ΟΙΚΟΝΟΜΙΚΟ ΠΑΝΕΠΙΣΤΗΜΙΟ ΑΘΗΝΩΝ

ΤΜΗΜΑ ΟΙΚΟΝΟΜΙΚΗΣ ΕΠΙΣΤΗΜΗΣ

Efficient Market Hypothesis
The Case of the London Stock Exchange

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Διατριβή υποβληθείσα προς μερική εκπλήρωση
των απαραιτήτων προϋποθέσεων
για την απόκτηση του
Μεταπτυχιακού Διπλώματος Ειδίκευσης

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To my Dad and Mom

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ABSTRACT

Plenty of papers have been published for the *Efficient Market Hypothesis* (EMH) whereas is the foundation of the financial theory. In the core of the *Efficient Market Hypothesis* (EMH) theory, is the idea that the future prices cannot be predicted based on the current information set i.e. past and current prices, and economic variables. Several statistical models have been developed through the years having this property for the variables. One of the most famous and most used models in the bibliography is the *Random Walk Model*.

The purpose of this thesis is not to be one of a numerous published researches for the market efficiency but, to clarify for the reader the theory and the implications of this hypothesis by collecting the main principles from different sources, so as to comprehend deeply its sense. Besides the theoretical intention, an empirical study is presented in order to set a more solid background to the reader and prove that under appropriate conditions the *Efficient Market Hypothesis* is not a theoretical assumption but, in practice it may apply.

For the implementation of the empirical work, the data from the *London Stock Exchange*, especially the FTSE 100, are used. The choice of this stock market becomes because it is the most international stock exchange, the largest in Europe and the fourth largest in whole the world. Therefore, it would be interesting if it was proved that this stock market is efficient since it affects the global economy. Applying some tests which are described analytically for easy understanding, it is proved that the *London Stock Exchange* is a market weak efficiency as it was expected. However, it seems that some short run anomalies such as *January Effect* occur.

Keywords: *Efficient Market Hypothesis*, *Random Walk*, *Weak form*, *January Effect, London Stock Exchange*, FTSE 100, Unit root, Non-stationarity.

Table of Contents

Table of Figures

TABLE OF ABBREVIATIONS	
ACF	Autocorrelation Function
ADF	Augmented Dickey-Fuller
ADJ	Adjusted
AIC	Akeik Information Criterion
AIM	Alternative Investment Market
APT	Asset Pricing Model
CAPM	Capital Asset Pricing Model
DF	Dickey-Fuller
DR	Depository Receipt
EMH	Efficient Market Hypothesis
EU	European Union
FTSE	Footsie Index of London Stock Exchange
IBO	International Book Offer
IID	Independent and indentical distributed
IPO	Initial Public Offering
P/E	Price Earnings
PACF	Partian Autocorrelation Function
PP	Phillips-Perron
R&D	Research and Development
RW	Random Walk
S&P	Standard and Poor's
SETS	Stock Exchange Electronic Trading Service
SIC	Schwarz Criterion
UK	United Kingdom
VR	Variance Ratio

TABLE OF SYMBOLS	
a	Confidence level
a(*s*)	Partial autocorrelation between time t+s and t
AER_t	Average excess return at time t
AR(p)	Autoregressive process of order p
Corr(a,b)	Correlation between a and b.
$E(. \| I_t)$	Expectation conditonal on current inforamation set
ER_{it}	Excess return of the stock i at time t
e_{t+1}	Error term at time t+1
H_a	Alternative hypothesis
H_o	Null hypothesis
I_t	Current information set
k	Number of the lag
log(a)	Logarith of a to base 10
m	Drift of transformed logarithmic random walk model
n	Total number of observations
n_A	Number of first run cycle
n_B	Number of the second run cycle
p	Number of lag
$P(W \| Z)$	Best linear projection of W conditional on Z
Prob	Probability
P_t	Adjusted close stock price at time t
p_t	Logarithmic adjusted close stock price at time t
R	Number of runs
r_{t+1}	Stock return between t and t+1
SE(φ)	Standard error of φ
std(a)	Standard deviation of a
Var(r_t)	Variance of stock return at time t
X_{t1}	Economic variable 1 at time t
γ(0)	Variance at time t
γ(s)	Autocovariance betweet time t+s and t
δ	Ceofficient of the AR(1) model in first differences
δ_p	Ceofficient of the AR(p) model
ΔP_{t+1}	Difference of the adjusted close stock prices between t+1 and t

Δp_{t+1}	Difference of logarimthmic adjusted close stock prices between t+1 and t
Δt	Difference between time t and t-1
μ	Drift
μ	Mean
ρ	Coefficient of the AR(1) model
$\rho(s)$	Autocorrelation between time t+s and t
σ^2	Variance
φ	Coefficient of the AR(p) model

1. INTRODUCTION

The *Efficient Market Hypothesis* (EMH) is one of the most considerable and arguable notions in finance and forms presupposition for the validity of a large number of financial models. In 1978, Harvard financial economist, ***Michael Jensen*** declared his belief that *"there is no other proposition in economics which has more solid empirical evidence supporting it."* [1]

According to the *Efficient Market Hypothesis* (EMH), popularly known as the *Random Walk Theory* (RW), under equilibrium conditions, the current stock prices fully reflect all available information of the market about the value of firms or their investment risk. This information concerns the past stock prices, the current value of fundamental variables of the economy or inside information of the managers about the dividend policy. As a result, there is no way to earn excess profits or make arbitrary investments.

The key reason for the existence of an efficient market is the intense competition among investors to profit from any new information since the arrival of new information affects the stock prices. As a result, the prices of shares would adjust so quickly to the new events and the investors will not have enough time to benefit from the shifts since all investors have the same access to the announcements. Consequently, the main idea is that the information is common available.

As long as the information plays a substantial role in the implementation of market efficiency, the theory divides the efficiency into three forms based on the information set. The stronger the form it is, the most difficult the market efficiency to hold since the strong form considers that the information set contains all public and inside information. Despite the great contribution of the market efficiency in financial issues, empirical researches have indicated that in short-term, there are anomalies in market. Moreover, many financial analysts, based their studies on technical analysis, are against the market efficiency.

[1] Jensen (1978), p. 95

The intension of this master thesis is dual; the first part is the theoretical part and aim to give to the reader the reasoning behind the theory, main principles and implications of the *Efficient Market Hypothesis* (EMH). The second part of this dissertation presents an empirical work, based on the most common used tools for checking the validity of the market efficiency. The purpose of the empirical part is to give a short overview how the *Efficient Market Hypothesis* is tested choosing the largest stock market in Europe, the *London Stock Exchange* as the subject of study and using as the sample, the FTSE 100 Index.

Chapter 2 introduces the theoretical and mathematical framework of the EMH, the relative studies during the 20th and 21st centuries for historical reasons and the most widely known market anomalies which have been observed in financial markets. In Chapter 3, the tests which are used in order to examine each form of efficient market are analyzed. The next Chapter represents the main characteristics of the London Stock Exchange for the reader to learn some basic information about the object of study. The methodology that is followed in the empirical work is analyzed in steps in Chapter 5. Chapter 6 gives an accurate description of the data which are used for getting results from the tests. The results of the empirical research and a short interpretation are displayed analytically in Chapter 7. The conclusions of the study are presented in the last Chapter.

2. THE THEORY OF MARKET EFFICIENT HYPOTHESIS

The purpose of this part is to provide an overview of the theory of the efficiency market which is remained popular for the last four decades. This hypothesis is fundamental for the financial models and it has very important implications for decision making of investors as well as for the financial managers.

2.1 Introduction

According to the *Efficient Market Hypothesis* (EMH) of the stock market, the security prices reflect all the available information unbiased and efficiently. This information is common available for all investors so everybody can have an absolute or comparative advantage for some assets, in order to earn higher profits than the reasonable. Thus, under this hypothesis of the market efficiency, even if there are profitable opportunities the investors will perceive them, immediately and thus, the market will be in balance.

The main assumption for the EMH is the existence of a perfect capital market. Since the capital market is intensively competitive, the asset prices are difficult to be under- or overvalued, significantly and systematically, for a long time. As a result, the investors cannot make abnormal profits through their transactions, but, they take the reasonable market return for the undertaken investment risk.

In order to hold the perfect capital market, the following assumptions should be made. Firstly, there are no taxes and secondly, all investors have the same available information. Furthermore, there are no agency costs to link with stock ownership and no transaction costs for individuals buying and selling securities and firms issuing and repurchasing shares. Finally, the market should be complete (Marseguerra, 1998). However, these assumptions are not realistic because there are taxes, agency costs, transaction costs etc, in the real economy. Thus, the question arises if this hypothesis is true since the root of this hypothesis is these assumptions. Answering this question, the EMH can be rated from the top as researchers will call it strong efficient form and to the bottom as inefficient.

In the chapter 2, I will present analytically the theoretical and mathematical framework, a historical background for the market efficiency and market anomalies. In the section 2.2, is presented the theoretical idea behind the EMH. In the next section, the Random Walk model with drift (RW) is represented as a mathematical background of the EMH. The section 2.4 is divided into three subsections that each subsection presents analytically a different form of the market efficiency. A historical analysis for the market efficiency is introduced to the section 2.5. The last section consists of the subsections which are referred to the different kind of market anomalies that they have been observed in the empirical work.

2.2 The concept

The EMH was largely accepted to hold by the early 1970s. The first time the term "*efficient market*" was in a 1965 paper by ***E.F. Fama*** who said that in an efficient market, "*on the average, competition will cause the full effects of new information on intrinsic values to be reflected "instantaneously" in actual prices*."[2]

The proposition of the EMH, mostly known as the *Random Walk Theory* (RW), is that under equilibrium conditions the current stock prices fully reflect all available information of the market about the value of firms or their investment risk. These information concerns the past stock prices, the current value of fundamental variables of the economy or inside information of the managers about the dividend policy. As a result, there is no way to earn excess profits or make arbitrary investments.

According to the EMH, the stock prices change in the arrival of new information about the economy or the firms. So, the key is that the stock prices adjust so quickly to the new information as the investors do not have time to trade on and profit from the new information.

[2] Jonathan Clarke, Tomas Jandik, Gershon Mandelker, Efficient Market Hypothesis,

These movements might be predictable when they represent changes in the investment risk. However, if these movements are not only caused by the investment risk changes but they are dependent on other factors like the inside information of the investors, then the market is not efficient and under some appropriate strategies it is possible to earn higher profits or returns than the market consider reasonably. Consequently, under EMH, all investments are fairly priced i.e. in average investors get exactly what they pay for.

The EMH presupposes that the capital market is competitive in an intensive manner and the investors. The sense of rationality ensures the following characteristics. The first characteristic of rationality is the awareness of the investment risk and the taking of measures for the risk premium. The second characteristic is the pricing of a stock which is based on its profitable prospects long-term.

Moreover, the prices' changes are not based on exogenous factors but reflect the behavior of the investors which depends on the arrival of the new information. The changes of the prices are random because the new information is not predictable. The fourth characteristic is the realization that it is required the use of the available information. Lastly, the fifth characteristic is the rejection of the repeated events or the mimic behavior for the determination of the investment behavior.

Hence, the rational behavior of the investors with these characteristics guarantees that the prices will change rapidly as the new information arrives, but if they don't change then the new information is not so significant to affect the prices. However, the rational behavior is sufficient condition for the EMH but not a necessary one.

The estimations for the stock price are different for each rational investor given the same information set. These different estimations are the reason why there is the trading activity. Through these transactions, the stock prices are balanced in the market and these stock prices are based on the different forecasts.

In the market exist two categories of investors, the rational and the irrational investors. The latter category consists of investors who may behave risky and randomly or correspond to unimportant signs. There are three versions about how their behavior affects the market operation. In the short-term, their influence will be paltry due to the fact that their transactions are random and unreasonable and so, they are mutually cancelled. Nevertheless, if their affection is not nugatory and they imitate the investment strategy of the other investors then the EMH would not hold except in case that both investors exist simultaneously. The rational investors in contrast to the irrational know when the stock prices deviate from the equilibrium prices and they build the appropriate strategy to make profits. As a result, they conduce to the market equilibrium though the irrational investors behave accidentally and unreasonably. Finally, in the long-term, the rational investors earn higher profits than the other investors and the latter, either they make losses until they pull out of the market or they mimic the behavior of the rational investors. Thus, under some circumstances, the EMH holds even if its form is not so strong.

When new information about a firm becomes available, the stock prices change immediately to reflect the new structure. However, this new information should be unpredictable; otherwise the prediction about this new information (which is itself a piece of information) by some investors and using trade rules it would allow higher returns than the reasonable market returns for undertaken risk investment. Hence, the market will not be efficient.

For instance, let P to be a stock price of firm, this price will not be underestimated or overestimated systematically but it will be the fair value of this stock since all the information about this firm is available to all investors. If this price becomes underestimated even for a while, then it would be common knowledge to all investors and they would quickly buy this stock. As a result, this stock price would increase until it reaches its fair value. However, if only some investors have this information (better inside information) then they will only buy this stock and the price will not increase until its fair value. After some time, this information would become known to the rest of investors and the share price would take the fair value but a small part of investors will have the benefit of this information and it will have earned higher return than the expected return of the stock.

So, if the market is efficient then the market prices, provide the best estimates of value but if the market is not efficient then the market prices deviate from the true value and the process of valuation gives a reasonable estimate of this value.

A good description of market efficiency and the underlying mechanics is the one by ***Cootner*** (1964):

> "*If any substantial group of buyers thought prices were too low, their buying would force up the prices. The reverse would be true for sellers. Except for appreciation due to earnings retention, the conditional expectation of tomorrow's price, given today's price, is today's price. In such a world, the only price changes that would occur are those that result from new information. Since there is no reason to expect that information to be non-random in appearance, the period-to-period price changes of a stock should be random movements, statistically independent of one another*."

2.3 Mathematical framework

According to EMH, the price changes are random and unpredictable since the new information is unpredictable. Therefore, the mathematical approach of the EMH is that the stock prices follow a *Random Walk with drift* (RW) [3]**:**

$$P_{t+1}=\mu+P_t+e_{t+1} \text{ with } E(e_{t+1}|I_t) = 0 \qquad (1)$$

where $E(\, . \, |I_t)$ is the expectation of a random variable conditional on available information set at time t, P_{t+1} is the future price stock, e_{t+1} is the random error at time t+1 which is independent and identical distributed (iid) with conditional mean zero and variance σ^2. Under the EMH, the random error e_{t+1} is not predictable on available information set I_t and so, the expectation of the random error is zero.

[3] Tzavalis – Petralias, Investments, Chapter 7, AUEB 2009

The available information set of a security consists of information about the past prices of this security $I_t = \{P_{t-1}, P_{t-2}, ...\}$ or information about the fundamentally economic variables which affect the security prices $I_t = \{X_{t1}, X_{t2}, ...\}$. These variables may be macroeconomic variables or economic variables of the companies such as their profits, their dividend policy, etc. Having different information sets, there are three different forms for the EMH, weak, semi-strong and strong form.

According to the relation (1), the stock price changes depend on a constant term μ and a random error e_{t+1}. Therefore, the stock price at t+1 deviates from the current price not only a constant term but, a random term. Therefore, the stock price changes having subtracted μ are unpredictable and the prices would change due to random events.

Hence,

$$P_{t+1} - P_t - \mu = e_{t+1} \qquad (2)$$

Taking expectations conditional on information set I_t, we have the following:

$$E(P_{t+1} - P_t - \mu \mid I_t) = E(e_{t+1} \mid I_t)$$

By $E(e_{t+1} \mid I_t) = 0$,

$$E(P_{t+1} - P_t \mid I_t) = \mu \iff$$

$$\boxed{E(\Delta P_{t+1} \mid I_t) = \mu} \qquad (3)$$

where $\Delta P_{t+1} = P_{t+1} - P_t$ is the difference of the stock price between t+1 and t.

Substituting (3) into (2),

$$\boxed{\Delta P_{t+1} - E(\Delta P_{t+1} \mid I_t) = e_{t+1}} \qquad (4)$$

In accordance with (4), the differences of the stock prices over time are not forecasted given the current information set I_t. Thus, the outcome of the RW with drift model is the mathematical approach of the EMH since the expectation of the random error at time t+1 given the current information set is zero. Hence, the random error e_{t+1} represents the arrival of new information which is unpredictable given the market information at time t and so, $E(e_{t+1} \mid I_t) = 0$.

Otherwise, the relation (4) can be written:

$$\Delta P_{t+1} = E(\Delta P_{t+1} \mid I_t) + e_{t+1} \qquad (4a)$$

Therefore, the difference of the stock price can be divided into two parts: the predictable part $E(\Delta P_{t+1} \mid I_t)$ and the unpredictable part e_{t+1}.

Having assumed a RW with drift model, it holds the relation $E(\Delta P_{t+1} \mid I_t) = \mu$ for the first part and it is related to the return or risk of the share. If the market conditions do not change over time then the risk can be estimated by an asset pricing model. For instance, the *Capital Asset Pricing Model* (CAPM) assumes that the risk of a security is a function of the market risk, the beta of a financial industry and the risk free. In order to be proved the connection between the stock return and the constant term μ, the relation (2) will be divided by the current price P_t.

Having (2),

$$P_{t+1} - P_t - \mu = e_{t+1} \iff$$

$$P_{t+1} - P_t = \mu + e_{t+1}$$

Dividing by P_t, we get:

$$\frac{P_{t+1} - P_t}{P_t} = \frac{\mu}{P_t} + \frac{e_{t+1}}{P_t} \quad \Leftrightarrow$$

$$\boxed{r_{t+1} = \frac{\mu}{P_t} + \frac{e_{t+1}}{P_t}} \qquad (5)$$

where $r_{t+1} = \frac{P_{t+1}}{P_t} - 1$ is the stock return between t and t+1.

Taking the conditional expectation of relation (5) given the current information set I_t,

$$E(r_{t+1} \mid I_t) = E(\frac{\mu}{P_t} + \frac{e_{t+1}}{P_t} \mid I_t) \quad \Leftrightarrow$$

$$E(r_{t+1} \mid I_t) = E(\frac{\mu}{P_t} \mid I_t) + E(\frac{e_{t+1}}{P_t} \mid I_t) \quad \Leftrightarrow$$

$$E(r_{t+1} \mid I_t) = E(\frac{\mu}{P_t} \mid I_t) + \frac{1}{P_t} E(e_{t+1} \mid I_t) \quad \Leftrightarrow$$

$$E(r_{t+1} \mid I_t) = E(\frac{\mu}{P_t} \mid I_t) \quad \Leftrightarrow$$

$$\boxed{E(r_{t+1} \mid I_t) = \frac{\mu}{P_t}} \qquad (6)$$

Therefore, the relation (6) shows that the expected stock return which should reflect the market risk for this stock is a function of the constant term μ and the current price P_t.The stock return can be estimated by an asset pricing model such as the CAPM, APT.

In practice, the logarithmic approach of the EMH is more useful, especially for the tests of the efficient market. It can be proved that the expected price changes of stocks are approximately equal to the expected stock returns which consist of the risk investment. In order to represent the logarithmic approach of the EMH, we rewrite the return of a stock between t and t+1:

$$r_{t+1} = \frac{P_{t+1} - P_t}{P_t} = \frac{P_{t+1}}{P_t} - 1 \Leftrightarrow$$

$$1 + r_{t+1} = \frac{P_{t+1}}{P_t}$$

Taking the logarithm of this equation, we obtain:

$$\log(1 + r_{t+1}) = \log\left(\frac{P_{t+1}}{P_t}\right)$$

Using the logarithmic approach $\log(1+x) \approx x$ that holds for prices, around zero such as the stock returns or rate of returns, we take:

$$\log\left(\frac{P_{t+1}}{P_t}\right) \approx r_{t+1} \Leftrightarrow$$

$$\log(P_{t+1}) - \log(P_t) \approx r_{t+1}$$

Setting the logarithmic prices with non-capital letters, we obtain:

$$\Delta p_{t+1} \equiv p_{t+1} - p_t \approx r_{t+1}$$

Taking expectations conditional on information set I_t, we have the following:

$$\boxed{E(\Delta p_{t+1} \mid It) \equiv E(p_{t+1} - p_t \mid It) \approx E(r_{t+1} \mid It)} \qquad (7)$$

Hence, this relation shows that the expected changes of logarithmic stock prices should be equal to their expected returns which can be predicted by an asset pricing model.

By the EMH, the Δp_{t+1} can be written as a sum of the expected price changes and an error term which represents the new market information for the stock price. Thus, we have:

$$\Delta p_{t+1} = E(\Delta p_{t+1} \mid I_t) + \varepsilon_{t+1}$$

where $E(\varepsilon_{t+1} \mid I_t) = 0$. Having the relation (7), we take:

$$\Delta p_{t+1} \approx E(r_{t+1} \mid I_t) + \varepsilon_{t+1} \qquad (8)$$

Otherwise, the relation (8) can be written as:

$$p_{t+1} = E(r_{t+1} \mid I_t) + p_t + \varepsilon_{t+1}$$

As a result, the logarithmic approach of stock prices follows a *Random Walk Model* (RW). If the expected return is constant over time i.e. it holds $E(r_{t+1} \mid I_t) = m$ then we have the following relation:

$$\boxed{p_{t+1} \approx m + p_t + \varepsilon_{t+1}} \qquad (9)$$

This is the *Random Walk with drift* (RW). It should be remarked that this model holds but there exists an approximate error since we use the logarithmic approach $\log(1+x) \approx x$.

