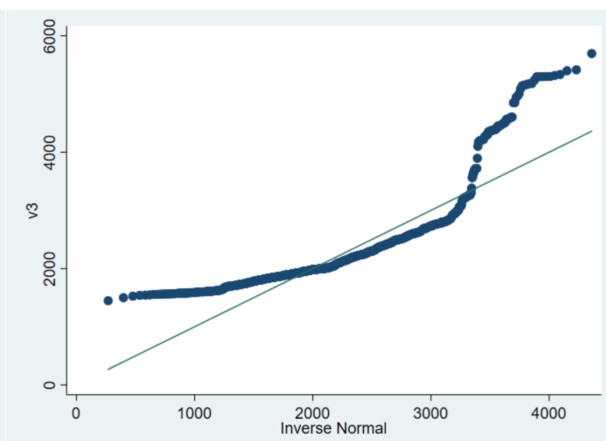
UNAF



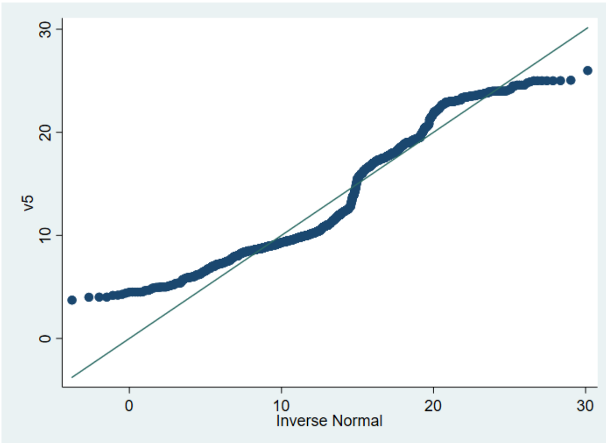
TATM



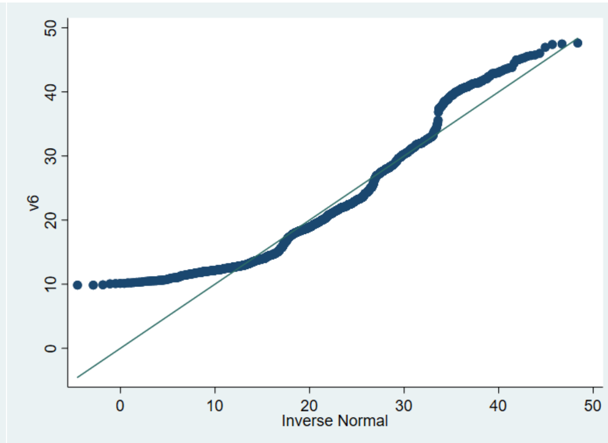
MSICH



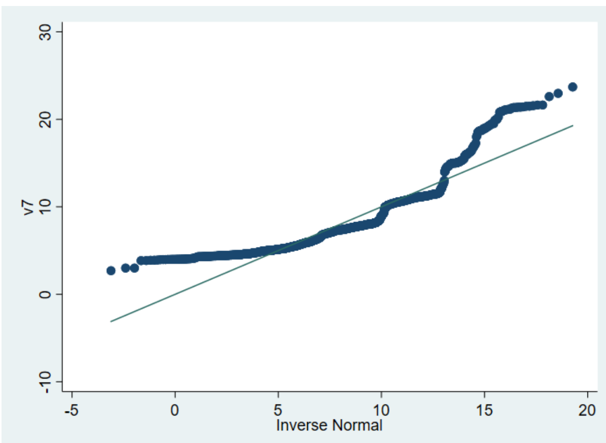
UTLM



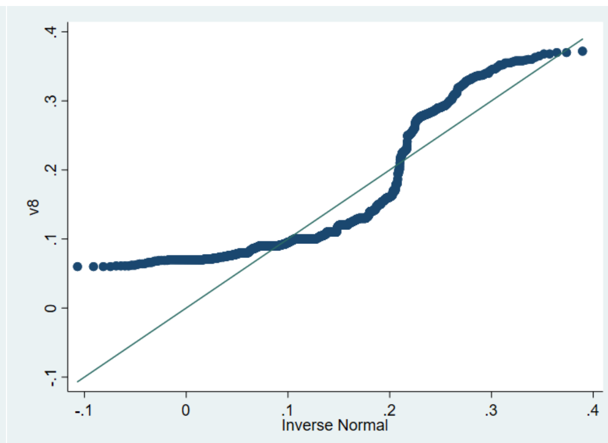
KVBZ



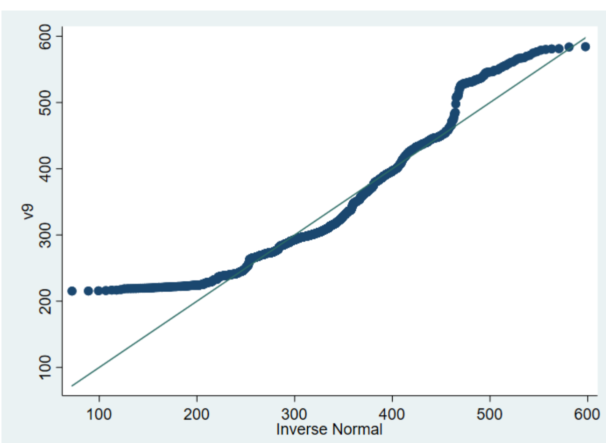
DOEN



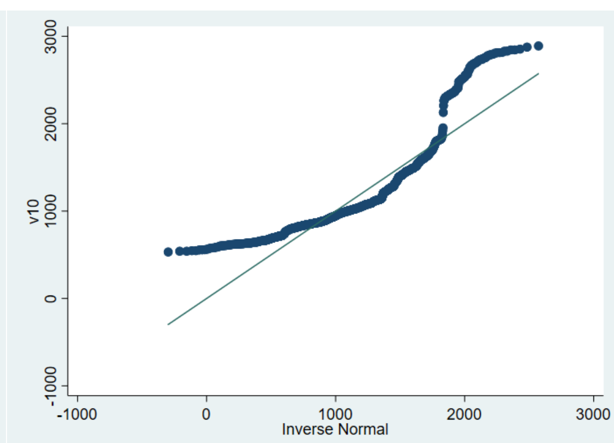
CEEN



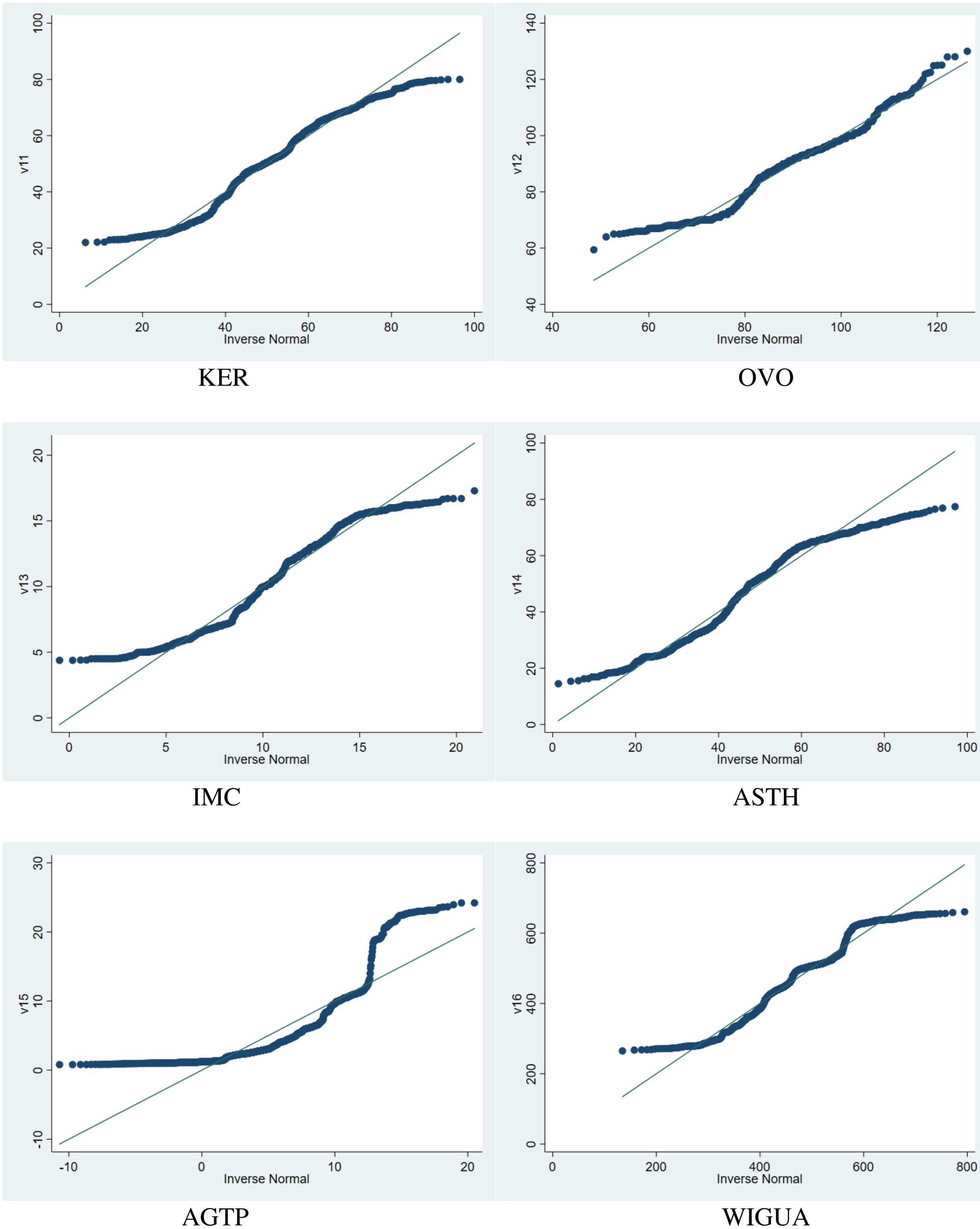
BAVL



PFTS



UX



Source: author’s calculations

Appendix B

MATLAB variance ratio and ADF tests script

```
data = readtable('data.csv')
onestock = data{:,_}
onestock = rmmissing(onestock)

[vr,pval] = vratiotest(onestock)
[adf,pvaladf] = adftest(onestock)
```

MATLAB Hurst exponent calculation script

```
function [Hal,He,Ht,pval95] = hurst(x,d,fontsize);
%HURST Calculate the Hurst exponent using R/S analysis.
%   H = HURST(X) calculates the Hurst exponent of time series X using the R/S analysis of
Hurst [2], corrected for small sample bias [1,3,4].

data = readtable('data.csv')
onestock = data{:,_}
onestock = rmmissing(onestock)
x = onestock

if nargin<3,
   fontsize = 14;
end
if nargin<2,
   d = 50;
end
if max(size(d)) == 1,
   % For scalar d set dmin=d and find the 'optimal' vector d
