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Bachelor Thesis

Can a Hurst exponent be useful for investors in cryptocurrency markets?

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Thesis title

Can a Hurst exponent be useful for investors in cryptocurrency markets?

Objectives of thesis

The main purpose of this thesis is to reexamine the Efficient Market Hypothesis in the crypto-currency market. It allows determining whether Bitcoin is a financial asset of a similar kind and follows the same market rules and patterns.

Methodology

To achieve the goal of this thesis, the Hurst exponent as a measure of long-term memory of a signal will be applied. In particular, the oldest method will be used – R/S analysis.

The proposed extent of the thesis

30-40

Keywords

Hurst exponent, crypto market, bitcoin, efficient market, rescale range, standard deviation, time series

Recommended information sources

MANDELBROT, B.; HUDSON, R. L. The (Mis)behavior of markets: a fractal view of risk, ruin, and reward.
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Declaration

I declare that I have worked on my bachelor thesis titled "Can a Hurst exponent be useful for investors in cryptocurrency markets?" by myself and I have used only the sources mentioned at the end of the thesis. As the author of the bachelor thesis, I declare that the thesis does not break the copyrights of any person.

In Prague on 30.03.2022 _____

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Can a Hurst exponent be useful for investors in cryptocurrency markets?

Abstract

This bachelor's thesis deals with the revision of the efficient market hypothesis as well as the choice of an appropriate model for analyzing the time series of cryptocurrencies, in particular Bitcoin. The chosen analysis will determine if Bitcoin is a similar type of financial asset and follows the same market rules and patterns.

The practical part of the dissertation presents the problem of modern time series analysis that investors face. This bachelor thesis deals with procedures of time series analysis using a main statistical measure of long-term memory of a time series in Fractal market hypothesis – Hurst exponent.

Hurst exponent - a modern measure used in time series analysis will be used in the analysis of Bitcoin quotes. This value decreases as the delay between two identical pairs of values in the time series increases. Calculating the Hurst exponent we measure the amount by which a given time series deviates from a random walk. In other words, the Hurst indicator makes it clear if the selected time series maintains the existing trend, the trend tends to change to the opposite, or it has a random movement that cannot be predicted. Based on all the Hurst exponent calculations carried out in Excel, a conclusion will be made regarding the behavior of Bitcoin prices. The possibility of applying the chosen method for the analysis of the crypto market is also being considered.

Keywords: Money, Internet, Bitcoin, Hurst exponent, Brownian motion, Long-term memory, Rescaled range analysis.

Může být Hurstův exponent užitečný pro investory na trzích s kryptoměnami?

Souhrn

Tato bakalářská práce se zabývá revizí hypotézy efektivního trhu a také výběrem vhodného modelu pro analýzu časových řad kryptoměn, zejména bitcoinu. Vybraná analýza určí, zda je bitcoin podobným typem finančního aktiva a zda se řídí stejnými tržními pravidly a vzory.

Praktická část disertační práce představuje problém moderní analýzy časových řad, se kterým se investoři potýkají. Tato bakalářská práce se zabývá postupy analýzy časových řad pomocí hlavního statistického měřítka dlouhodobé paměti časové řady v hypotéze fraktálního trhu – Hurstův exponent. Hurstův exponent - moderní měřítko používané v analýze časových řad bude použito při analýze kotací bitcoinů. Tato hodnota se snižuje se zvyšujícím se zpožděním mezi dvěma identickými páry hodnot v časové řadě. Výpočtem Hurstova exponentu měříme velikost, o kterou se daná časová řada odchyluje od náhodné procházky. Jinými slovy, indikátor Hurst jasně ukazuje, zda zvolená časová řada zachovává stávající trend, trend má tendenci se měnit k opačnému nebo má náhodný pohyb, který nelze předvídat. Na základě všech výpočtů Hurst exponentů provedených v Excelu bude učiněn závěr ohledně chování cen bitcoinů. Zvažuje se také možnost použití zvolené metody pro analýzu kryptotrhu.

Klíčová slova: Peníze, Internet, Bitcoin, Hurstův exponent, Brownův pohyb, Dlouhodobá paměť, Analýza změněného rozsahu.

Table of content

List of Tables

List of used abbreviations

BTC – Bitcoin

ADA – Cardano, smart contract platform

BNB - Binance coin

DASH – Dash coin

DOGE – Dogecoin (meme currency)

ETH – Ethereum (2nd cryptocurrency)

LTC – Litecoin

NEO – Neo coin, smart contract platform

XLM – Stellar Lumens

EMH – Efficient Market Hypothesis

FMH – Fractal Market Hypothesis

H – Hurst exponent

1. Introduction

“It’s easy to forget that success is the result of a process of attrition that is largely driven by luck. Survivor bias is a dangerous thing.” (Taleb, 2007)

„This is the central illusion in life: that randomness is a risk, that it is a bad thing…“ (Taleb, 2012)

Through history since the advent of financial and capital markets, people have been looking for a theory that will explain the behavior of financial markets, their unpredictable ups and, downs. For a long time, investors and traders used the Efficient Market Theory (EMH) introduced by Fama (1965) and the Modern portfolio theory in time series analysis, however, practice and history have shown - this theory was not entirely correct. Both these theories are based on the assumptions of the Gaussian probability distribution and independence of consecutive returns. The assumptions of a normal probability distribution for asset returns and a random walk for asset prices are routinely applied for simplicity. Regrettably, for investors and portfolio managers, empirical asset-return series exhibit much greater disorder. The series diverges widely from the theoretical expectations of well-behaved data-generating processes. They seem to be misbehaving. The concept of a well-behaved random walk as an appropriate representation of asset prices in capital markets is an old one.