2.4 Forms

In according to the above definition of EMH, the market prices should incorporate all available information at any point in time. However, the financial researchers make a distinction among three forms of market efficiency, based on the term "*all available information*". This separation is very important for the tests of market efficiency which will be represented in another chapter. Under each version of efficient market, there are different tests that are used in empirical work. But, the majority of empirical work concerns the weak form of EMH. In this subsection, it will be represented only the definition of each form and it is noticed that each stronger form of efficiency incorporates all weaker forms of efficiency.

2.4a Weak form of EMH [4]

The weak form of the EMH claims that the current stock prices fully reflect all available information about the past history of the stock prices only. This information should be common for all investors. Under the weak form of the EMH, the information set is defined as $I_t = \{P_{t-1}, P_{t-2}, P_{t-3}, \ldots\}$ and the stock prices should be changed only by the arrival of the new information about the market. This new information would concern the stock prices which are uncorrelated with the information set I_t.

In accordance with the above definition of the weak version of the market efficiency, it is impossible to be earned higher profits or returns by the investment in securities than the predicted market profits or returns for the undertaken risk investment given the information set $I_t = \{P_{t-1}, P_{t-2}, P_{t-3}, \ldots\}$. The financial analysts use widely known methods of prediction of prices such as the technical analysis. However, the technical analysis is supported in the studying of the past stock price series and trading volume data for forecasting the direction of the prices and hence, it is opposed to the EMH which states that stock market prices are essentially unpredictable. The empirical evidence for this specific form of market efficiency, and therefore against the value of technical analysis, is pretty strong and quite consistent. The above corollary

[4] Tzavalis – Petralias, Investments, Chapter 7, AUEB 2009

is based on the assumption that the current stock prices have embodied all the disposable information efficiently. After taking into account transaction costs, it is not required an extra charge for buying stocks apart from the value for the undertaken risk investment since the cost of incorporation is insignificant and there is no need for additional effort of the collection of information. Therefore, it is very difficult to make profits on publicly available information such as the past sequence of stock prices $I_t = \{P_{t-1}, P_{t-2}, P_{t-3}, \ldots\}$.

The incorporation of the market information in prices effectively follows a simple process. In other words, the investors determine the demand or supply for a stock based on the common information set $I_t = \{P_{t-1}, P_{t-2}, P_{t-3}, \ldots\}$. Under the competitive market conditions, the equilibrium price P_t should reflect all the information of this set efficiently and the arbitrage opportunities are excluded in the equilibrium condition. But, if one of the investors desires making abnormal profits then he should find some information which will be out of the information set $I_t = \{P_{t-1}, P_{t-2}, P_{t-3}, \ldots\}$. Although, this information could not affect the stock prices under the weak form of the EMH, since this information set is common available.

2.4b Semi-strong form of EMH [5]

The semi-strong form of the EMH suggests that the stock prices should fully reflect all available information about not only the past history of the stock prices but also, the market or company at time t. This information is referred to the fundamentals of the company such as its financial statements (annual reports, income statements, filings for the Security and Exchange Commission, etc.), earnings and dividend announcements, announced merger plans, the financial situation of firm’s competitors, expectations regarding macroeconomic factors (such as inflation, unemployment), etc, that change the stock prices. This information set is defined as $I_t = \{X_{1,t}, \ldots, X_{K,t}, P_{i,t-1}, P_{i,t-2}, P_{i,t-3}, \ldots\}$,where $X_{1,t}, \ldots, X_{K,t}$ are the fundamental variables which affect the stock price P_t at current time t. In fact, the public information does not even have to be of a strictly financial nature, i.e. the public information could include publications about the current state of a research in a relevant domain or an innovation of the company (R&D).

[5] Tzavalis – Petralias, Investments, Chapter 7, AUEB 2009

Under this version of the EMH, the collection of extra information for the determination of the prices is necessary. Arguably, it is difficult to gather this information since it demands a lot of time and effort and is a costly process since the semi-strong efficiency of market requires the existence of market analysts who are able to comprehend implications of vast financial information, macroeconomists, experts who understand the processes of product and input markets, besides financial economists. Therefore, it may not be sufficient to gain the information from major newspapers and company-produced publications but the analysts may have to follow reports, professional publications and databases, local papers, research journals etc, in order to gather all information necessary to effectively analyze securities.

Therefore, in contrast with the weak form of the market efficiency, the semi-strong form supposes that apart from the risk investment, the stock prices should reflect the value of the analysis of available information from investors or brokers which is a costly process. However, this cost would be low and common for all stocks because there are many investment companies or brokers that analyze these systematically and uniformly. As a result, the stock prices would reflect all available information about the current and past variables and prices which affect the securities, the investment risk and the cost of the analysis of market data. Hence, the shifts of the share prices are causing the arrival of the new information which are uncorrelated or orthogonal with information set $I_t = \{X_{1,t}, \ldots, X_{K,t}, P_{i,t-1}, P_{i,t-2}, P_{i,t-3}, \ldots\}$.

To sum up, the allegation behind the semi-strong form of the EMH is still that one should not be able to profit using the public information which is related to the past sequence of prices and also, the fundamental economic variables that affect the market at time *t*. The stock prices would embody this information and the cost of its evaluation effectively, and thus, the abnormal earnings are impossible. However, if some investors have inside information about the stock prices or the policy which would be followed by the company then the excess profits will be feasible. Concluding, it may be noticed that the assumption for the semi-strong type of the efficient market is far stronger than that of weak-form efficiency and financial researchers have found empirical evidence that is overwhelming consistent with the semi-strong form of the EMH.

2.4c Strong form of the EMH [6]

The strong form of the EMH is the strictest version of the market efficiency and states that the current prices fully incorporate all existing information, both public and private. The term "public" information implies the past and current prices and fundamental variables that affect the stock prices. The "private" information is called the inside information that each investor is able to find about the shares and trades on these with aim to make higher profits. As a result, the prices would be affected by the inside information of the brokers or investors. Nevertheless, the strong form of the efficient market asserts that the insiders are not able to systematically gain from inside information by buying company's shares. Even if the arbitrage opportunities exist, they will be eliminated quickly because of the volume of transactions which is daily announced in the market and it will uncover the existence of the profitable occasions. In other words, the investors will perceive these opportunities immediately and thus, they will be included in the common information set. As a result, the prices will reflect all this information (public and private) efficiently.

The main difference between the semi-strong and strong efficiency hypothesis is that in the latter case, nobody should be able to systematically generate profits even if trading on information not publicly known at the time. The intuition of strong-form market efficiency is that the market anticipates, in an unbiased manner, future developments and therefore, the stock price may have incorporated the information and evaluated in a much more objective and informative way than the insiders. Not surprisingly though, empirical research in finance has found evidence that is inconsistent with the strong form of the EMH.

The below graph depicts the forms of the EMH and their information sets.

[6] Tzavalis – Petralias, Investments, Chapter 7, AUEB 2009

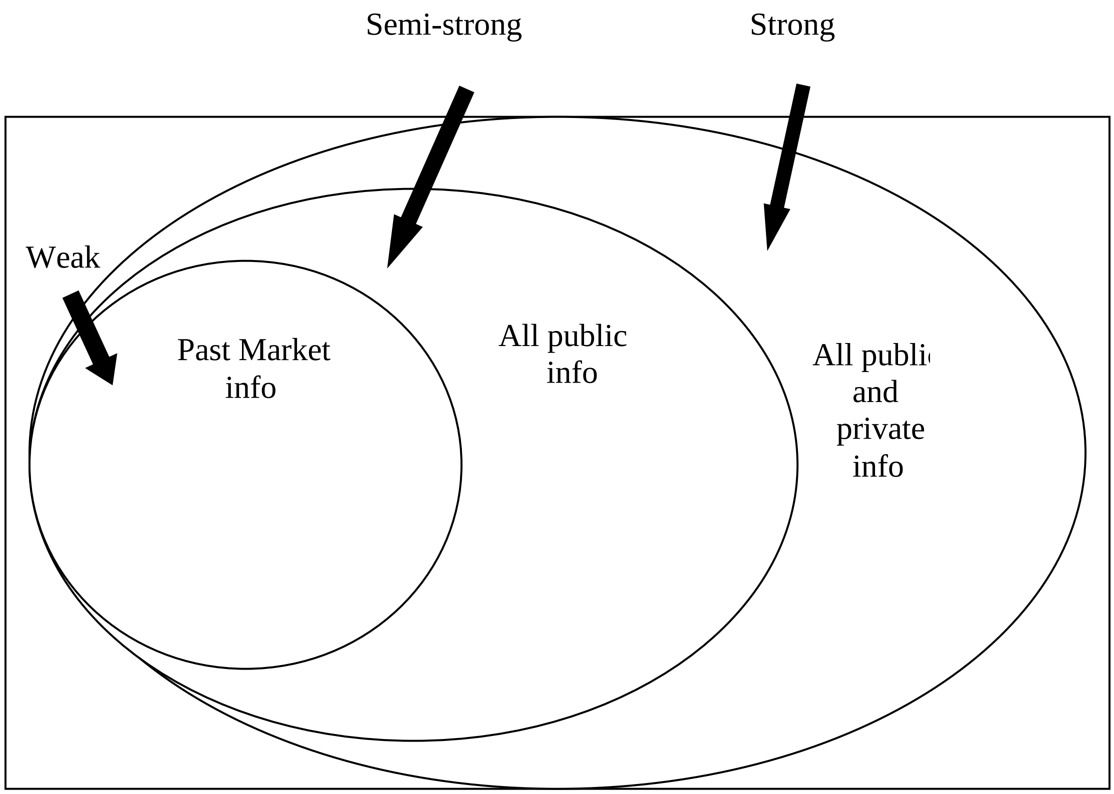


Figure 1: Forms of EMH

The graph is inspired by the following site: http://www.slideshare.net/Zorro29/market-efficiency-and-empirical-evidence

2.5 Historical background of the EMH

In this section, it will be presented the history of the EMH which has its roots at the beginning of the 19th century. However, there have been some references in this meaning without using the term "efficient" earlier this century. The source of this history is the published research of the University College of London (UCL) under the title "History of the Efficient Market Hypothesis" by Martin Sewell (RN/11/04, Sewell, 2011).

In the 16th century, an Italian mathematician (and doctor), called ***Girolamo Cardano***, in a paragraph entitled "*The Fundamental Price of Gambling*" (Cardano and *Liber de Ludo Aleae*, c. 1565) wrote *"The most fundamental principle of all in gambling is simply equal conditions, e.g. of opponents, of bystanders, of money, of situation, of the dice box, and of the die itself. To the* *extent to which you depart from that equality, if it is your opponents favour, you are a fool, and if in your own, you are unjust".*

At the middle of the 19th century, a French economist**, *Jules Regnault*,** was the one who first suggested a modern theory of stock price changes in the book *"Calcul des Chances et Philosophie de la Bourse"* (1863) and used a random walk model. His basic observation was that the deviation of prices is directly proportional to the square root of time (*Regnault, Calcul des Chances et Philosophie de la Bourse, 1863, p.50*). In 1888, ***John Venn***, a British logician and philosopher, famous of a Venn diagram, discussed both a *Random Walk* and *Brownian motion* (Venn, The Logic of Chance, 1888). The following year, efficient markets were clearly mentioned in the book *"The Stock Markets of London, Paris and New York"* by ***George Gibson*** who wrote that *"when shares become publicly known in an open market, the value which they acquire may be regarded as the judgment of the best intelligence concerning them"* (Gibson, 1889). The next important contribution was by the famous economist ***Alfred Marshall*** in his book-milestone *"Principles of Economics"* in 1890.

Furthermore, the concept of market efficiency was published by a French mathematician, ***Louis Bachelier*** in his dissertation entitled *"The Theory of Speculation"* to the Sorbonne, also in 1900. He first discussed the use of "*Brownian Motion"* to evaluate the stock options and is the first paper in history of finance, in which advanced mathematics are used in order to study related phenomena. ***Bachelier*** recognised that *"past, present and even discounted future events are reflected in market price, but often show no apparent relation to price changes".* This recognition of the informational efficiency leaded ***Bachelier*** to conclude that *"if the market, in effect, does not predict its fluctuations, it does assess them as being more or less likely, and this likelihood can be evaluated mathematically".* He laid the theoretical foundations for further analysis of the EMH but his work was ignored until it was discovered by ***Savage*** in the second half of the 20th century. Five years later, ***Albert Einstein***, unaware of Bachelier's work, published a paper in which the "*Einstein-Wiener process"* was included (Annus Mirabilis**,** 1905). At the same time, an English mathematician, ***Karl Pearson*** first introduced the term *Random Walk* in the Nature (Pearson, 1905). The following years, a number of papers published for the equations of *Brownian Motion* such as the papers of ***Smoluchowski*** (1906), ***Barriol*** (1908), ***de Montessus*** (1908), **Langevin** (1908).

Afterwards, the *Laws of Supply and Demand* are published by ***George Binney Dibblee*** (Dibblee, 1912) and the book, *Le Jeu, la Chance et le Hasard* is published by ***Bachelier*** in 1914 (Bachelier, 1914). A year later, ***Wesley C. Mitchell*** who was an American Economist first noted that *"the empirical distributions of price changes are too 'peaked' to be relative to samples from Gaussian populations"* (Mitchell, 1915). That was also an assertion from ***Benoit Mandelbrot*** (Mandelbrot, 1963), nevertheless, he praised **Bachelier's** work which assumed a normal (Gaussian) distribution of relative price changes.

In 1921, ***F. W. Taussig*** published a paper entitled *"Is Market Price Determinate?"* In 1923 the English famous economist ***John Maynard Keynes*** asserted that investors on financial markets are rewarded not for knowing better than the market what the future has in store, but rather for risk bearing, this is a consequence of the EMH (Keynes, 1923). ***Frederick MacCauley*** stated that there was a striking similarity between the fluctuations of the stock market and those of a chance curve which may be obtained by throwing a dice (MacCauley, 1925). A year later, ***Maurice Olivier*** proved the leptokurtic nature of the distribution of returns in his doctoral dissertation (Olivier, 1926) while ***Frederick C. Mills*** proved the leptokurtosis of returns in the book *"Introduction to "The Behavior of prices""* (Mills, 1927). The *Wall Street Crash*, known as *Black Tuesday*, occurred in late October 1929 which was the most devastating stock market crash in the history of the United States, when taking into consideration the full extent and duration of its fallout.

In 1933, ***Alfred Cowles***, 3rd, analysed the performance of investment professionals and concluded that stock market forecasters can not forecast. Cowles, also, founded and funded both *Econometric Society* and its journal *"Econometrica"* and set up the "*Cowles Commision for Economic Research"*. In 1934, ***Holbrook Working*** supported that stock returns behave like numbers from a lottery (Working, 1934). Thence, in the book *"General Theory of Employment, Interest, and Money"*, published by ***Keynes***, the stock market was compared with a beauty contest, and ***Keynes***, also, claimed that most investors' decisions can only be as a result of *"animal spirits"* (Keynes, 1936). The following year, ***Eugen Slutzky*** showed that sums of independent random variables may be the source of cyclic processes (Slutzky, 1937). In 1937, ***Cowles and Jones*** observed significant evidence of serial correlation in averaged time series indices of stock prices. That paper was the only one published before 1960 in which found significant inefficiencies (Cowles and Jones, 1937).

Cowles reported, in a continuation of his 1933 publication, that the investment professionals do not beat the market (Cowles, 1944). In 1949, ***Holbrook Working*** showed that it would be impossible for any professional forecaster to predict price changes successfully in an ideal futures market (Working, 1949).

In 1953 ***Milton Friedman***, a famous American economist, denoted that, due to arbitrage, the case for the market efficiency can be made even in situations where the trading strategies of investors are correlated (Friedman, 1953). Analysing 22 price-series at weekly intervals, ***Kendall*** found that they were essentially random which was unexpected. In addition, he was the first to point out the time dependence of the empirical variance (non stationarity) (Kendall, 1953). In 1956, ***Bachelier's*** name reappeared when ***Paul A. Samuelson***, economist and student of MIT at that time, wrote his thesis on options-like pricing. An anticipatory market model was built by ***Working*** in 1958. The next year, ***Harry Roberts*** claimed that a random walk will look like an actual stock series (Harry, 1959). Meanwhile, ***M. F. M. Osborne*** showed that the logarithm of common-stock prices follows Brownian motion and found evidence of the square root of time rule. Regarding the distribution of returns, he finds 'a larger *"tangential dispersion"* in the data at these limits' (Osborne, 1959).

In 1960, ***Larson*** presented the results of an application of a new method of time series analysis and remarked that the distribution of price changes is *"very nearly normally distributed for the central 80 per cent of the data, but there is an excessive number of extreme values"*. In the same year, ***Cowles*** revisited the results in Cowles and Jones (1937), correcting an error introduced by averaging, and still finds mixed temporal dependence results and ***Working*** showed that the use of averages can introduce autocorrelations which do not present in the original series.

In 1961 ***Houthakker*** used stop-loss sell orders and found patterns. He, also, found leptokurtosis, non-stationarity and suspected non-linearity. ***Alexander*** realised that spurious autocorrelation could be introduced by averaging or if the probability of a rise is not 0.5. He concluded that the random walk model best fits the data, but found leptokurtosis in the distribution of returns. Also, this paper was the first to test for non-linear dependence. In the same time, ***John F. Muth*** introduced the rational expectations hypothesis in economics (Muth, 1961).

In 1962 ***Mandelbrot*** first suggested that the tails of the distribution of returns follow a power law, in IBM Research Note NC-87 (Mandelbrot, 1962). ***Paul H. Cootner*** stated that the stock market is not a random walk (Cootner, 1962). ***Osborne*** investigated deviations of stock prices from a simple random walk, and his results include the fact that stocks tend to be traded in concentrated bursts. ***Arnold B. Moore*** found insignificant negative serial correlation of the returns of individual stocks, but a slight positive serial correlation for the index (Moore, 1962). ***Jack Treynor*** wrote his unpublished manuscript *"toward a theory of market value of risky assets"*, the first paper on the Capital Asset Pricing Model (CAPM), yet rarely cited and often incorrectly referred to as *"Treynor"*.

The following year, ***Berger and Mandelbrot*** proposed a new model for error clustering in telephone circuits, and if their argument is applicable to stock trading, it might afford justification for the Pareto Levy distribution of stock price changes, claimed by ***Mandelbort*** (Berger and Mandelbort, 1963). ***Granger and Morgenstern*** performed spectral analysis on market prices and found that short-run movements of the series obey the simple random walk hypothesis, but that long-run movements do not, and that *'business cycles'* were of little or no importance (Granger and Morgenstern, 1963). Meanwhile, ***Mandelbrot*** presented and tested a new model of price behaviour using natural logarithms of prices and replacing the *Gaussian* distributions with the more stable *Paretian* distribution (Mandelbrot, 1963). ***Fama*** discussed Mandelbrot's *"stable Paretian hypothesis"* and concluded that the tested market data conforms to the distribution (Fama, 1963).

In 1964, ***Alexander,*** trying to answer to the critics against his 1961 paper, came up with the result that the S&P industrials do not follow a random walk. In the same year, ***Cootner*** (1964) edited his classic book "*The Random Character of Stock Market Prices*", a collection of papers by Roberts, Bachelier, Cootner, Kendall, Osborne, Working, Cowles, Moore, Granger and Morgenstern, Alexander, Larson, Steiger, Fama, Mandelbrot and others", while ***Godfrey*** et al. (1964) published another significant book named *"The random walk hypothesis of stock market behaviour"*. Also, ***Steiger*** (1964) made an important contribution in the analytical framework by testing for non-randomness and argued in favour of the same result in which Alexander had already ended, that stock prices do not follow a random walk. Finally, the growing importance of the field in general economics is proved by the acceptance of ***Sharpe's*** (1964) published work on the CAPM, which later gave him a Nobel Prize in Economics.

Moreover, the following year we have the first clear definition of what an ***"Efficient Market"*** is, in a ***Fama's*** paper regarding to the empirical analysis of stock market prices, which leads to the conclusion, in contrast to ***Alexander*** and ***Steiger***, that stock market prices follow a random walk. Moreover, in a slightly previous work ***Fama*** (1965a) explained how the theory of random walks in stock market prices presents important challenges to the proponents of both technical analysis and fundamental analysis. In parallel, ***Samuelson*** (1965) provided the first formal economic argument for efficient market in his article ***"****Proof that properly anticipated prices fluctuate randomly"*, in which he focussed on the concept of a martingale, rather than a random walk as ***Fama*** did in his own work. ***Harry Roberts*** (Roberts, 1967) made a further step by coining the term efficient markets hypothesis and by making the distinction between weak and strong form tests, which became the classic taxonomy in ***Fama*** (1970).

The contribution of ***Fama*** was continued by undertaking the first ever event study (the ***Fama*** et al. (1969). The results of that work drove to a considerable support to the conclusion that the stock market is efficient. Furthermore, ***Fama*** published his first significant review paper (which was followed by two more), in which he defines an efficient market thus: *"A market in which prices always "fully reflect" available information is called "efficient and becomes the first one to consider the 'joint hypothesis problem"*. The same year was also published the ***Granger's*** and ***Morgenstern's*** book *"Predictability of Stock Market Prices"*, which also pushed forward the research in the relevant area. The next important contribution was made by ***Scholes*** in 1972 that studied the price effects of secondary offerings and found that the market is efficient except for some indication of post-event price drift.