   dmin = d;
   % Find such a natural number OptN that possesses the largest number of divisors among all
natural numbers in the interval [0.99*N,N]
   N = length(x);
   N0 = floor(0.99*N);
   dv = zeros(N-N0+1,1);
   for i = N0:N,
      dv(i-N0+1) = length(divisors(i,dmin));
   end
   OptN = N0 + max(find(max(dv)==dv)) - 1;
   % Use the first OptN values of x for further analysis
   x = x(1:OptN);
   % Find the divisors of x
```

```
    d = divisors(OptN,dmin);
else
    OptN = length(x);
end

N = length(d);
RSe = zeros(N,1);
ERS = zeros(N,1);

% Calculate empirical R/S
for i=1:N;
   RSe(i) = RScalc(x,d(i));
end

% Compute Anis-Lloyd [1] and Peters [3] corrected theoretical E(R/S)
% (see [4] for details)
for i=1:N;
    n = d(i);
    K = [1:n-1];
    ratio = (n-0.5)/n * sum(sqrt((ones(1,n-1)*n-K)./K));
    if (n>340)
        ERS(i) = ratio/sqrt(0.5*pi*n);
    else
        ERS(i) = (gamma(0.5*(n-1))*ratio) / (gamma(0.5*n)*sqrt(pi));
    end
end

% Calculate the Anis-Lloyd/Peters corrected Hurst exponent
% Compute the Hurst exponent as the slope on a loglog scale
ERSal = sqrt(0.5*pi.*d);
Pal = polyfit(log10(d),log10( RSe - ERS + ERSal ),1);