That primitive work in late 60's and early 90's was succeeded by thousands of relative works and publications. Specifically, in 1973 ***Samuelson*** (1973a) wrote his survey paper, "*Mathematics of speculative price"*, ***LeRoy*** (1973) showed that under risk-aversion, there is no theoretical justification for the martingale property, ***Lorie*** and ***Hamilton*** (1973) published the book *"The Stock Market: Theories and Evidence"* and ***Malkiel*** published the classic *"A Random Walk Down Wall Street"*. Moreover, ***Samuelson*** (1973b) also generalized his earlier (1965) work to include stocks that pay dividends. In 1976, ***Cox*** and ***Ross*** authored *"The valuation of options for alternative stochastic processes"*,

Grossman described a model which shows that *"informationally efficient price systems aggregate diverse information perfectly, but in doing this the price system eliminates the private incentive for collecting the information"* and ***Fama*** (1976) published the book *"Foundations of Finance".* The following year Osborne published *"The Stock Market and Finance From a Physicist's Viewpoint"* and ***Beja*** (1977) showed that the efficiency of a real market is impossible. In 1978, ***Ball*** wrote a survey paper which revealed consistent excess returns after public announcements of firms' earnings and ***Jensen*** famously wrote, *"I believe there is no other proposition in economics which has more solid empirical evidence supporting it than the Efficient Market Hypothesis"*, while ***Robert E. Lucas, Jr.*** built a theoretical model of rational agents which shows that the martingale property need not hold under risk aversion. Finally, in 1979 ***Radner*** showed through his theoretical model that if the number of alternative states of initial information is finite then, generically, *"rational expectations equilibria"* exist that reveal to all traders all of their initial information. Also n 1979, ***Dimson*** reviewed the problems of risk measurement (estimating beta) when shares are subject to infrequent trading, ***Harrison*** and ***Kreps*** published *"Martingales and arbitrage in multiperiod securities markets"* and ***Shiller*** showed that the volatility of long-term interest rates is greater than predicted by expectations models.

During the 80's we have a continuing development of the calculating methods and data analysis, through the breakthrough in computer industry. The result of this development is shown in total the economics and especially in fiancé and stock markets analysis. Also, in late 80's we had a real case in stock markets. On *"Black Monday"*, 19 October 1987, stock markets around the world crashed. The crash began in Hong Kong, spread west to Europe, then hit the United States causing the largest daily percentage loss in the history of the Dow Jones Industrial Average, -22.61%. That was a tough test for the theories until then.

In theory, relatively to the efficient market hypothesis we have also some significant procedures. In 1980, ***Grossman*** and ***Stiglitz*** showed that it is impossible for a market to be perfectly informationally efficient. Their argument was that due to the fact that information is costly, prices cannot perfectly reflect the information which is available, since if it did investors who spent resources on obtaining and analyzing it would receive no compensation. ***LeRoy*** and ***Porter*** (1981) showed that stock markets exhibit *"excess volatility"* and they also reject market efficiency.

The same year, ***Stiglitz*** showed that even with apparently competitive and 'efficient' markets, resource allocations may not be "*Pareto efficient"*, while ***Shiller*** showed that stock prices move too much to be justified by subsequent changes in dividends, also claiming that stock prices exhibit excess volatility. However, his method was later analysed by ***Marsh*** and ***Merton*** (1986), who conclude that it is not appropriate to be used to test the hypothesis of stock market rationality.

Milgrom and ***Stokey*** (1982) showed that under certain conditions, the receipt of private information cannot create any incentives to trade. ***Tirole*** (1982) showed that unless traders have different priors or are able to obtain insurance in the market, speculation relies on inconsistent plans, and thus is ruled out by rational expectations. ***Osborne*** and ***Murphy*** (1984) found evidence of the square root of time rule in earnings. ***Roll*** (1984) examined US orange juice futures prices and the effect of the weather. He found excess volatility. In 1985 ***De Bondt*** and ***Thaler*** discovered that stock prices overreact, evidencing substantial weak form market inefficiencies, setting the bases for a new sector, called behavioral finance.

Also, a quite original contribution to the theory was made by ***Fischer Black*** in 1986, who introduced the concept of *"noise traders"*, those who trade on anything other than information, and showed that noise trading is essential to the existence of liquid markets. Summers argued that many statistical tests of market efficiency have very low power in discriminating against plausible forms of inefficiency. ***French*** and ***Roll*** (1986) found that asset prices are much more volatile during exchange trading hours than during non-trading hours; and they deduced that this is due to trading on private information.

At late 80's we also have some other interesting results. Most of them are based in empirical work and data analysis. For example, ***Fama*** and ***French*** (1988) found large negative autocorrelations for stock portfolio return horizons beyond a year. ***Lo and MacKinlay*** (1988) strongly rejected *"the random walk hypothesis"* for weekly stock market returns. ***Poterba*** and ***Summers*** (1988) showed that stock returns show positive autocorreation over short periods and negative autocorrelation over longer horizons. ***Conrad and Kaul*** (1988) characterized the stochastic behavior of expected returns on common stock. ***Eun and Shim*** (1989) found that a substantial amount of interdependence exists among national stock markets, and the results are consistent with informationally efficient international stock markets. ***Ball*** (1989) discusses the specification of stock market efficiency. ***LeRoy*** (1989) claimed that the transition between the intuitive idea of market efficiency and the martingale is far from direct.

Laffont and Maskin (1990) show that the efficient market hypothesis may well fail if there is imperfect competition. ***Lehmann*** (1990) found reversals in weekly security returns and also rejected the "*efficient market hypothesis"*. ***Jegadeesh*** (1990) documented strong evidence of predictable behaviour of security returns and rejected the famous in 70's "*random walk hypothesis"*.

In a similar to previous decade pace, in 90's we also have a lot of important results regarding to the theory of finance in general and to the "*efficiency market hypothesis"* more specifically. Again, most of the works were mainly empirically supported. ***Kim et al***. (1991) re-examined the empirical evidence for *"mean-reverting behavior"* in stock prices and found that mean reversion is entirely a pre-World War II phenomenon. ***Jackson*** (1991) explicitly modeled the price formation process and shows that if agents are not price-takers, then it is possible to have equilibrium with fully revealing prices and costly information acquisition. ***Lo*** (1991) developed a test for long-run memory that is robust to short-range dependence, and concludes that there is no evidence of long-range dependence in any of the stock returns indices tested. ***Chopra et al.*** (1992) found that stocks overreact. ***Bekaert and Hodrick*** (1992) characterized predictable components in excess returns on equity and foreign exchange markets. ***Jegadeesh and Titman*** (1993) found that trading strategies that bought past winners and sold past losers realized significant abnormal returns. ***Richardson*** (1993) showed that the patterns in serial-correlation estimates and their magnitude observed in previous studies should be expected under the null hypothesis of serial independence. ***Roll*** (1994) observed that in practice it is hard to profit from even the strongest market inefficiencies. ***Huang and Stoll*** (1994) provided new evidence concerning market microstructure and stock return predictions. ***Metcalf and Malkiel*** (1994) found that portfolios of stocks chosen by experts do not consistently beat the market. ***Lakonishok et al***. (1994) provide evidence that value strategies yield higher returns because these strategies exploit the suboptimal behavior of the typical investor and not because these strategies are fundamentally riskier.

Dow and Gorton (1997) investigated the connection between stock market efficiency and economic efficiency. ***Arthur et al***. (1997) proposed a theory of asset pricing by creating an artificial stock market with heterogeneous agents with endogenous expectations. ***Bernstein*** (1999) criticized the EMH and claims that the marginal benefits of investors acting on information exceed the marginal costs. ***Zhang*** (1999) presented a theory of marginally efficient markets

In that decade we have also many new books related to the topic and some important review papers and surveys, which put together all the theory until then, giving a specific form of the area. The most famous review papers were written by ***Fama***, although the general publishing activity was very high***. Haugen's*** book is a great example of that activity.

The growing importance of the sector and its influence is witnessed by the election of ***Eugene Fama*** as a fellow of the American Finance Association in 2001.the same year, an excellent historical review paper was written by ***Andreou et al***., in which it was traced the development of various statistical models proposed since ***Bachelier*** (1900) in an attempt to assess how well these models capture the empirical regularities exhibited by data on speculative prices, while the famous economist ***Mark Rubinstein*** re-examined some of the most serious historical evidence against market rationality and concluded that markets are rational (Rubinstein, 2001). Also in 2001, ***Shafer and Vovk*** mixed up game theory and the finance theory in their work "*Probability and Finance: It's Only a Game!"*

The following year, ***Lewellen and Shanken*** concluded that parameter uncertainty can be important for characterizing and testing market efficiency, while ***Chen and Yeh***, through investigating the emergent properties of artificial stock markets, show that the EMH can be satisfied with some portions of the artificial time series. In 2003, ***Malkiel*** examined the attacks on the *"efficient market hypothesis"* and concludes that stock markets are far more efficient and far less predictable than some recent academic papers would have us believe and ***Schwert*** showed that when anomalies are published, practitioners implement strategies implied by the papers and the anomalies subsequently weaken or disappear. In other words, research findings cause the market to become more efficient. ***Timmermann and Granger*** (2004) discussed the *"efficient market hypothesis"* from the perspective of a modern forecasting approach. ***Malkiel*** (2005) showed that professional investment managers do not outperform their index benchmarks and provides evidence that by and large market prices do seem to reflect all available information. ***Blakey*** (2006) looked at some of the causes and consequences of random price behaviour, meanwhile ***T´oth and Kert´esz*** (2006) found evidence of increasing efficiency in the New York Stock Exchange. ***Wilson and Marashdeh*** (2007) demonstrated that co integrated stock prices are inconsistent with the EMH in the short run, but consistent with the EMH in the long run. The elimination of arbitrage opportunities means that stock market inefficiency in the short run ensures stock market efficiency in the long run. ***McCauley*** et al. (2008) show that "*martingale stochastic processes"* generate uncorrelated, generally non-stationary increments; explain why martingales look ***Markovian*** at the level of both simple averages and 2-point correlations; and prove that arbitrary martingales are topologically inequivalent to *"Wiener processes"*. ***Yen and Lee*** (2008) presented a survey article that gives a chronological account of empirical findings and conclude that the *"efficient market hypothesis"* is here to stay. Finally, ***Lee et al. (2010)*** investigated the stationarity of real stock prices for 32 developed and 26 developing countries covering the period January 1999 to May 2007 and conclude that stock markets are not efficient.

2.6 Anomalies

The EMH is a controversial issue in the finance which has received criticism about its non-validity. Many criticizers consider that it is possible to predict the direction of the stock price changes and earn higher profits than the predictable market profits, systematically. In accordance with this statement, the EMH would no longer hold.

However, the possibility of some investors to be able to forecast the share price changes due to the fact that they have information or necessary experience to interpret the market conditions would not violate the EMH since, either in the short-run or in the long run, the equilibrium will be reached. In the case of the insiders, if the number of them is low then it would not affect the prices but if the number is high then the authorities of the financial markets may discover their illegal behaviour or the rest investors will mimic their behaviour. In the other case that some investors have enough experience to predict the shifts of the security prices, all investors could be able to have this right since the ability of making prediction, becomes a competitive advantage.

The scientific review state, which the rational behaviour of the investors, is based on the EMH is historically contested. It has been observed that there exist periods in which the prices are undervalued or overvalued. These effects do not contain significant information which explains these shifts of stock prices. Thus, there are doubts for the rational actions of the investors and the rational mechanism of prices.

There are a lot of kinds of market anomalies which have observed in the financial markets. In this section, the anomalies which are going to be presented appear more systematically in the stock markets. These anomalies can be owing to calendar effects, behavior of firms for making profits, behavior of economic agents, fundamental factors, structural factors, random events etc.

Thus, due to the market inefficiency, it is feasible to be predicted the changes of the stock prices and make abnormal profits.

2.6.1 The Calendar Effect

It has been observed that there are fluctuations in the stock prices which are related to the calendar schedule and for this reason it is called *"Calendar Effect".* Many empirical researches have observed that the prices increase or decrease depending on day or month etc and as a result, it is feasible that the managers have the chance to benefit from these predictable shifts of stock prices and make profits (if the transaction costs are less than the stock returns). The current literature is referred to many calendar effects such as *January effect*, *weekend effect*, *Monday effect*, *turn-of-the month effect*, *seasonal effects*, *Halloween indicator* etc. In this subsection, are presented the most popular calendar effects, the January effect and the Weekend effect.

2.6.1a The January effect

The most common anomaly which has been observed in financial markets is the *January effect*. The stock prices have the tendency to increase between 31st December and the first week of January and for this reason the investors buy stocks in the lower prices at the end of December and sell them when the prices have increased. As a result, they make profits from the differences of stock prices. Thus, the main observance for the *January effect* is the rise in buying of securities at the end of year and the rise in selling at the beginning of year. As a result, this effect is contrast to the market efficiency since the investors make abnormal profits.

A logical explanation for the appearance of this phenomenon is the capital taxation. In other words, many investors who are tax-sensitive and hold small stocks, sell them at the end of year so as to claim capital losses and counterbalance the tax liability with the capital gains and reinvest at the beginning of the next year. However, this cause is commonly approval but not sufficient since this effect appears in some countries like Japan which do not impose capital taxes or do not allow the offset between capital gains and losses for tax reasons. Another reason for the *January effect* is the window dressing i.e. the improvement of the appearance of the portfolio by managers before its presentation to clients or shareholders.

2.6.1b The weekend effect

Many empirical researches have proved that another usual effect in financial markets is the *Weekend effect*. During the week, the stock returns, change systematically exhibiting significantly higher returns on Fridays (especially, higher closing prices) than the returns (opening prices) on Mondays. This observance has been based on data of New York Stock Exchange.

The interpretation about the *Weekend effect* is ambiguous and so, there are several theories in which is attributed this effect. A theory states that the investment companies prefer to announce the bad news after the closing of the financial market on Fridays and as a result, the bad news incorporate into the opening prices on Mondays' morning. Moreover, the short selling could be another explanation for this phenomenon since it affects the returns of shares with high short interesting positions. Finally, there are alternative theories based on the emotional reasons and they consider the investors feel more optimistic on Fridays due to the coming weekend rather than on Mondays.

2.6.2 Behavioral Biases

Besides the calendar effects which is a cause for the failure of the EMH there are several factors which affect the behavior of the investors and thus, the mechanism of prices does not create unbiased predictions.

2.6.2a Under and overreactions

An often anomaly in financial markets is the exaggerated reaction of the investors to the market news. There some periods that the prices fall constantly and the investors are seized with panic and make irrational decisions. On the other hand, there are periods that the prices rise continuously and the investors behave too much optimistically related to the events. Thus, the information becomes more important in the making decisions process and the prices may deviate from the fair market value. As a result, the under or overreaction of the investors to the new information on the market is not consistent with EMH.

The behavior of the investors is supported to their prior beliefs and so, they believe that if the stock prices have a trend they will continue to do the same. In other words, they expect that if stock prices have gone up or down in previous periods they will persist to go up or down, respectively. Thus, the behavior of the investors is characterized by conservatism and representativeness. Many researches have proved that the individuals maintain their initial believes and take consecutive and irrational decisions. As a result, they under or overreact to the arrival of new information. In accordance with this anomaly, a lot of financial crises have occurred and there are many evidences for the failure of the market efficiency.

2.6.2b Momentum Effect

The *Momentum effect* is another market anomaly which has been observed in financial markets. The idea behind the *Momentum effect* is that the tendency of the prices won't change direction i.e. there is a high possibility that the rise or fall of stock prices will be followed by a further rise or fall of the prices. The further increase of the stock prices is warranted by the EMH only if the fundamental of the markets change like demand, supply or arrival of new information. The appearance of *Momentum effect* has been attributed to the cognitive biases and irrational behavior of the investors which do not fully incorporate the new information into prices. Recent studies claim that the *Momentum effect* has been observed even if rationality exists.

2.6.3 Fundamental anomalies

Another category of market anomalies is the fundamental anomalies *like Small-cap firm effect, value effect, low P/E* etc. This market inefficiency is based on the fundamental analysis of the financial markets that its aim is to study qualitative and quantitative factors which affect the security's value. These factors can be the financial conditions, macroeconomic factors, economic factors, industry's economy etc. The fundamental anomalies are *the return on equity, the Small firm effect and the P/E effect*. The two last effects are the most common effects and presented in the following subsections.

2.6.3a Small firm effect

The calendar effects are linked to a different kind of anomalies which is called *Small firm effect*. Empirical evidences showed that a part of the high returns on January is owing to small quoted firms. Checking the returns of large quoted companies, it is observed that the January effect disappears.

The theory behind the term "*Small firm effect*" is that the smaller firms outperform larger firms. In other words, smaller cap companies (with small capitalization) have greater room for growth and more volatile business environment. As a result, they have lower stock prices and larger price appreciations than larger cap companies.

2.6.3b P/E effect

The price earnings ratio (P/E) is a factor of valuation and defined as the company's share price per share earnings. Using this ratio, the investors can compare the price and earnings per share for the companies and the value of stocks. When the P/E of a firm is high, the investors expect higher earnings growth in the future and these companies are considered more certain compared to the companies with low P/E which are riskier.

Several studies have shown that the P/E predicts the next period's returns. ***Basu*** (1977) in his research stated that the portfolios with low P/E earn higher returns than the other with high P/E ratio (since he adjusted for the risk). However, this anomaly is not an upfront failure of EMH since the prices do not fully reflect the information in as rapid manner as demanded. Furthermore, the transaction costs and taxed hinder the investors to make abnormal profits. In any case, there exists anomaly which is explained by exaggerated expectations of investors.

2.6.4 Autocorrelation effect

Using data of financial markets and right tests, it has been observed the presence of autocorrelation in the stock prices. The daily and monthly data are mainly positively correlated implying that when the stock prices or returns increase (or decrease), the stock prices or returns of the next period will increase (or decrease). The existence of the autocorrelation among time series data of stock price is due to systematical shifts of the investment risk or random events for a short period such as good or bad market days. The EMH is violated by the occurrence of the autocorrelation if it is not attributed to the intertemporal changes of the investment risk.

However, the annually data of the security prices or returns have negative autocorrelation. The rises or drops of the share prices are followed by the drops or rises of the share prices, respectively. Many researchers have concluded that this correlation among annual or long-run prices is a correction of the overreaction of the investors to the arrival of new information.

3. TESTING THE EMH

The definition of market efficiency is based on the full reflection of the available information to the stock prices. However, this definition is so general that it is difficult to test it. ***Fama*** describes it with the following phrases:

"*The definitional statement that in an efficient market, price "fully reflect" available information is so general that it has no empirically testable implications. To make the model testable, the process of price formation must be specified in more detail. In essence we must define somewhat more exactly what is meant by the term "fully reflect*"[7].

Depending on the available information, the EMH split up to different forms (see Section 2.4). Due to the fact that it is hard to find evidences for insiders, the empirical tests concern the weak or semi-strong of the EMH. The strong form of the EMH is difficult to be tested. Essentially, the aim of the tests is to check:

- if the share prices respond fast to the arrival of new information (announcements)
- the shifts of predictions of the stock returns should be linked with the changes of their investment risk
- making abnormal profits through trading rules is unfeasible.

3.1 Testing the weak form of EMH

Having defined the weak form of the EMH to rely on the past history of stock prices and thus of data, several methods exist in order to test the weak form of market efficiency. The most important and common empirical tests are presented below.

[7] Cp. Fama (1970), p. 384

Some of the tests which have been formulated in the literature use trading rules based on the past share prices. The idea behind the test is that if the application of the trading rule can earn risk-adjusted profits in excess of the market return. One of the empirical tests is the **filter rule**[8]. This rules involves buying the stock when its price increase at least x% and holding it until the fall of the stock price at least x% in comparison with the previous maximum price and then, selling the stock till the rise of stock prices at least x% compared to the previous minimum price. The value of x implies the expansion or shrinkage of the limits of the transactions. The smaller the value of x is the highest number of transactions is that the rule imposes on. In according to this rule, the market would be inefficient when the drop (rise) of stock prices is followed by the drop (rise) of prices. As a result, this strategy allows investors to make higher earning than the reasonable.

Except for the filter rule, the presence of serial correlation or autocorrelation among stock prices proves the inefficiency of the market. In order to measure the serial correlation is used the **autocorrelation function (ACF)** and **partial autocorrelation function (PACF)**.

Suppose a time series $\{X_t\}$, **the autocorrelation function (ACF)** of a time between time t and s is defined as:

$$\rho(s) = \frac{\gamma(s)}{\gamma(0)} = \frac{E[(X_{t+s} - \mu)(X_t - \mu)]}{E(X_t - \mu)^2} \qquad (10)$$

The definition of **partial autocorrelation function (PACF)** is:

$$\alpha(k) = Corr(X_{t+k} - P(X_{t+k} \mid X_{t+1}, \ldots, X_{t+k-1}), X_t - P(X_t \mid X_{t+1}, \ldots, X_{t+k-1})) \qquad (11)$$

where $P(W \mid Z)$ is the best linear projection of W on Z i.e $P(W \mid Z) = \sum_{wz} \sum_{zz}^{-1} Z$ with Σzz = Var(*Z*) as the covariance matrix of the regressors and Σwz = Cov(*W,Z*) as the matrix of covariances between *W* and *Z*.

[8] Cp. Fama (1970), pp. 394-395.

Variance Ratio (VR) test is also used in order to examine the weak form of EMH. The basic idea is that if a time series is stationary its variance does not increase over time; otherwise, a time series with unit root will have an increasing variance. The intuition of the test is to compare the variance of a subset of the time series in early periods with the variance of a similarly-sized subset of the process in later periods. The **VR test** was formulated by ***Lo*** and ***MacKinlay*** (1988b) and essentially, it tests the existence of RW. The matter of the random walk is the restriction that the series of errors is serially uncorrelated or that innovations are unforecastable from past innovations.

The **VR test** for k periods is defined as 1/k times the ratio of the variance of the k^{th} lag difference of a series to that of the first lag difference such that:

$$VR(k,1) = \frac{Var(r_t^k)/k}{Var(r_t)/1} \qquad (12)$$

where $r_t^k = p_t - p_{t-k}$ and $r_t = p_t - p_{t-1}$.

If we calculate the variance of the series of returns every Δt periods the **VR test** is defined as:

$$VR(k) = \frac{Var(r_t^k \Delta t)/k}{Var(r_t \Delta t)/1}$$

Under the RW, the **VR test** will be equal to 1 since the price series will be uncorrelated and hence, the return variance will be proportional to the return horizon. Therefore, under the null hypothesis which is the *Random Walk Hypothesis*, if the variance of the return series is σ^2 every Δt periods then taking the sample every kΔt periods, the variance would be $k\sigma^2$. If the VR is higher than 1 then we have mean aversion and if the VR is below 1 we have mean reversion due to the negative serial correlation.

Another category tests which are used in empirical papers is the tests that examine the existence of anomalies in financial markets. In according to the definition of the EMH (see Section 2.6), the presence of anomalies in stock markets such as the seasonality in security prices is evidence against the EMH since it causes the making of abnormal profits for the investors. Such anomalies are the **January effects**, **Monday effects**, **Holiday effects**, etc which can be tested and their existences will imply the market inefficiency.

3.2 Testing the semi-strong form of the EMH

The semi-strong form of EMH which its definition is presented in previous chapter requires the available information that is full reflected in the share prices to consist of all public information. All public information concerns, not only the past history of stock prices, but, the fundamental variables of the companies and total economy too. Several empirical tests have been formulated for the semi-strong form of the EMH and some of them will be presented below.

The **Event Analysis** or **Event Studies** are the most common employed tests for the semi-strong analysis. The **Event Study** is designed to examine the reactions of market and the returns around announcements regarding certain stocks. These announcements are related to new information about the specific firm such as earnings and dividends or macroeconomic variables. The concept of the **Event Study** is that the share of the firm will be affected by the information events and exhibit excess returns.

The intuition is to identify the event/announcement and the date on which the announcement was published. Determining the event, we can collect the returns around the dates of the announcement. The analysis could concern weekly, daily or short interval returns around the event. Furthermore, depending on the sample, the periods before and after the announcement should be chosen. This is called *Event Window*.

The excess return on any given day is given by subtracting the market return from the stock's actual return. The market return maybe a portfolio index or an expected return derived from an asset pricing model like the CAPM.

Therefore:

$$ER_{it} = r_{it} - r_{tM}$$

Or:

$$ER_{it} = r_{it} - [r_{if} + \beta \cdot (r_{tM} - r_{if})]$$

The Average excess return across all firms on day t:

$$MER_{t} = \frac{1}{N}\sum_{i=1}^{N} ER_{it}$$

By calculating the abnormal stock returns for the days leading up to and following the announcements, it is displayed the speed of adjustment of the stock returns. As a result, we set the question whether the excess returns around the event are equal to zero or not. Estimating the t-statistic and observing the statistical significance, we end up if the event affects the stock returns. In the case of the excess returns, at dates other than t, are statistically significant then the market react inefficiency to new information.

The most popular study in this analysis is ***Fama's***, ***Fisher's***, ***Jensen's*** and ***Roll's*** study (1969).

3.3 Testing the strong form of the EMH

The strong form of the EMH implies that the security prices fully reflect all the owned public and private information by investors. The strong form of the EMH is difficult to be tested since the inside information can not be recognised. However, few tests have been formulated. These tests are similar to the tests of **Event Analysis** in the sense that when an event is announced the reactions of prices can be examined. The difference lies in the kind of announcement since it has to concern information that insiders could acquire like dividend policy, rise of the equity fund etc.

The tests, called **Mutual Fund Performance**, compare the returns of various mutual funds which are diversified by equities, bonds and other securities with the returns of randomly constructed portfolios of stock market index. In other words, it denotes whether the money managers earn higher returns investing in mutual fund than a passive investing in a portfolio with random share indices. Under the null hypothesis of the test, it is considered that there is no difference between random portfolios and mutual fund schemes. Note that the application of the test presupposes the building of random portfolios. Due to the hypothesis that the prices fully reflect all available information, each share is evaluated truthfully.

4. LONDON STOCK EXCHANGE

Chapter 4 represents some important information about London Stock Exchange where its indices are used for the experimental part of this thesis.

4.1 Introduction

The London Stock Exchange is a stock exchange located in London, in the United Kingdom. It is the fourth larger stock exchange in the world after the Tokyo Stock Exchange and the largest stock exchange in Europe. In December 2012, it had a market capitalization of USD 3,396 billions[9].

It is considered that the London Stock Exchange is one of the most international stock exchanges since around 3,000 companies from over 70 countries are admitted to trade on its market. The largest, most successful and dynamic companies have quoted stocks in the Exchange. Over 400 firms, mainly banks and stockbrokers are members.

The London Stock Exchange is one of the oldest stock exchanges and its history started 300 years ago in the coffee houses of the 17th century in London. It was quickly developed in a strong and well-regulated stock market. Today, it is among the most important financial institutions in the world.

[9] http://www.londonstockexchange.com

4.2 Short History[10]

The first centre of commerce in London, which was founded in 1565 by Thomas Gresham, being inspired by a bourse in Antwerp, was the *Royal Exchange*. Being officially opened by Queen Elizabeth I in 1571, she assigned the royal title and license for the selling of alcohol. However, during 17th century, the stockbrokers were not allowed in the Royal Exchange due to their rudeness and so they started to operate in the streets' coffee houses. An example was the *Jonathan's coffee house* in *Change Alley* in which John Casting, the broker, listed the prices a few commodities, exchange rates and some supplies such as salt, paper and coal in 1698. The list was published only a few days a week, not daily. *The Royal exchange* was destroyed in the Great Fire of London in 1666. In 1669, a second exchange opened which was designed by Edward Jarman but was also destroyed by fire on 10 January 1838. This was a step towards the model of the modern stock exchanges since the *Royal Exchange* was home to merchants and merchandisers besides brokers. As a result, a regulated stock market was born and there were penalties by the Parliament to the brokers who trade without having a license. Furthermore, it sets a fixed number of brokers. However, these regulations created several problems in *Royal Exchange*. One of them was that many brokers leaved the *Royal Exchange* either by theirs own choice or through expulsion and started dealing in London street. The street was known as *Change* or *Exchange Alley* which was near the Bank of England and Parliament tried also to regulate this and prohibit the unofficial dealing in the streets.

In 1720, one of the worst financial bubbles and known as *South Sea Bubble popped* and the stock market crashes. A fire destroyed most of the coffee houses in 1748. Although a lot of them were rebuilt. After *Seven Years' War* (1756–1763), the trade at *Jonathan's coffee house* boomed again and a group of 150 brokers formed a club. In 1773, they constructed their own building in *Sweeting's Alley*, known as *New Jonathan's*. However, they soon change the name to *Stock Exchange*. An entrance fee was set to the traders in order to enter the stock room and trade shares. Fraud proposed setting an increased fee to some dealers, so some trades to be prevented. But the final solution was given by forming the annual fees and transforming the *Exchange* into a *Stock Subscription room*.

[10] http://en.wikipedia.org/wiki/London_Stock_Exchange

In 1801, the first regulated exchange in London, the *Subscription room,* was created. The modern stock exchange was born under a formal membership subscription basis. After a year, the *Exchange* moved into a new and bigger building in *Capel Court*. In 1812, the General Purpose Committee endorsed a set of recommendations. These recommendations became the foundation of the first codified rule book of the *Exchange*. In Manchester and Liverpool, the first regional exchanges were opened in 1836. In 1845, the price of railway shares increased more and more and the earnings were spilled by speculators. As a result, the collapse was fatal. The *Railway Mania* was an instance of speculative frenzy in United Kingdom. In 1853, the *Exchange* was overcrowded by members and brokers. Thus, the new establishment was the only solution. After a year, the *new Stock Exchange* building was built by the main architect, Thomas Allason. In 1876, a new *Deed of Settlement* for the Stock Exchange comes into force.

In 1914, the *First World War* affected the *Stock Exchange*. The prices increased due to the fact they were afraid that the borrowed money and their loans would be called back. For this reason, the Committee and Parliament decided to prohibit the operation of the banks and close from the end of July until the New Year and so the street business was introduced again, as well as on the *"challenge system"*. On 4 January 1915, the *Exchange* opened under the limitation that the transactions would be in cash only. The restrictions and the challenges were the cause that a thousand members quit the *Exchange* between 1914 and 1918. After the end of the war, the mood for the trade was daunted. In 1923 the *Exchange* received its own [Coat of Arms](), with the Motto *"Dictum Meum Pactum"*, *"My Word is My Bond".* Having the experience from the *First World War*, the authorities of the *Stock Exchange* had planned how to handle a new war situation. In 1939, the *Second World War* started and the *Exchange* was closed for 6 days. On the 7^{th} of September, the doors reopened. The floor of the *House* closes for only one more day, in 1945 due to damage from a V2 rocket, after that the trading continued in the basement. After these tumultuous times, there were some booming years for the businesses and stock market in the late 1950s. As a result, the officials should find a new more suitable space to accommodate them. The works started in 1967 and Queen Elizabeth II opened the new 26-storey office block with 23,000 sq ft trading floor in 1972. After a year, changes marked the *Stock Exchange*; both female and foreign-born members were admitted to the market on the floor and eleven (11) British and Irish regional exchange merged with the *London Exchange*. In February 1984, the

Financial Times and the *Stock Exchange* launched the **FTSE 100 Index** (see Chapter 6). Two years later, the financial markets in the UK were deregulated suddenly. It is known as *Big Bang* in order to describe the undertaken measures. Some of these were the following:

- All firms became brokers with dual capacity
- Member firms could be owned by an outside corporation
- Minimum scales of commission were negated
- Individual members had no longer rights to vote
- Trade conducted through computer and telephone from separate dealing rooms
- Stock Exchange transformed into a private limited company under the Companies Act 1985.

Furthermore, the governing Council of the Exchange was substituted by a Board of Directors, drawn from the Exchange's executive, customer and user base. The trading name changed to "*The London Stock Exchange*" in 1991 and it remains until today. After four years, they launched the *international market* (AIM) for growing companies; two years later, the *Stock Exchange Electronic Trading Service* (SETS) were launched for greater speed and efficiency to the market and the CREST settlement service was also launched.

In the second millennium, the *London Stock Exchange* were voted to become a public limited company; *London Stock Exchange plc*. A year later, they list their own *Main Market* and celebrated the 200th anniversary. In 2003, a new international equity derivatives business, *EDX London*, was created, in partnership with OM Group. The Exchange also acquired *Proquote Limited*, a new generation supplier of real-time market data and trading systems. Finally, in 2007, *London Stock Exchange* merged with Borsa Italiana, and creating *London Stock Exchange Group*.

4.3 Activities

The activities of the London Stock Exchange are divided into five categories and are represented below:

Primary Markets

The London Stock Exchange allows UK and international companies to join the London equity market in order to gain access to capital and as a result to raise money, increase their share capital and obtain a market valuation through *Initial Public Offering* (IPO) process. Furthermore, it gives the opportunity in different sized companies to quote since it runs several markets. Companies from around to the world can list a number of products plus shares, depositary receipts and debt in order to raise their capital. For instance, the London Stock Exchange opened a Honk Kong Office and attracted more than 200 companies originated from the Asia-Pacific region in 2004.

For the largest companies exists the *Premium Listed Main Market*. The *Alternative Investment Market* (AIM) operates for the smaller firms of the London Stock Exchange. For international companies which fall outside of the Europe Union, it runs the *Depository Receipt* (DR) in order to list and raise their capital. In addition, exists a market that facilitates the raising of capital through the dept securities or depositary receipts to professional investors and it is called *Professional Securities Market*. For more sophisticated fund vehicles, governance models and security, the *Specialist Fund Market* is designed. It is only for institutional, professional and experienced investors.

Secondary Markets

The London Stock Exchange has two main markets for the trade on; *Main Market* and *Alternative Investment Market*. The largest, most-well regulated and known companies from around the world are listed in this first market. Over 1,300 companies from 60 different countries enjoy the privileges the London Stock Exchange offers. The past 10 years over £366 billion has been raised by *Main Market* companies. The FTSE 100 Index is the main share index of the 100 most highly capitalised UK companies listed on the *Main Market* (see Chapter 6). The second referred market is for smaller growing companies. A lot of businesses are trying to join this market asking access to growth capital. However, there are several electronic markets that trade different products.

Trading

In order to maximise the liquidity of stocks the London Stock Exchange offers the trading services such as the *International Book Offer* (IBO), the *European Quoting Service* and a *pan-European trade reporting service*.

Information services[11]

Every second of trading day the London Stock Exchange provides information ranging the data from individual trades and stock price shifts to company announcements.

Derivatives

EDX London was created to bring the cash equity and derivatives markets closer together. As a result, it expands the equity derivatives trading while it decreased the risk and cost.

[11] http://www.londonstockexchange.com/about-the-exchange/company-overview/company-overview.htm

5. METHODOLOGY

In a previous chapter, I described several methods in order to test the EMH depending on the form of the EMH. In this part, I am going to analyze the methodology which I follow in order to test the EMH and the results of the testing will be presented in next chapter.

STEP 1

I found the data which are presented analytically in the next chapter in order to use them for the tests below. My interesting based on the London Stock Exchange (see Chapter 4) and especially, the **FTSE 100 Index** since there is no doubt it is the most important index in Europe, represents the 80% of the UK share market and is seen as a measure of success of the UK economy.

STEP 2

In accordance with the theory of the EMH that has been presented in the Chapter 2, the EMH can be explained by the RW with drift. The RW is the best known example of unit-root non-stationary time series. The price series is a non-stationary series since there is no fixed level for the price and so, they are not predictable. By empirical evidences, it has been observed that the log return series of a market index tends to have a small and positive mean. This is the reason why the RW with drift is used. Thus, this implies the following model for the log prices:

$$p_{t+1} \approx m + p_t + \varepsilon_{t+1}$$

where $E(p_{t+1} - p_t \mid I_t) = m$. It is called drift and is very important for the finance. The drift represents the time trend of the p_t. The ε_{t+1} is a white noise series.

In order to test if the log prices follow a RW with drift we use unit-root tests. As a result, the 2nd step of my study is to test if my data which I chose has a unit root and thus, they follow a RW with drift. The most common unit-root tests are the *Dickey-Fuller* test, the *Augmented Dickey-Fuller* test and the *Phillips-Perron* test.

Therefore, we suppose that:

$$p_t \approx m + \rho p_{t-1} + \varepsilon_t$$

where ε_t denotes the error term.

Consider the null hypothesis H_o: $\rho=1$ and the alternative hypothesis H_a: $\rho<1$

$$\text{DF} \equiv \text{t-ratio}=\frac{\hat{\rho}\text{-1}}{\text{std}\left(\hat{\rho}\right)}=\frac{\sum_{t}^{T} p_{t-1}\varepsilon_t}{\sigma_\varepsilon \sqrt{\sum_{t}^{T} p_{t-1}^2}}$$

However, for larger and more complicated time series like this studied price series, it is used an augmented version of the *Dickey-Fuller* test (DF); the *Augmented Dickey-Fuller* test (ADF). The *Augmented Dickey-Fuller* static was presented by statistician *David Alan Dickey* and *Wayne Arthur Fuller* in 1979 and 1981. It is a negative number and the more negative it is, the stronger the rejection of the null hypothesis that there is unit root at some confidence level.

We use a AR(p) process and perform the test H_o: $\varphi=0$ versus H_a: $\varphi<0$ using the regression:

$$\Delta x_t = m + \beta t + \varphi x_{t-1} + \delta_1 \Delta x_{t-1} + ... + \delta_{p-1} \Delta x_{t-p+1} + \varepsilon_t$$

where *m* is the drift, β the coefficient on a time trend and *p* the lag order of the autoregressive process. Imposing the constraint $\beta=0$ corresponds to a RW with a drift. The ADF test allows higher-order autoregressive process. As a result, we use *p* differences for the stationarity. The lag length has to be determined when applying the test. The *Akaike Information Criterion* (AIC) and the *Schwarz Criterion* (SIC) are used for the selection of the lag p.

Thus, the unit root test is defined as:

$$\text{ADF} \equiv = \frac{\hat{\varphi}}{SE(\hat{\varphi})} \tag{13}$$

Computing the ADF test statistic and comparing it with the critical value for the *Dickey-Fuller test*, we can reject or not the null hypothesis. If the test statistic is less than critical value then the null hypothesis is rejected at the specific level of confidence and there is no unit root.

The intuition behind the ADF test is that relies on a parametric transformation of the model in order to eliminate the serial correlation in the error term introducing lags Δx_t as regressors in the test equation. Therefore, when the series have been integrated the lagged level of the series x_{t-1} will not contain relative information so as to be predicted the change in x_t series. In this case, the null hypothesis could not be rejected.

To test the unit root of a time series it is also used the *Phillips-Peron* test (PP) which was made up by *Peter C. B. Phillips* and *Pierre Perron*. This idea behind the test is the same idea as ADF test i.e. a time series may have a higher order autocorrelation than it is accepted whether taking a lagged level (making x_{t-1} endogenous) in the test equation. Therefore the DF test will not be valid.

In contrast to the ADF test, the PP test makes a non-parametric correction of the t-test statistic in order to eliminate the serial correlation without affecting the asymptotic distribution. It is robust with respect to unspecified autocorrelation and heteroskedasticity. Under the null hypothesis of the PP test, the time series has order of integration 1 i.e. the transformed statistics have DF distributions.

Thus:

$$\Delta x_t = \delta \Delta x_{t-1} + e_t \tag{14}$$

Under the null hypothesis, $\delta = 0$.

<u>STEP 3</u>

Besides the ADF and PP test, I will examine the existence of the RW running the VR test (see Chapter 3.1). The intuition of the test is to examine the existence of unit root comparing the variances among time intervals. In according to the definition of the VR test, if the time series is not correlated the variance of the returns will be proportional to the time intervals. It means that whether the variance of the return series is σ^2 every Δt periods then taking the sample every kΔt periods, the variance would be $k\sigma^2$. The VR test is defined as:

$$VR(k,1) = \frac{Var(r_t^k)/k}{Var(r_t)/1}$$

Suppose that H_o: $VR=1$ versus H_a: $VR \neq 1$

<u>STEP 4</u>

Moreover, evidence against the EMH is the existence of the serial correlation of the time series. In order to examine the autocorrelation, I will perform ACF and PACF test. These tests give us a sense how correlated the time series is.

The autocorrelation function (ACF) of a time between time t and s is defined as:

$$\rho(s) = \frac{\gamma(s)}{\gamma(0)} = \frac{E[(X_{t+s} - \mu)(X_t - \mu)]}{E(X_t - \mu)^2}$$

The definition of partial autocorrelation function (PACF) is:

$$\alpha(k) = Corr(X_{t+k} - P(X_{t+k} \mid X_{t+1}, \ldots, X_{t+k-1}), X_t - P(X_t \mid X_{t+1}, \ldots, X_{t+k-1}))$$

where $P(W \mid Z)$ is the best linear projection of W on Z i.e $P(W \mid Z) = \sum_{wz} \sum_{zz}^{-1} Z$ with Σ*zz* = Var(*Z*) as the covariance matrix of the regressors and Σ*wz* = Cov(*W*,*Z*) as the matrix of covariances between *W* and *Z*.

STEP 5

The main assumption of the statistical tests is the independency of the sample i.e. the sample is random. In this step, I will check if this assumption is violated using the *Runs Test* which examines whether the order of the values is random. The *Runs Test* is a non-parametric statistical procedure and the notion behind of it is that it sorts each value of the variable as falling above or below a measure of the central tendency (mean, median, mode). After, it checks consecutive observations of the sample to confirm the randomness of the data.

A run is called a sequence of observations which are repeated and have the same value. A sample with too many or too few runs proves its non-randomness. Under the null hypothesis, the number of runs is a random variable which is normally distributed with following mean:

$$. \ \mu = \frac{2\, n_A n_B + n}{n} \tag{15}$$

and following variance:

$$\sigma^2 = \frac{2\, n_A n_B - (2\, n_A n_B - n)}{n^2 (n-1)} \tag{16}$$

where n is the total number of the observations, n_A is the number of first run cycle and n_B is the number of the second run cycle. The number of runs is marked as R. The test compares the actual number of runs with expected number of runs μ. Hence, the null hypothesis is μ=E(runs).