Hal = Pal(1);
% Calculate the empirical and theoretical Hurst exponents
Pe = polyfit(log10(d),log10(RSe),1);
He = Pe(1);
P = polyfit(log10(d),log10(ERS),1);
Ht = P(1);

% Compute empirical confidence intervals (see [4])
L = log2(OptN);
% R/S-AL (min(divisor)>50) two-sided empirical confidence intervals
pval95 = [0.5-exp(-7.33*log(log(L))+4.21) exp(-7.20*log(log(L))+4.04)+0.5];
C = [   0.5-exp(-7.35*log(log(L))+4.06) exp(-7.07*log(log(L))+3.75)+0.5 .90];
C = [C; pval95                                                     .95];
C = [C; 0.5-exp(-7.19*log(log(L))+4.34) exp(-7.51*log(log(L))+4.58)+0.5 .99];
```

```
function d = divisors(n,n0)
% Find all divisors of the natural number N greater or equal to N0
i = n0:floor(n/2);
d = find((n./i)==floor(n./i))' + n0 - 1;

function rs = RScalc(Z,n)
% Calculate (R/S)_n for given n
m = length(Z)/n;
Y = reshape(Z,n,m);
E = mean(Y);
S = std(Y);
for i=1:m;
   Y(:,i) = Y(:,i) - E(i);
end;
Y = cumsum(Y);
% Find the ranges of cummulative series
MM = max(Y) - min(Y);
% Rescale the ranges by the standard deviations
CS = MM./S;
rs = mean(CS);
```

Source: adaptation of script by Weron, 2011