The z-score is :

$$z = \frac{R - \mu}{std(R)}$$

<u>STEP 6</u>

The purpose of this step is to check the existence of evidences against the EMH. Such evidences are presented analytically in the Section 2.6. I am going to examine the existence of the January Effect in my data which is the more often observed calendar effect. The occurrence of January Effect implies the increase of stock prices or returns in the month January. Hence, the investors prefer buying stocks before January and sell them the January so as to benefit the rise of the stock prices and make earnings. Therefore, the main characteristic of the January Effect is the closing of prices in higher values in January than the values in December. Using the data set, I will check if this shift exists. Nevertheless, as being referred to the Section 2.6, the existence of these evidences does not mean necessarily the market inefficiency.

6. DATA DESCRIPTION

The aim of the empirical part of this dissertation is to check the validity of the EMH using the tests which were described in the previous chapter. The used data for the tests concern the FTSE 100 Index of the London Stock Exchange and are given on a daily level of the adjusted close prices. The period of the observation is from the 2nd April 2003 to the 26th April 2013 and the sample consists of 2543 observations. The collection of data was obtained from the site www.yahoofinance.com.

The graph below shows the movement of the adjusted close prices of the FTSE 100 Index for 10 years.

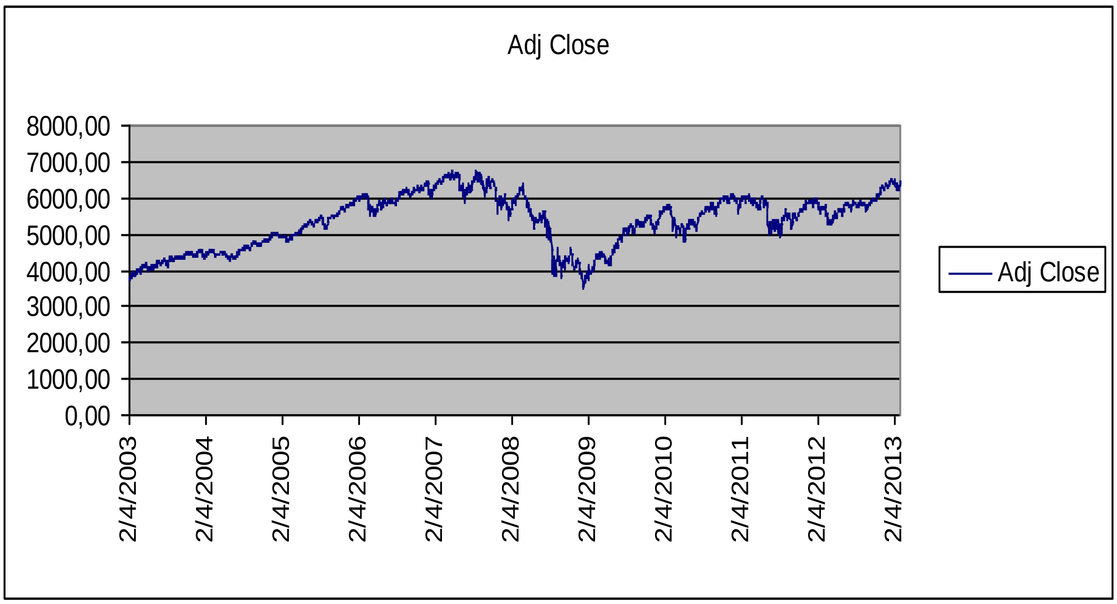


Figure 2: FTSE 100 Index Movements

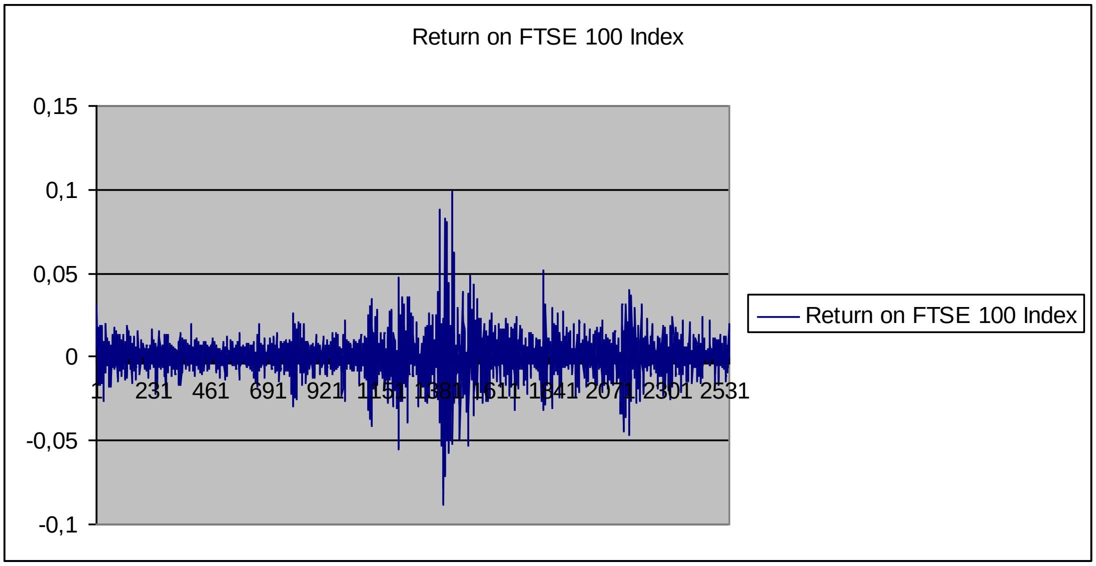


Figure 3: Return on FTSE 100 Index

The graph above depicts the returns of the FTSE 100 Index for 10 years.

The index which is used for the conduct of this study is called FTSE 100 Index or FTSE 100 or FTSE[12] and came from the initials *Financial Times* and *London Stock Exchange*. It is known as a leading stock index in Europe and made up of the 100 highly performance companies (companies with highest market capitalization). The FTSE 100 Index is seen as an indicator of the strength of the UK economy.

The constituents of the FTSE 100 Index began on 3 January 1984. The highest value reached to date is 6950.6, on 30 December 1999. According to the used sample for this study, the highest value was 6732.4 on 15th June 2007 and the lowest value was observed during the financial crisis of 2007-2010 and was 3512,1 on 3rd March 2009. However, after the falling of the index, it recovered to 6426.4 on 26th April 2013 which is the last observation of this sample.

[12] http://en.wikipedia.org/wiki/FTSE_100_Index

The FTSE Group maintains the FTSE 100 Index that represents about 80% of the entire market capitalisation of the London Stock Exchange. The FTSE Group is a subsidiary of the London Stock Exchange and acts independently. Its origin is a joint venture between the Financial Times and the London Stock Exchange. Other indices of the FTSE Group are the FTSE 250 Index which contains the next largest 250 firms after the FTSE 100, the FTSE 350 Index which is the aggregation of the FTSE 100 and 250, FTSE SmallCap Index, the FTSE Fledgling Index and finally, the FTSE All-Share that aggregates the FTSE 100, FTSE 250 and FTSE SmallCap.

The FTSE Indices are calculated as:

$$\text{Index level} = \frac{\sum_i \left(\text{Price of stock}_i \times \text{Number of shares}_i\right) \times \text{Free float adjustment factor}_i}{\text{Index divisor}}$$

where "*Free float adjustment factor"* is representing the percentage of all issued shares that are readily available for trading. Then, the factor is rounded up to the nearest multiple of 5%. Thus, the free float capitalization is computed as market cap (number of shares x share price) multiplied by its free-float factor. http://en.wikipedia.org/wiki/FTSE_100_Index

7. RESULTS

In this chapter, the most important results of my empirical work and a short analysis of them will be presented. The outcomes derived following all steps that I referred to the methodology. For the application of tests the program EVIEWS and SPSS were used. Note that the step 1 has been presented in the Chapter 6.

STEP 2

After applying the ADF test with Akeik Information Criterion (AIC) for the choice of the lags to the levels of the logarithmic adjusted close prices of the FTSE100 stock index, I had the following results:

Null Hypothesis: LOG_ADJ_CLOSE_ has a unit root
Exogenous: Constant
Lag Length: 6 (Automatic - based on AIC, maxlag=26)

		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-2.250836	0.1885
Test critical values:	1% level	-3.432735	
	5% level	-2.862480	
	10% level	-2.567315	

*MacKinnon (1996) one-sided p-values.

Augmented Dickey-Fuller Test Equation
Dependent Variable: D(LOG_ADJ_CLOSE_)
Method: Least Squares
Date: 05/24/13 Time: 14:09
Sample (adjusted): 4/11/2003 4/26/2013
Included observations: 2536 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LOG_ADJ_CLOSE_(-1)	-0.003764	0.001672	-2.250836	0.0245
D(LOG_ADJ_CLOSE_(-1))	-0.055737	0.019859	-2.806701	0.0050
D(LOG_ADJ_CLOSE_(-2))	-0.051281	0.019853	-2.583021	0.0098
D(LOG_ADJ_CLOSE_(-3))	-0.071947	0.019835	-3.627206	0.0003
D(LOG_ADJ_CLOSE_(-4))	0.065025	0.019815	3.281568	0.0010
D(LOG_ADJ_CLOSE_(-5))	-0.058456	0.019823	-2.948836	0.0032
D(LOG_ADJ_CLOSE_(-6))	-0.043805	0.019824	-2.209635	0.0272
C	0.014128	0.006229	2.268070	0.0234

R-squared	0.023072	Mean dependent var	8.98E-05
Adjusted R-squared	0.020367	S.D. dependent var	0.005274
S.E. of regression	0.005220	Akaike info criterion	-7.669623
Sum squared resid	0.068875	Schwarz criterion	-7.651206
Log likelihood	9733.082	Hannan-Quinn criter.	-7.662942
F-statistic	8.529169	Durbin-Watson stat	1.998470
Prob(F-statistic)	0.000000		

Looking carefully the table of results, we observe that the critical values at 1%, 5%, 10% confidence level are less than ADF t-statistic. Thus, the null hypothesis can not be rejected at these levels of confidence and so, the process has a unit root. The number of lags in according to the Akeik Information Criterion (AIC) in order to be eliminated the autocorrelation is 6 and their coefficients are statistically significant.

After applying the ADF test with the Schwarz Criterion (SIC) for the model selection to the lags to the levels of the logarithmic adjusted close prices of the FTSE100 stock index, the results are the following:

Null Hypothesis: LOG_ADJ_CLOSE_ has a unit root
Exogenous: Constant
Lag Length: 5 (Automatic - based on SIC, maxlag=26)

		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-2.244014	0.1908
Test critical values:	1% level	-3.432734	
	5% level	-2.862479	
	10% level	-2.567315	

*MacKinnon (1996) one-sided p-values.

Augmented Dickey-Fuller Test Equation
Dependent Variable: D(LOG_ADJ_CLOSE_)
Method: Least Squares
Date: 05/24/13 Time: 12:50
Sample (adjusted): 4/10/2003 4/26/2013
Included observations: 2537 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LOG_ADJ_CLOSE_(-1)	-0.003751	0.001671	-2.244014	0.0249
D(LOG_ADJ_CLOSE_(-1))	-0.053173	0.019843	-2.679693	0.0074
D(LOG_ADJ_CLOSE_(-2))	-0.053551	0.019824	-2.701246	0.0070
D(LOG_ADJ_CLOSE_(-3))	-0.070126	0.019774	-3.546361	0.0004
D(LOG_ADJ_CLOSE_(-4))	0.066939	0.019797	3.381258	0.0007
D(LOG_ADJ_CLOSE_(-5))	-0.056287	0.019810	-2.841431	0.0045
C	0.014073	0.006227	2.260134	0.0239

R-squared	0.021122	Mean dependent var	8.72E-05
Adjusted R-squared	0.018801	S.D. dependent var	0.005274
S.E. of regression	0.005224	Akaike info criterion	-7.668183
Sum squared resid	0.069056	Schwarz criterion	-7.652073
Log likelihood	9734.090	Hannan-Quinn criter.	-7.662338
F-statistic	9.098654	Durbin-Watson stat	2.004463
Prob(F-statistic)	0.000000		

Observing the results, the t-statistic value of the ADF test is larger than the critical value at all confidence levels. As a result, there is a unit root since the null hypothesis can not be rejected at all confidence levels. Using the Schwarz Criterion (SIC), the number of lags for the elimination of the serial correlation is 5 and their coefficients have statistical significance.

The results below came out applying the ADF test to the first differences of the logarithmic adjusted close prices of the FTSE 100 Index with AIC and SIC, respectively.

Null Hypothesis: D(LOG_ADJ_CLOSE_) has a unit root
Exogenous: Constant
Lag Length: 26 (Automatic - based on AIC, maxlag=26)

		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-9.971096	0.0000
Test critical values:	1% level	-3.432756	
	5% level	-2.862489	
	10% level	-2.567320	

*MacKinnon (1996) one-sided p-values.
Augmented Dickey-Fuller Test Equation
Dependent Variable: D(LOG_ADJ_CLOSE_,2)
Method: Least Squares
Date: 05/24/13 Time: 12:52
Sample (adjusted): 5/15/2003 4/26/2013
Included observations: 2515 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
D(LOG_ADJ_CLOSE_(-1))	-1.246024	0.124964	-9.971096	0.0000
D(LOG_ADJ_CLOSE_(-1),2)	0.193470	0.122691	1.576887	0.1149
D(LOG_ADJ_CLOSE_(-2),2)	0.150294	0.120034	1.252097	0.2107
D(LOG_ADJ_CLOSE_(-3),2)	0.079419	0.117205	0.677611	0.4981
D(LOG_ADJ_CLOSE_(-4),2)	0.138170	0.114410	1.207670	0.2273
D(LOG_ADJ_CLOSE_(-5),2)	0.077784	0.111638	0.696747	0.4860
D(LOG_ADJ_CLOSE_(-6),2)	0.032969	0.108799	0.303030	0.7619
D(LOG_ADJ_CLOSE_(-7),2)	0.058844	0.105727	0.556568	0.5779
D(LOG_ADJ_CLOSE_(-8),2)	0.081395	0.102664	0.792831	0.4280
D(LOG_ADJ_CLOSE_(-9),2)	0.048014	0.099495	0.482580	0.6294
D(LOG_ADJ_CLOSE_(-10),2)	0.069116	0.096427	0.716763	0.4736
D(LOG_ADJ_CLOSE_(-11),2)	0.055214	0.093283	0.591892	0.5540
D(LOG_ADJ_CLOSE_(-12),2)	0.052398	0.089876	0.583007	0.5599
D(LOG_ADJ_CLOSE_(-13),2)	0.038946	0.086454	0.450483	0.6524
D(LOG_ADJ_CLOSE_(-14),2)	0.015913	0.083018	0.191687	0.8480
D(LOG_ADJ_CLOSE_(-15),2)	-0.003841	0.079496	-0.048319	0.9615
D(LOG_ADJ_CLOSE_(-16),2)	0.027392	0.075823	0.361258	0.7179
D(LOG_ADJ_CLOSE_(-17),2)	0.021481	0.072066	0.298069	0.7657
D(LOG_ADJ_CLOSE_(-18),2)	-0.021442	0.067944	-0.315582	0.7523
D(LOG_ADJ_CLOSE_(-19),2)	-0.020400	0.063811	-0.319702	0.7492
D(LOG_ADJ_CLOSE_(-20),2)	-0.036988	0.059209	-0.624692	0.5322
D(LOG_ADJ_CLOSE_(-21),2)	-0.004487	0.054014	-0.083075	0.9338
D(LOG_ADJ_CLOSE_(-22),2)	-0.010793	0.048697	-0.221637	0.8246
D(LOG_ADJ_CLOSE_(-23),2)	-0.029108	0.043335	-0.671698	0.5018
D(LOG_ADJ_CLOSE_(-24),2)	-0.056336	0.036409	-1.547336	0.1219
D(LOG_ADJ_CLOSE_(-25),2)	-0.035720	0.029027	-1.230569	0.2186
D(LOG_ADJ_CLOSE_(-26),2)	0.038256	0.019970	1.915645	0.0555
C	0.000103	0.000104	0.982345	0.3260

R-squared	0.544178	Mean dependent var	6.44E-07
Adjusted R-squared	0.539229	S.D. dependent var	0.007670
S.E. of regression	0.005207	Akaike info criterion	-7.666703
Sum squared resid	0.067420	Schwarz criterion	-7.601797
Log likelihood	9668.880	Hannan-Quinn criter.	-7.643146
F-statistic	109.9657	Durbin-Watson stat	1.998697
Prob(F-statistic)	0.000000		

Null Hypothesis: D(LOG_ADJ_CLOSE_) has a unit root
Exogenous: Constant
Lag Length: 4 (Automatic - based on SIC, maxlag=26)

		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-24.23588	0.0000
Test critical values:	1% level	-3.432734	
	5% level	-2.862479	
	10% level	-2.567315	

*MacKinnon (1996) one-sided p-values.

Augmented Dickey-Fuller Test Equation
Dependent Variable: D(LOG_ADJ_CLOSE_,2)
Method: Least Squares
Date: 05/24/13 Time: 12:52
Sample (adjusted): 4/10/2003 4/26/2013
Included observations: 2537 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
D(LOG_ADJ_CLOSE_(-1))	-1.173354	0.048414	-24.23588	0.0000
D(LOG_ADJ_CLOSE_(-1),2)	0.118473	0.043172	2.744194	0.0061
D(LOG_ADJ_CLOSE_(-2),2)	0.063209	0.036280	1.742286	0.0816
D(LOG_ADJ_CLOSE_(-3),2)	-0.008331	0.028837	-0.288890	0.7727
D(LOG_ADJ_CLOSE_(-4),2)	0.057473	0.019818	2.900026	0.0038
C	0.000102	0.000104	0.984806	0.3248

R-squared	0.536169	Mean dependent var	-1.03E-07
Adjusted R-squared	0.535253	S.D. dependent var	0.007670
S.E. of regression	0.005229	Akaike info criterion	-7.666983
Sum squared resid	0.069193	Schwarz criterion	-7.653174
Log likelihood	9731.567	Hannan-Quinn criter.	-7.661973
F-statistic	585.1458	Durbin-Watson stat	2.004667
Prob(F-statistic)	0.000000		

Observing these tables, the null hypothesis is rejected. Therefore, the model has a unit root and follows a Random Walk. If the null hypothesis was not rejected then the model would be integrated of order 2 and not be a Random Walk.

The table below shows the results applying the ADF test and considering that the model has a trend. By observing the results, we can conclude that the time series has not a trend since its coefficient is not statistically significance (Prob > a, the null hypothesis cannot be rejected).

Null Hypothesis: LOG_ADJ_CLOSE_ has a unit root
Exogenous: Constant, Linear Trend
Lag Length: 5 (Automatic - based on SIC, maxlag=26)

		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-2.297200	0.4348
Test critical values:	1% level	-3.961661	
	5% level	-3.411579	
	10% level	-3.127657	

*MacKinnon (1996) one-sided p-values.

Augmented Dickey-Fuller Test Equation
Dependent Variable: D(LOG_ADJ_CLOSE_)
Method: Least Squares
Date: 05/24/13 Time: 12:54
Sample (adjusted): 4/10/2003 4/26/2013
Included observations: 2537 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LOG_ADJ_CLOSE_(-1)	-0.004298	0.001871	-2.297200	0.0217
D(LOG_ADJ_CLOSE_(-1))	-0.052812	0.019853	-2.660174	0.0079
D(LOG_ADJ_CLOSE_(-2))	-0.053181	0.019835	-2.681201	0.0074
D(LOG_ADJ_CLOSE_(-3))	-0.069776	0.019784	-3.526963	0.0004
D(LOG_ADJ_CLOSE_(-4))	0.067274	0.019806	3.396645	0.0007
D(LOG_ADJ_CLOSE_(-5))	-0.055957	0.019818	-2.823508	0.0048
C	0.015981	0.006882	2.322197	0.0203
@TREND(4/02/2003)	1.03E-07	1.59E-07	0.651369	0.5149

R-squared	0.021286	Mean dependent var	8.72E-05
Adjusted R-squared	0.018577	S.D. dependent var	0.005274
S.E. of regression	0.005225	Akaike info criterion	-7.667562
Sum squared resid	0.069044	Schwarz criterion	-7.649151
Log likelihood	9734.302	Hannan-Quinn criter.	-7.660883
F-statistic	7.857683	Durbin-Watson stat	2.004396
Prob(F-statistic)	0.000000		

In the following table, the results of the PP test are presented. The PP test is applied to the level of the logarithmic adjusted close prices of the FTSE 100 Index. I have supposed only intercept. I have chosen the spectral estimation method to be Bartlet Kernel and the bandwith to be the Newey-West.

Null Hypothesis: LOG_ADJ_CLOSE_ has a unit root
Exogenous: Constant
Bandwidth: 4 (Newey-West automatic) using Bartlett kernel

		Adj. t-Stat	Prob.*
Phillips-Perron test statistic		-2.467697	0.1236
Test critical values:	1% level	-3.432729	
	5% level	-2.862477	
	10% level	-2.567314	

*MacKinnon (1996) one-sided p-values.

Residual variance (no correction)	2.78E-05
HAC corrected variance (Bartlett kernel)	2.32E-05

Phillips-Perron Test Equation
Dependent Variable: D(LOG_ADJ_CLOSE_)
Method: Least Squares
Date: 05/24/13 Time: 12:57
Sample (adjusted): 4/03/2003 4/26/2013
Included observations: 2542 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LOG_ADJ_CLOSE_(-1)	-0.004362	0.001675	-2.604621	0.0093
C	0.016338	0.006238	2.618983	0.0089

R-squared	0.002664	Mean dependent var	9.19E-05
Adjusted R-squared	0.002271	S.D. dependent var	0.005279
S.E. of regression	0.005273	Akaike info criterion	-7.651623
Sum squared resid	0.070625	Schwarz criterion	-7.647028
Log likelihood	9727.213	Hannan-Quinn criter.	-7.649956
F-statistic	6.784053	Durbin-Watson stat	2.111096
Prob(F-statistic)	0.009251		

The PP statistic is around -2.47. The critical value at 1% level is -3.43. Hence, the H_o is not rejected at 1% level. As a result, there is unit root. At 5% level, the critical value is -2.86. The PP statistic is higher than the critical value, thus, the time series follows Random Walk at level confidence 5%. With 10% probability to be wrong, there is unit root in our sample.

Running the PP test with the same options as above, but imposing trend and intercept in the regression, we take the following outcomes:

Null Hypothesis: LOG_ADJ_CLOSE_ has a unit root
Exogenous: Constant, Linear Trend
Bandwidth: 3 (Newey-West automatic) using Bartlett kernel

		Adj. t-Stat	Prob.*
Phillips-Perron test statistic		-2.526517	0.3151
Test critical values:	1% level	-3.961654	
	5% level	-3.411575	
	10% level	-3.127655	

*MacKinnon (1996) one-sided p-values.

Residual variance (no correction)	2.78E-05
HAC corrected variance (Bartlett kernel)	2.33E-05

Phillips-Perron Test Equation
Dependent Variable: D(LOG_ADJ_CLOSE_)
Method: Least Squares
Date: 05/24/13 Time: 12:55
Sample (adjusted): 4/03/2003 4/26/2013
Included observations: 2542 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LOG_ADJ_CLOSE_(-1)	-0.005061	0.001876	-2.697076	0.0070
C	0.018774	0.006901	2.720639	0.0066
@TREND(4/02/2003)	1.32E-07	1.60E-07	0.826074	0.4088

R-squared	0.002932	Mean dependent var	9.19E-05
Adjusted R-squared	0.002146	S.D. dependent var	0.005279
S.E. of regression	0.005273	Akaike info criterion	-7.651105
Sum squared resid	0.070606	Schwarz criterion	-7.644212
Log likelihood	9727.555	Hannan-Quinn criter.	-7.648605
F-statistic	3.732801	Durbin-Watson stat	2.110188
Prob(F-statistic)	0.024057		

However, the time series is proved that it has not trend since the probability of the trend 0.4 less than 0.05 (level confidence) and hence, we do not reject the null hypothesis that the coefficient of the trend is zero at this confident level.

In contrast to the previous tables, I run the PP test using the first differences of the variable logarithmic adjusted close prices. The other options are the same as above (without trend).

Null Hypothesis: D(LOG_ADJ_CLOSE_) has a unit root
Exogenous: Constant
Bandwidth: 6 (Newey-West automatic) using Bartlett kernel

		Adj. t-Stat	Prob.*
Phillips-Perron test statistic		-53.75446	0.0001
Test critical values:	1% level	-3.432730	
	5% level	-2.862477	
	10% level	-2.567314	

*MacKinnon (1996) one-sided p-values.

Residual variance (no correction)	2.78E-05
HAC corrected variance (Bartlett kernel)	2.39E-05

Phillips-Perron Test Equation
Dependent Variable: D(LOG_ADJ_CLOSE_,2)
Method: Least Squares
Date: 05/24/13 Time: 13:08
Sample (adjusted): 4/04/2003 4/26/2013
Included observations: 2541 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
D(LOG_ADJ_CLOSE_(-1))	-1.057377	0.019813	-53.36844	0.0000
C	9.64E-05	0.000105	0.921574	0.3568

R-squared	0.528697	Mean dependent var	-1.23E-06
Adjusted R-squared	0.528511	S.D. dependent var	0.007678
S.E. of regression	0.005272	Akaike info criterion	-7.651913
Sum squared resid	0.070577	Schwarz criterion	-7.647316
Log likelihood	9723.756	Hannan-Quinn criter.	-7.650246
F-statistic	2848.190	Durbin-Watson stat	2.005744
Prob(F-statistic)	0.000000		

STEP 3

In the Step 3 of the methodology, I presented the VR test that checks the unit root of the model. Applying this test, I got the following results:

Null Hypothesis: LOG_ADJ_CLOSE_ is a martingale
Included observations: 2542 (after adjustments)
Heteroskedasticity robust standard error estimates
User-specified lags: 2 4 8 16

Joint Tests	Value	df	Probability
Max |z| (at period 4)*	2.333184	2542	0.0763

Individual Tests

Period	Var. Ratio	Std. Error	z-Statistic	Probability
2	0.943330	0.037102	-1.527415	0.1267
4	0.833328	0.071436	-2.333184	0.0196
8	0.767016	0.116426	-2.001134	0.0454
16	0.721290	0.171380	-1.626273	0.1039

*Probability approximation using studentized maximum modulus with parameter value 4 and infinite degrees of freedom

Test Details (Mean = 9.18736838294e-05)

Period	Variance	Var. Ratio	Obs.
1	2.8E-05	--	2542
2	2.6E-05	0.94333	2541
4	2.3E-05	0.83333	2539
8	2.1E-05	0.76702	2535
16	2.0E-05	0.72129	2527

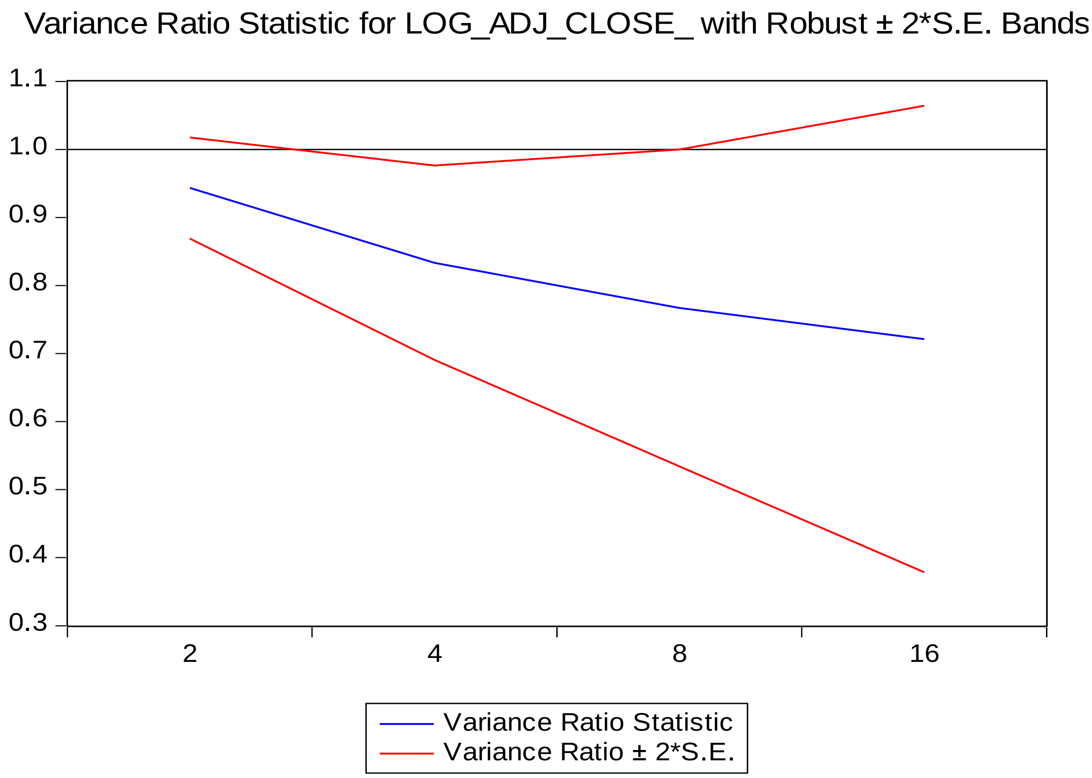


Figure 4: Variance Ratio

For two periods, the VR is around 1 and the probability is 0.126 which higher than the level of confidence with values 1%, 5%, 10%. Thus, the null hypothesis cannot be rejected and the data follows a Martingale Model. The RW is an example of Martingale Model.

STEP 4

At this point of my empirical study, I run the ACF and PACF tests in order to examine the autocorrelation of the time series.

Autocorrelations

Series: Log(Adj close)

Lag	Autocorrelation	Std. Error(a)	Box-Ljung Statistic		
			Value	df	Sig.(b)
1	,995	,020	2520,068	1	,000
2	,990	,020	5017,491	2	,000
3	,986	,020	7494,581	3	,000
4	,982	,020	9955,007	4	,000
5	,978	,020	12395,572	5	,000
6	,975	,020	14818,436	6	,000
7	,971	,020	17224,696	7	,000
8	,967	,020	19613,691	8	,000
9	,963	,020	21984,240	9	,000
10	,960	,020	24338,087	10	,000
11	,956	,020	26674,069	11	,000
12	,952	,020	28992,911	12	,000
13	,949	,020	31294,644	13	,000
14	,945	,020	33580,644	14	,000
15	,942	,020	35851,076	15	,000
16	,938	,020	38106,432	16	,000

a. The underlying process assumed is independence (white noise).

b. Based on the asymptotic chi-square approximation.

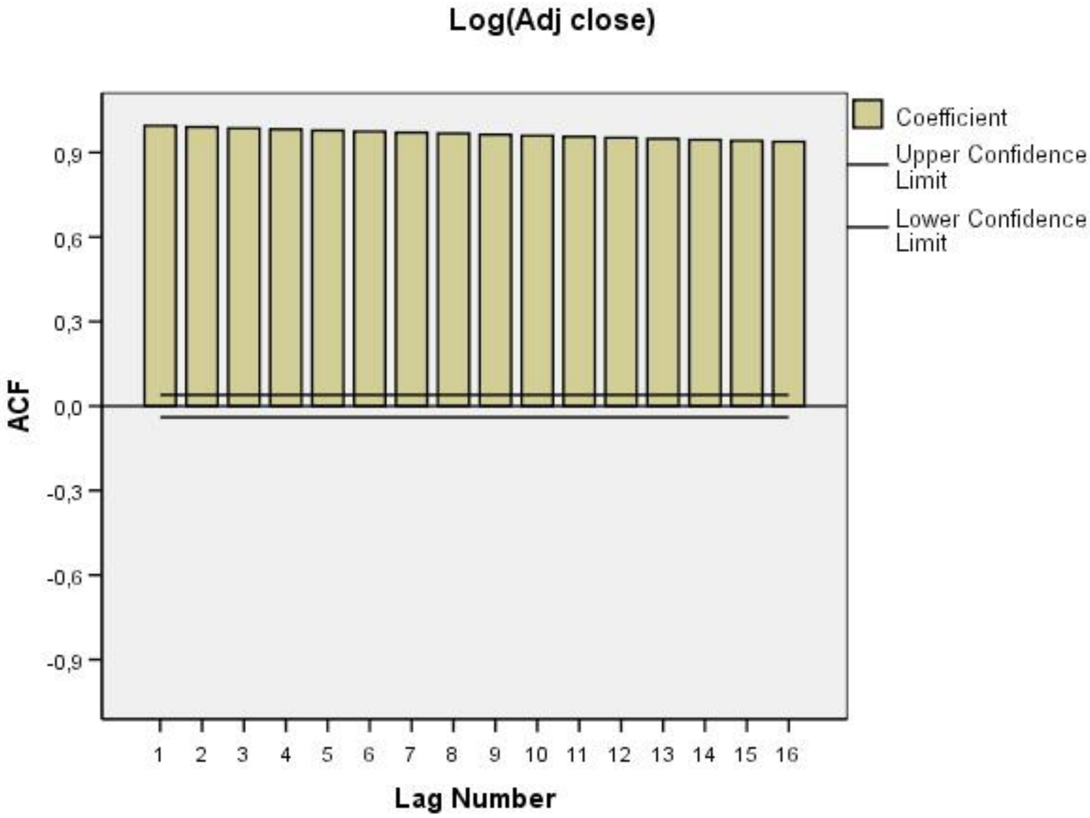


Figure 5: Autocorrelation Function

Looking the graph, we conclude that the observations are highly correlated. In addition, when the lags increase, we do not notice a significant decrease of the autocorrelation as we expected. However, it makes sense since the sample consists of the daily data.

Partial Autocorrelations

Series: Log(Adj close)

Lag	Partial Autocorrelation	Std. Error
1	,995	,020
2	,040	,020
3	,043	,020
4	,072	,020
5	-,058	,020
6	,041	,020
7	,022	,020
8	-,019	,020
9	-,017	,020
10	,027	,020
11	-,029	,020
12	,013	,020
13	,003	,020
14	,017	,020
15	,010	,020
16	,009	,020

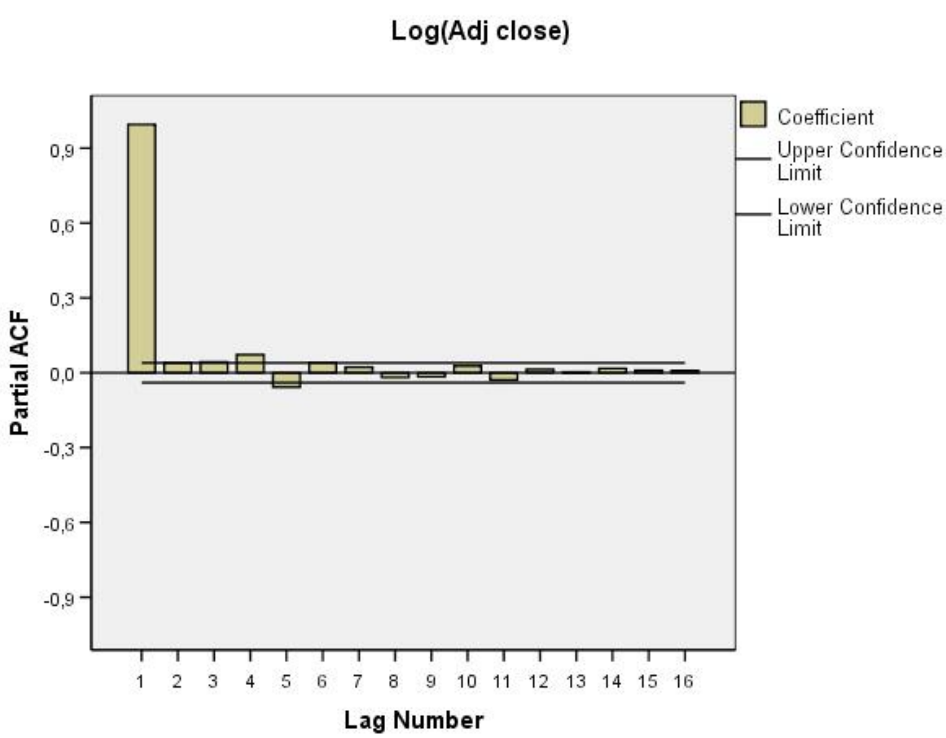


Figure 6: Partial Autocorrelation Function

Taking the first differences, we can observe that the autocorrelation has been almost eliminated from the time series.

Autocorrelations

Series: Log(Adj close)

Lag	Autocorrelation	Std. Error(a)	Box-Ljung Statistic		
			Value	df	Sig.(b)
1	-,057	,020	8,378	1	,004
2	-,047	,020	14,102	2	,001
3	-,067	,020	25,544	3	,000
4	,079	,020	41,625	4	,000
5	-,058	,020	50,338	5	,000
6	-,040	,020	54,488	6	,000
7	,020	,020	55,491	7	,000
8	,038	,020	59,218	8	,000
9	-,033	,020	61,927	9	,000
10	,016	,020	62,620	10	,000
11	-,013	,020	63,050	11	,000
12	,009	,020	63,243	12	,000
13	-,019	,020	64,175	13	,000
14	-,018	,020	64,960	14	,000
15	-,016	,020	65,633	15	,000
16	,034	,020	68,601	16	,000

a The underlying process assumed is independence (white noise).
b Based on the asymptotic chi-square approximation.

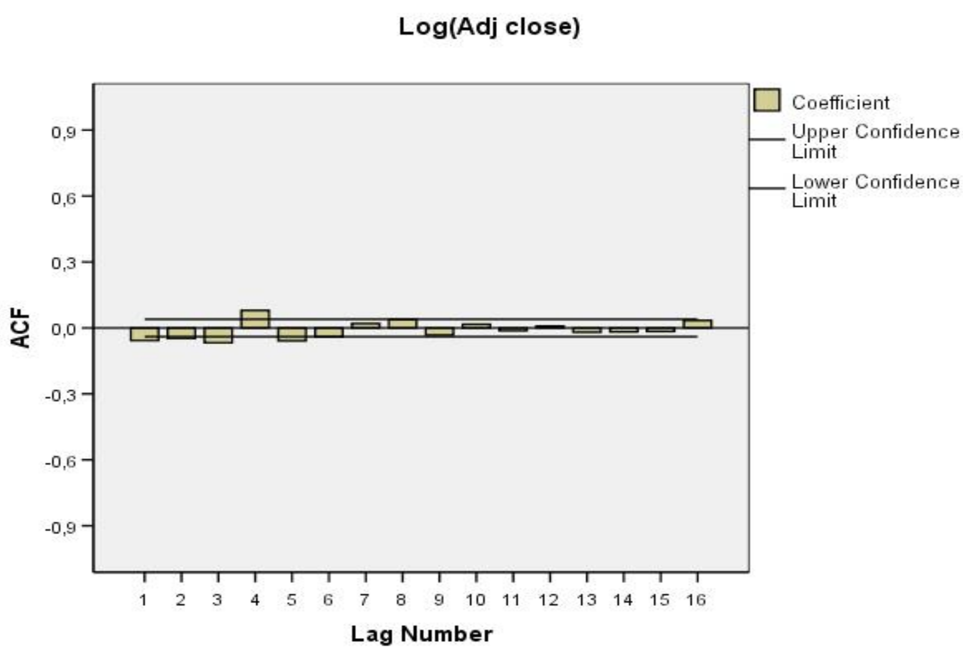


Figure 7: Autocorrelation Function in 1st Differences

Partial Autocorrelations

Series: Log(Adj close)

Lag	Partial Autocorrelation	Std. Error
1	-,057	,020
2	-,051	,020
3	-,073	,020
4	,069	,020
5	-,057	,020
6	-,045	,020
7	,020	,020
8	,023	,020
9	-,025	,020
10	,022	,020
11	-,017	,020
12	,001	,020
13	-,008	,020
14	-,025	,020
15	-,019	,020
16	,028	,020

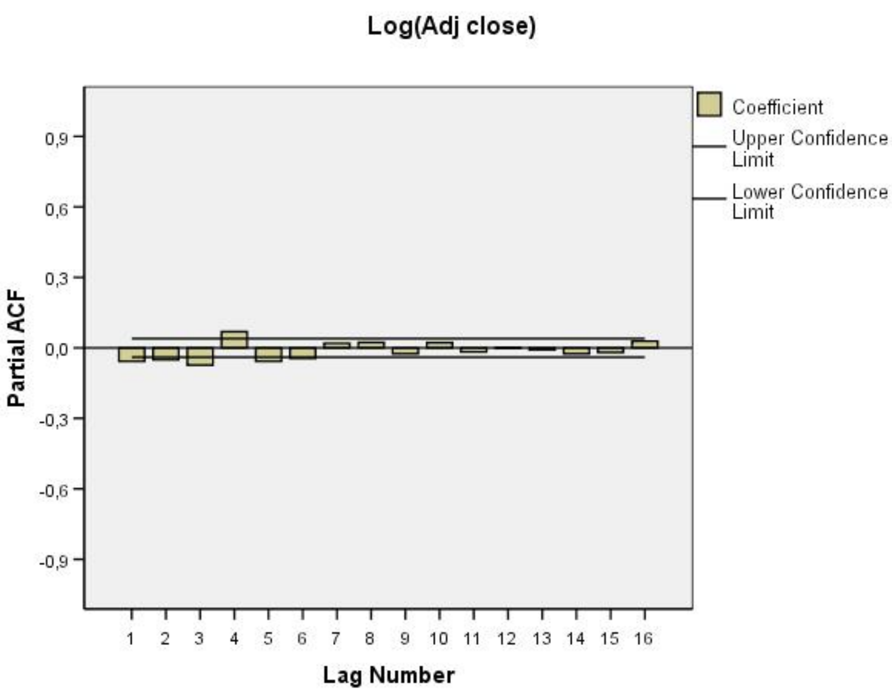


Figure 8: Partial Autocorrelation in 1st Differences

STEP 5

As I referred to the Step 5 of the Chapter 5, main assumption of the statistical tests is that the realizations of a variable have to be random. As a result, I decided to examine the randomness of the variable logarithmic adjusted close prices of the FTSE 100. In order to check this, I use the Runs Test. The table below shows the result of the test:

Runs Test

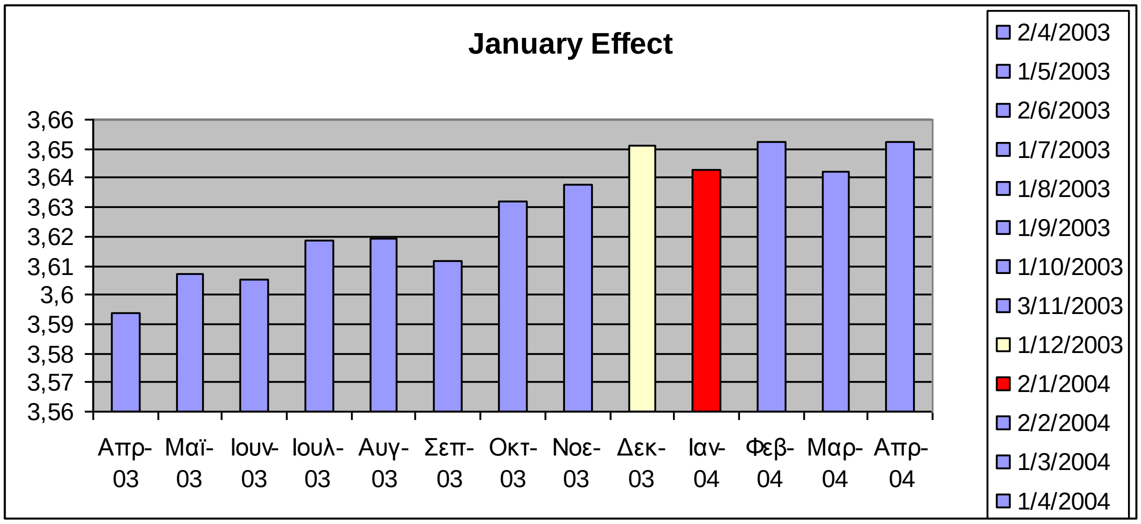
	Log(Adj close)
Test Value(a)	3,739983503369
Cases < Test Value	1271
Cases >= Test Value	1272
Total Cases	2543
Number of Runs	50
Z	-48,494
Asymp. Sig. (2-tailed)	,000

a Median

Using the median as a measure of central tendency, the probability is less than a (confidence level) which may be 1%, 5% or 10%. Hence, the null hypothesis is rejected. The order of the values is not random. Finally, the runs are too many.

STEP 6

Testing for market anomaly in the London Stock Exchange using the FTSE 100 Index we get the following graphs:



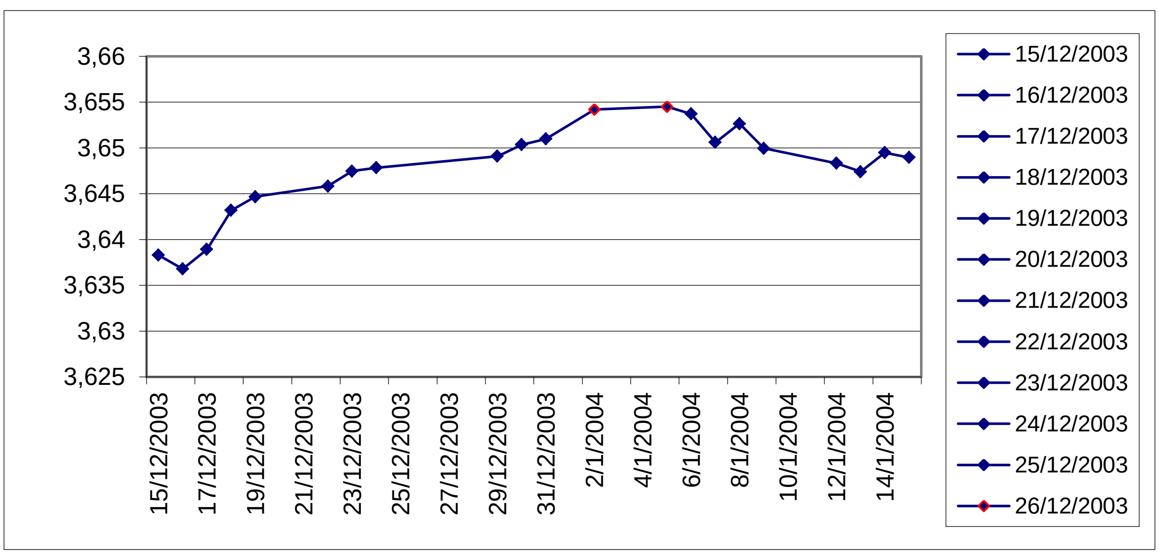


Figure 9: January Effect 2003-2004

In accordance with the intuition of the January Effect, the log prices would be lower at the end of December than the log prices at the begging of January. The year 2003-2004 we don't observe something like this.

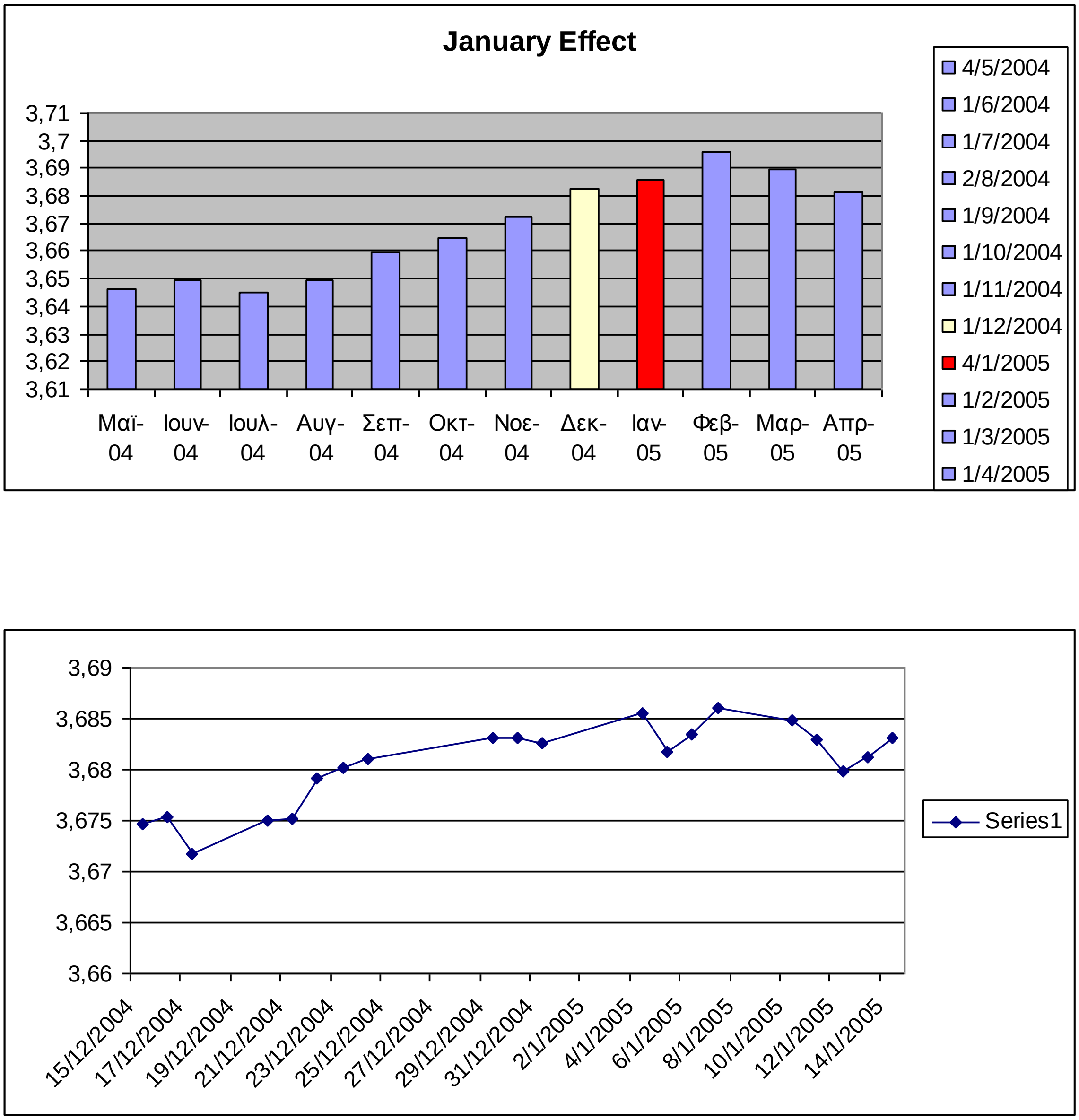
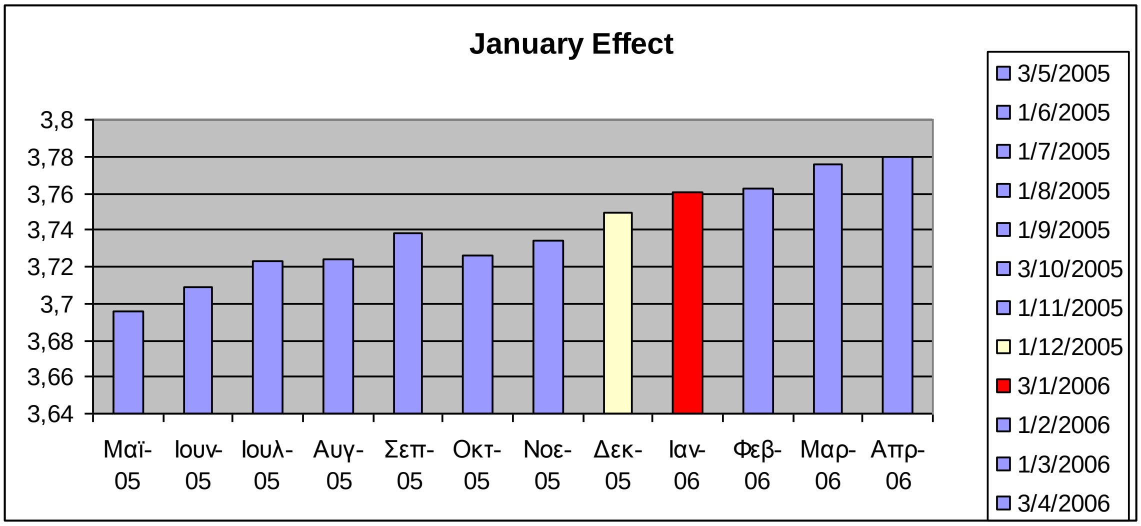


Figure 10: January Effect 2004-2005

The log prices present a rise at the first week of January; hence we could conclude that there is evidence for market anomaly.



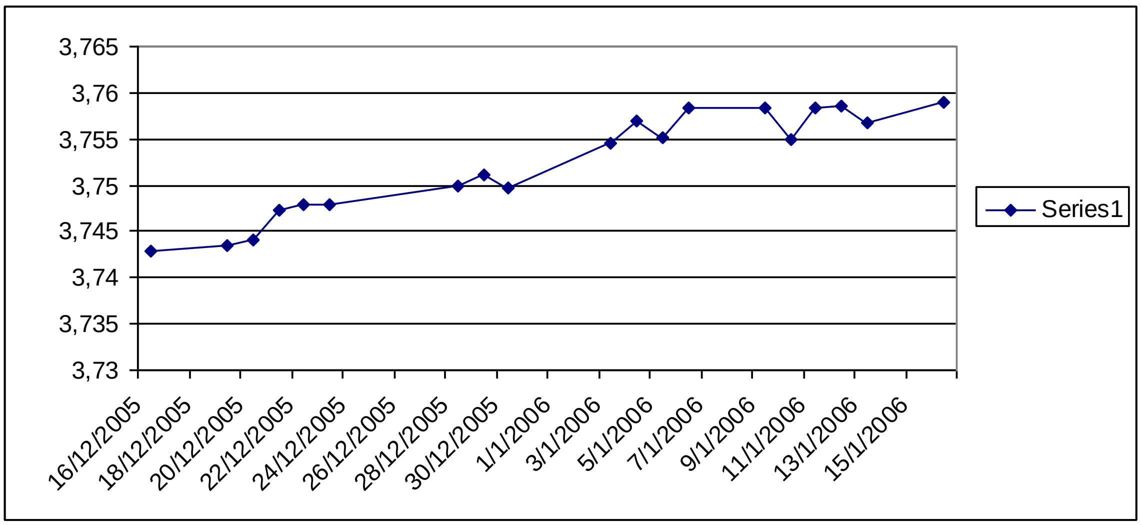
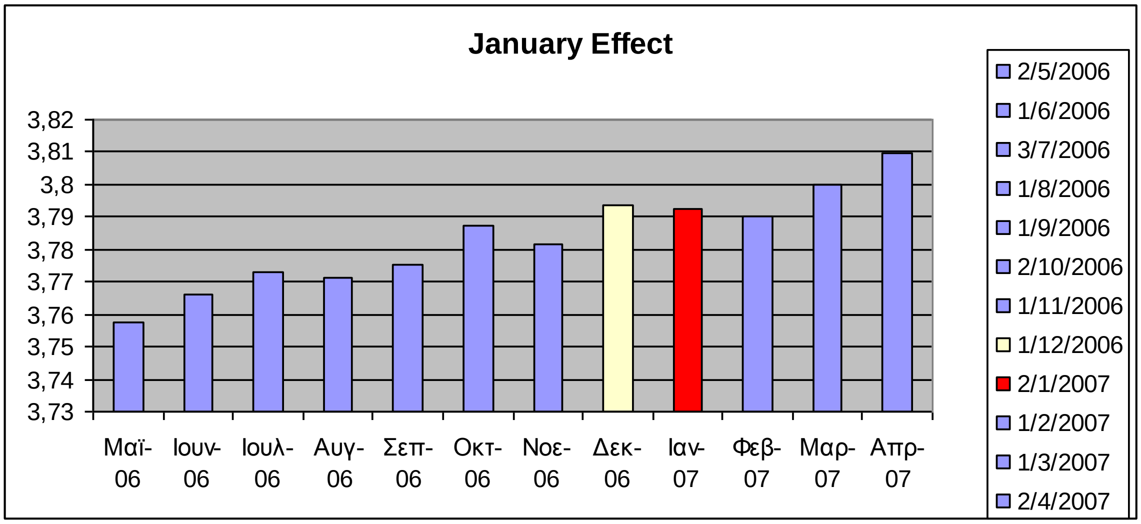


Figure 11: January Effect 2005-2006

There is a great increase of the prices of the first week of January. Thus, the January Effect is intensive between the end of the 2005 and the beginning of 2006.



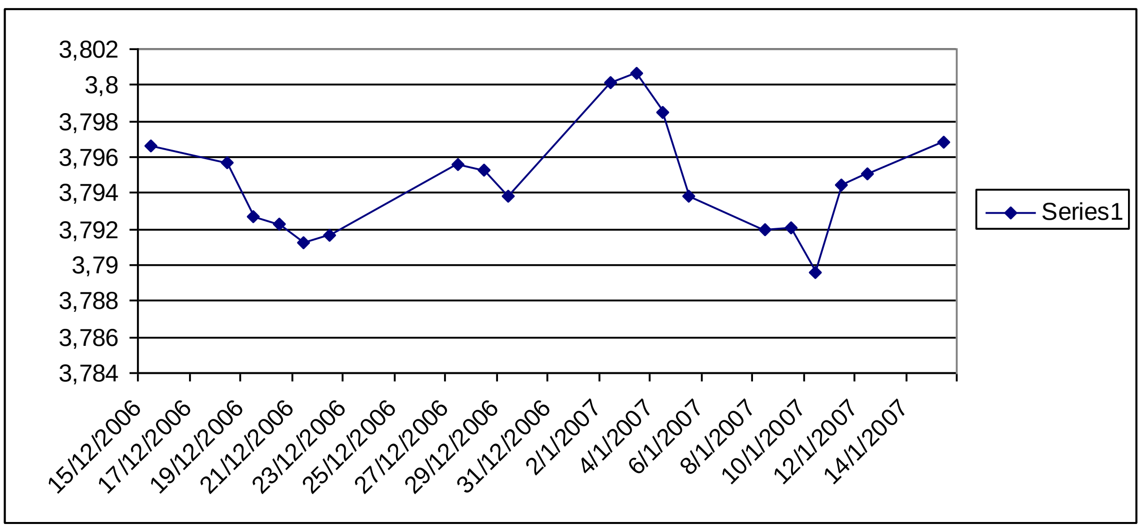
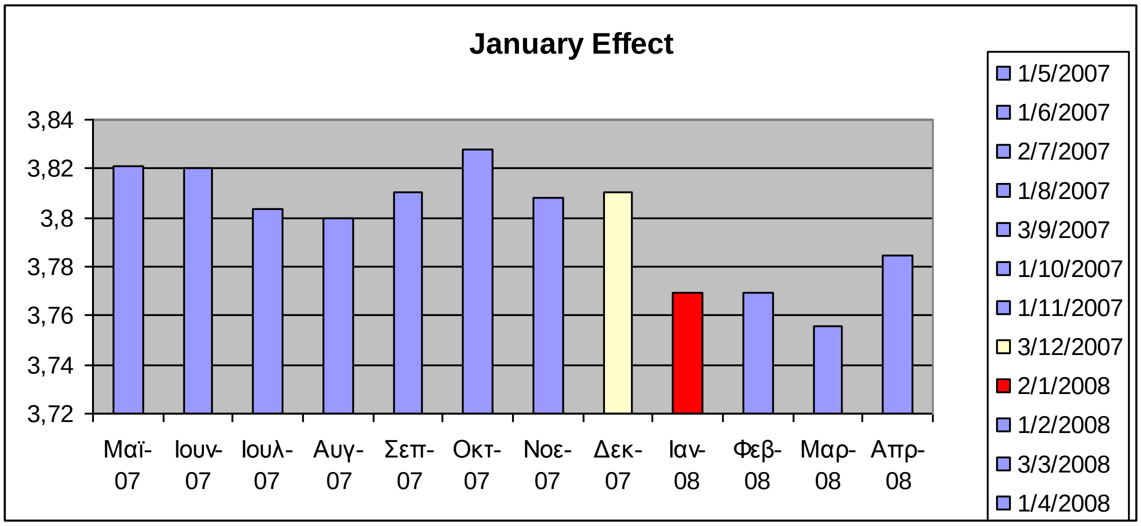


Figure 12: January Effect 2006-2007

Between 29/12/2006 and 4/1/2007, the rise of the prices is remarkable. Therefore, the market anomaly of the January is obvious.



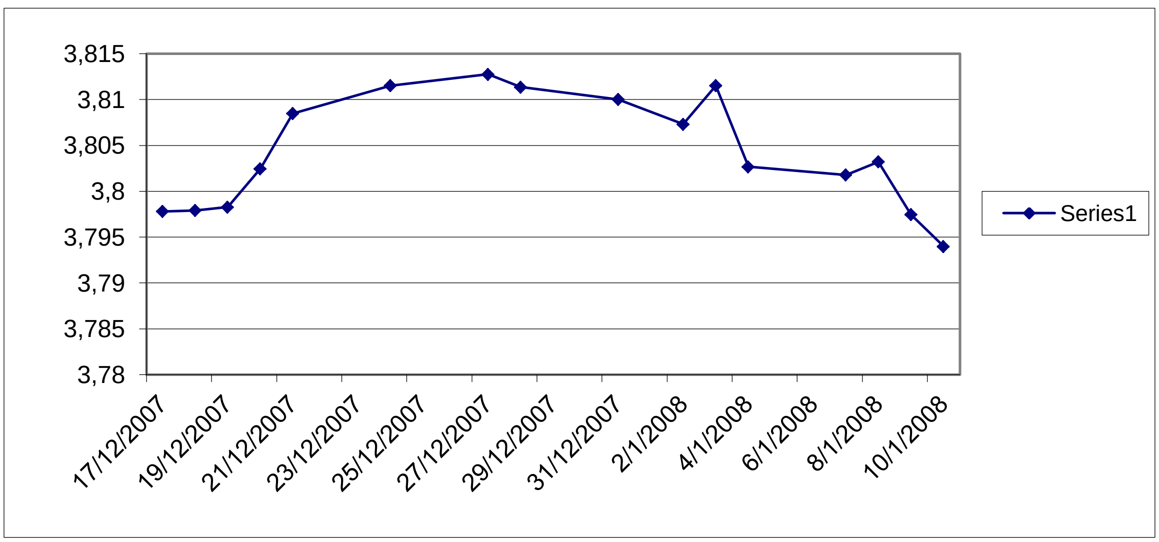
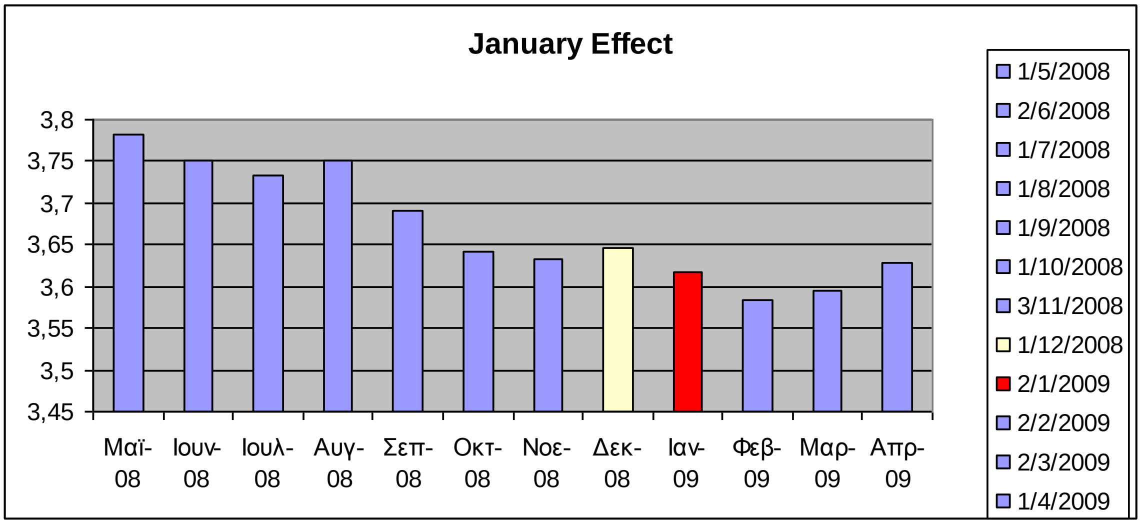


Figure 13: January Effect 2007-2008

The period 2007-2008, we observe a marked drop of the FTSE 100 due to the starting of the financial crisis. Consequently, there are not evidences for the January Effect.



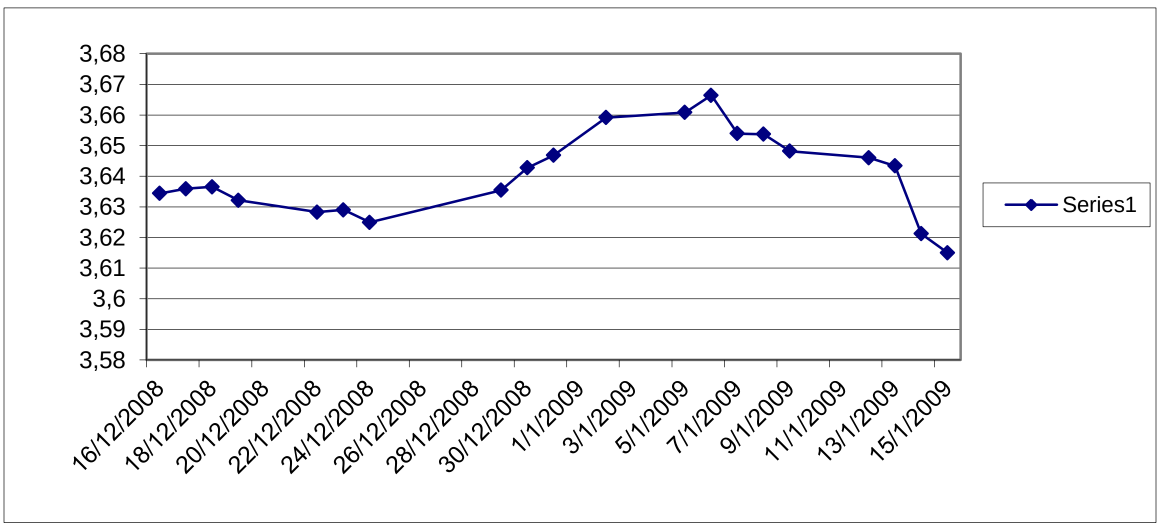
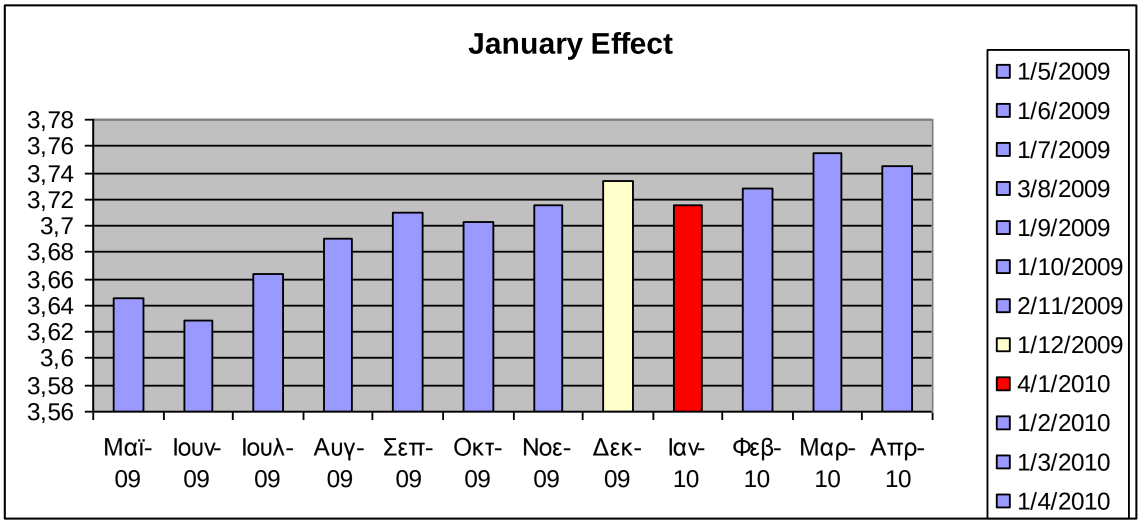


Figure 14: January Effect 2008-2009

By interpreting the former table we conclude that the stock prices fall. Although, the latter table presents evidences for the January Effect since the prices increase from the last week of December to the first of January.



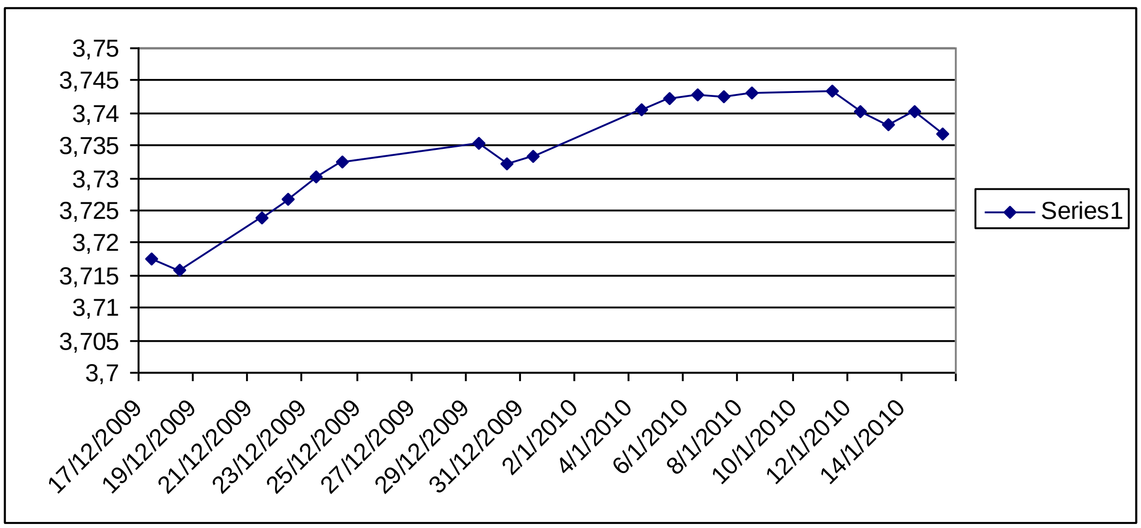
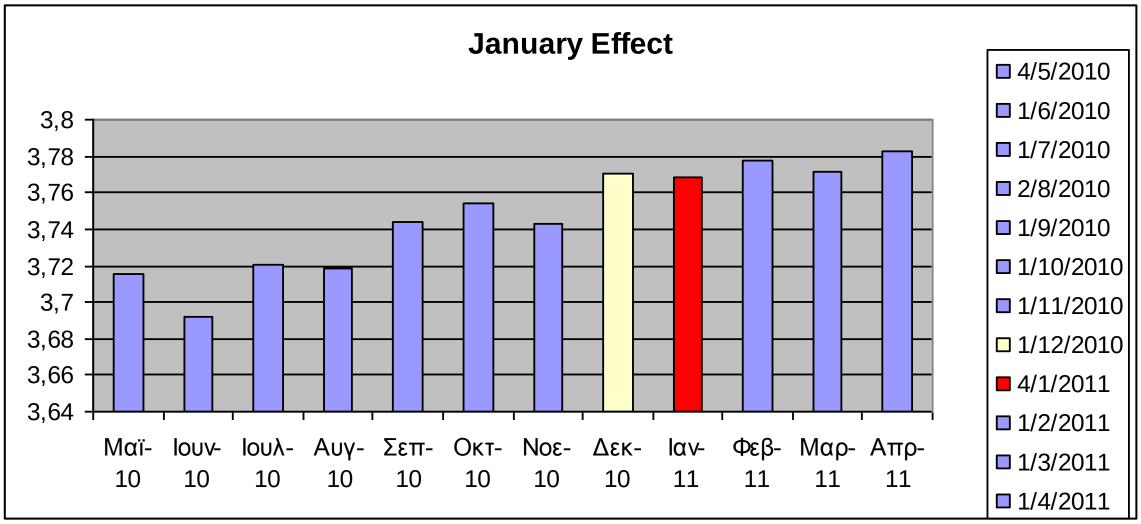


Figure 15: January Effect 2009-2010

The January Effect, also, exists between 2009 and 2010.



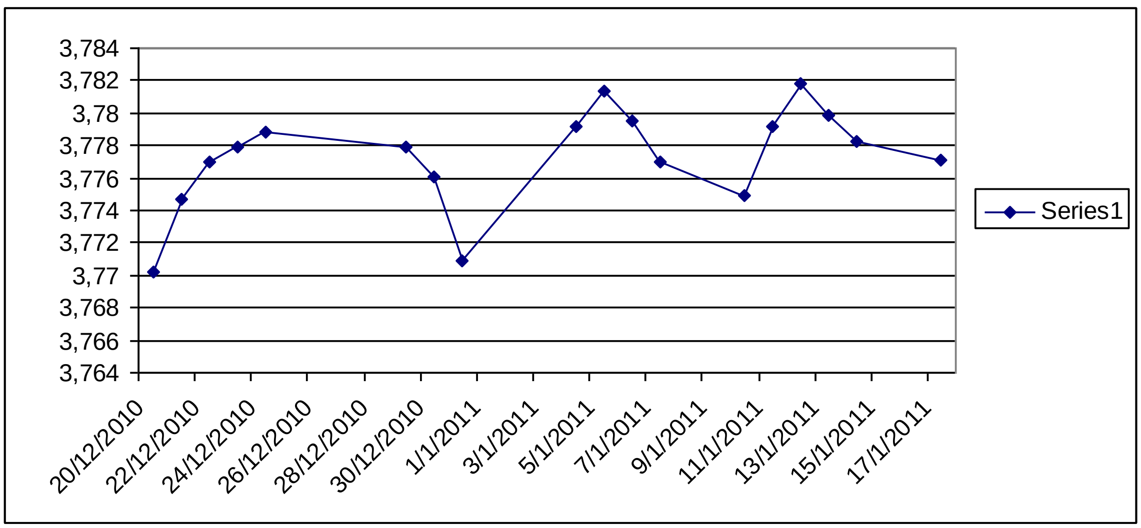
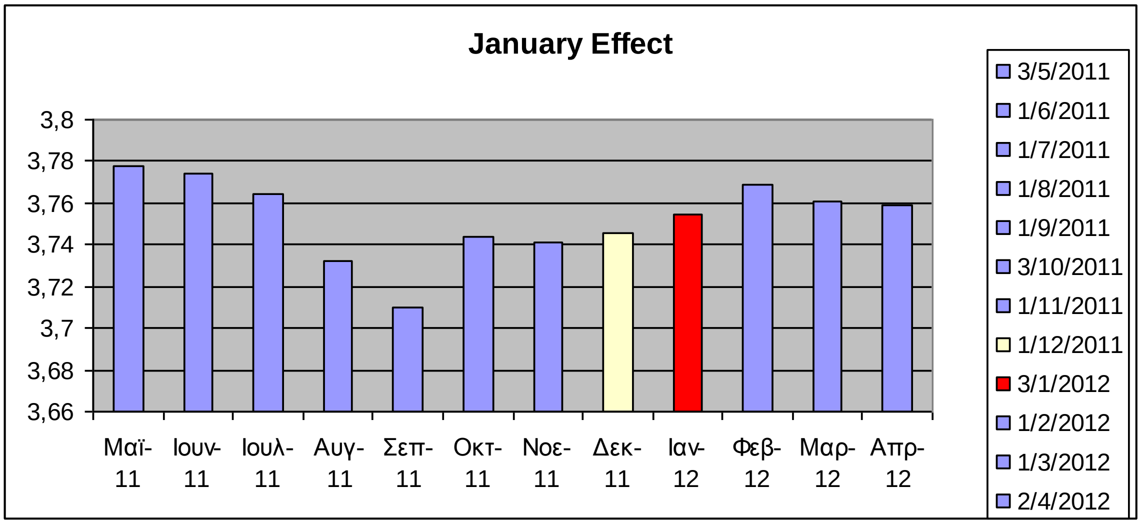


Figure 16: January Effect 2010-2011

The rise of prices from 30/12/2010 and 5/1/2011 confirm the existence of January Effect.



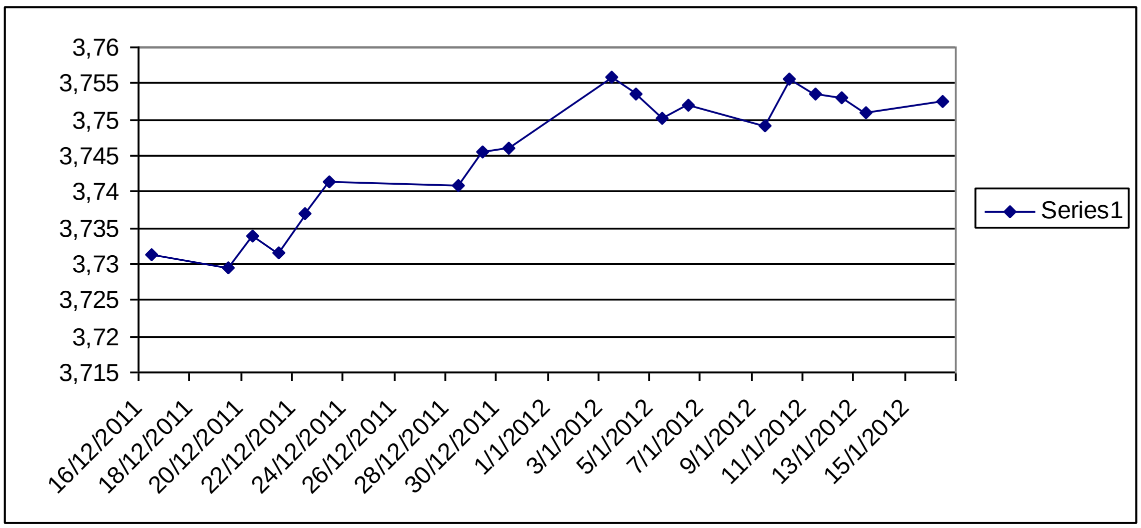
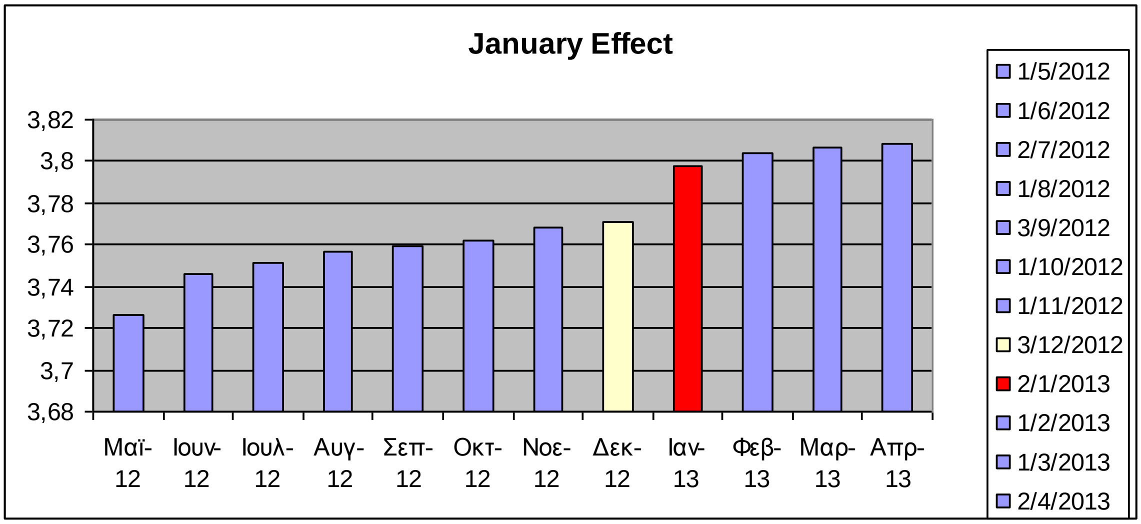


Figure 17: January Effect 2011-2012

There exists an apparent increase of the prices which it implies the presence of anomaly in the stock market.



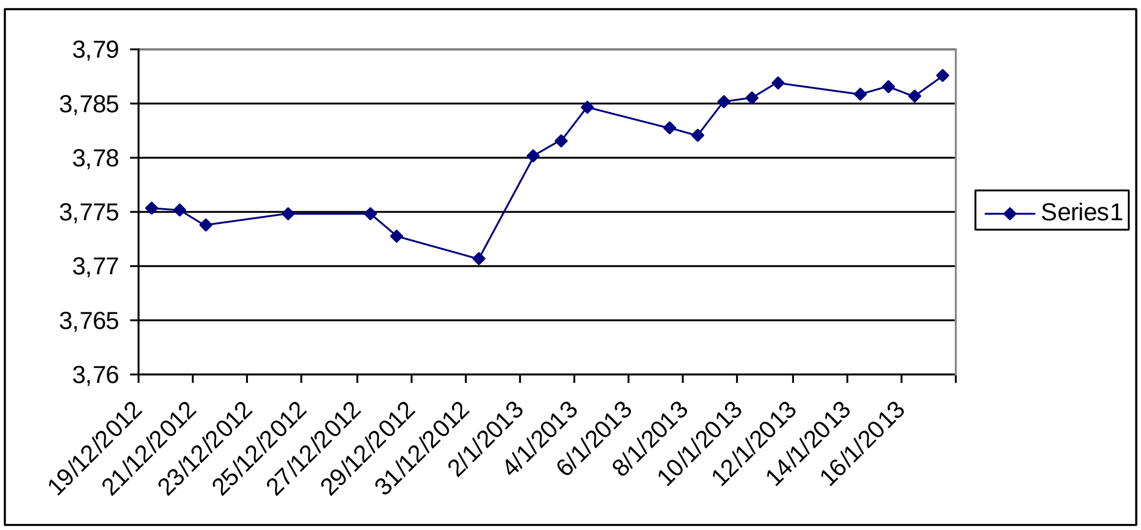


Figure 18: January Effect 2012-2013

At the first days of January, it is observed a rise of the stock prices. Hence, this predictable increase of the prices contradicts to the market efficiency of the stock markets.

Depicting the stock prices in graphs for each year, we conclude that there are evidences for the January Effect. However, we cannot ensure the London Stock Exchange is not an efficient market due to this effect. The fact that the stock prices increase at the first of week of January is an indication for market anomaly but, it is not sufficient whereas we do not know if they investors have earned higher profits than the reasonable market profits.

8. CONCLUSION

The objective of my empirical work was to test the weak efficiency of the *London Stock Exchange*. Following accurately the steps which I described in the methodology and getting the results, I came to some conclusions for if the results were as I expected.

First of all, I examined the existence of unit root in my sample since it is a proof that the time is non-stationary. Applying the ADF and PP test in the levels of the regressors and comparing the t-statistics with the corresponding critical values, the time series has a unit root. Due to the non-stationarity, it is impossible to make inference and hence, I took the first differences of the time series and I repeated the process in the first differences. The outcome showed that the transformed model has not a unit root and hence, it is stationary. Thus, the time series is integrated of order 1 and hence, it follows a *Random Walk*. Applying the VR test in the second step, I came to the same conclusion that, i.e. the time series is a *Random Walk* because the VR test for two periods is around 1. Therefore, by running these tests, we end up that the stochastic sequence follows a *Random Walk*, and so, the weak form of *Efficient Market Hypothesis* holds.

In the next step, using the ACF and PACF, I tested how correlated my data is. From the correlogram, applied in levels of my data, the series is highly correlated and the correlations are not eliminated by the rise of lags. Although, taking the first differences of the series and following the same process, I observed that the correlation falls in time i.e. when the number of lags increases. As a result, my data is correlated as I expected, because the sample consists of daily observations, but not strongly.

Finally, I was interested in checking if the *January Effect* occurs in the *London Stock Market*. Depicting the logarithmic prices for a period of 30 days between the middle of December and the middle of January for each year, I remarked that the prices increase at the beginning of January. This is an evidence for the existence of *January Effect*. However, it is not a sufficient indicate of market inefficiency because we do not have adequate information about the profits of the investors in these periods so as to end up to something so strong like this.

To sum up, according to the results from the empirical tests and combining them with the theory of *Efficient Market Hypothesis*, I want to cite my final conclusion which is that the *London Stock Exchange* is a weak efficiency market with some evidences for short run market anomalies. Nevertheless, I have to notice that there is room for improvement in the empirical study so that the effect of market efficiency to be more robust.

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