In the relatively recent past the, EMH theory was replaced by the Fractal Market Hypothesis (FMH) proposed by Ed Peters (1994). FMH theory postulated that returns are not independent of each other’s and were probably correlated, i.e. the data generation process has some memory in it. Also, the inverse series seems to be non-stationary. The central limit theorem (the fundamental assumption of probability and statistical inference theory) is also violated quite frequently since a single extreme observation can easily dominate the whole sample. Therefore, a large change in a certain period can be caused by a single major jump, whereas, all the other observations are irrelevant to the total change in this period. From an investor’s perspective, this means that the total realized return on investment for a given period is

crucially dependent on the entry and exit date, sometimes even the exact time when the transaction is realized, since just a few large movements can fully determine the magnitude of the total change. Hence The Gaussian probability distribution ceases to be an appropriate model whenever the population variance is infinite and the data-generating process exhibits long memory. In this work using the Hurst exponent (H) as a measure of the type of memory of a series of observations, the hypothesis that asset returns follow a random walk is examined. To answer the research question – of what long-term memory analysis is applicable for the crypto–market, especially Bitcoin is the same as for capital markets, a Hurst exponent was estimated for Bitcoin quotes for a 7 and 3,7-year period.

2. Objectives and Methodology

2.1 Objectives

The main objective of the thesis is to determine if time series analysis applies to cryptocurrency quotes and Bitcoin in particular and whether it has a long–term memory. This dissertation analyzes various methods of time series analysis and their application nowadays, including the analysis of the time series of cryptocurrencies.

2.2 Methodology

This thesis has two parts introduced first the theoretical and then followed by the practical section. The theoretical part is based on scientific literature. This part is devoted to the history of money, the history of its regulation. It also includes the emergence and transformation of the Internet and the basic concepts of Bitcoin and Blockchain technology to better understand the topic of cryptocurrencies. Based on the history of the emergence of money, modern theories of market analysis and further analysis of their application to crypto-currency will be described. For this, it is necessary to analyze the practical significance of the fractal market hypothesis. I will analyze the behavior of Bitcoin and determine whether the theory of fractal markets applies to relatively new and not fully explored assets. The property of long-term

memory on bitcoin quotes and the accompanying conclusion regarding the price movement of cryptocurrencies will be considered.

The practical part begins with a description of the chosen methodology and its steps. The original rescaled range (R/S) analysis for time series analysis of long-term memory and its main statistical measure - Hurst exponent were used. A significantly large time series was chosen for estimating Bitcoin's behavior. I chose two different time windows: 7 – year period – a larger one that aims to show a global perspective and 3,7 – year period for a more detailed study of cryptocurrency quotes. For 7 years, daily logarithmic returns were calculated as the difference of logarithms of nominal close prices so that a log-return series of the length of 2560 observations were obtained. 3,7 years with a length of 1280 observations were obtained. Same time the series of log returns was split up into non-overlapping time windows of length $\tau(i)$. The number of boxes 2^n was applied, where n ranges from 1 to 7, i.e. the original series of 2560 observations was split into 2 and up to 128 subperiods with the length ranging from 1280 to 20 observations. And a smaller time series of 3,7 years was also split into 2 and up to 128 subperiods with the length ranging from 640 to 10 observations.

For a more accurate analysis, I also chose a few cryptocurrencies to see what behavior they follow. The following cryptocurrencies were included: ADA, BNB, DASH, DOGE, ETH, LTC, NEO, XLM. It was also made to see if the cryptocurrencies are highly correlated with Bitcoin, if they are not then they can be observed separately, and therefore the results may vary. It is necessary to mention that the crypto sphere is quite young therefore in most cases only a few past years were analyzed.

Using Excel as a powerful big data analysis tool we will determine what type of time dependence bitcoin belongs to. We will determine it by calculating a Hurst exponent. Based on the calculations I will explain why Bitcoin and some other cryptocurrencies behave this way.

3. Literature review

3.1 History of money

As far as we know from the Encyclopedia of Global Archaeology (SMITH, 2014) the modern form of Homo sapiens first appeared about 100,000 years ago. During these quite struggling times humankind was not able to create or invent revolutionary things. They were mostly worried about the protection of themselves and their offspring. Back in those days, people could only exchange things that could originally have been obtained by hunting, gathering, or through their craft. However, according to Smith (2014) with the increasing development of people and their methods and ways of exchange, competition arose. They no longer needed to limit themself in choosing who to exchange with and its gave rise to healthy competition in the market, which led to an even greater development of human civilization. At some time people realized that it is not always convenient to exchange things, because there were more and more people and their needs became more and more diverse. It would be logical to introduce something as a measure of value that could be exchanged without involving third or more parties. Thus people began to try various measures of value such as cattle, grain, furs, pearls, shells until they came to precious metals. BC people mainly used metal arrowheads, shovels or other tools which had any metal in their parts such as copper, bronze, iron, or silver. Only in some countries like Assyria or Egypt for the 2nd millennium BC. e. they used gold for money. Of course, these were not coins yet, but rather just bars of gold with different fineness. And it's made it more difficult to use it in calculation and funding methods. After all, when it comes to a certain calculation, it was necessary not only to find out the weight of the ingot but also its purity.

In the handbook of the History of Money and Currency Stefano Battilossi (2020) states that only in the 7th century AD minted coins appear in circulation. The rapid distribution of coins is associated with the convenience of storing and their relatively high cost with low weight and volume, which is very convenient for exchange. Over time to prevent counterfeiting and body kits, the metal began to be marked with a public stamp. This is how minted coins and mints came into being.

3.1.1 Banks and fiat money

As it was stated in the book of Ammous (2021) “The Fiat Standard” back in those times it was quite hard to constantly have a bag of money and scales with you. And therefore, together with the mints, the first banks appeared. Banks provided services for storing the coins of their customers. From the bank’s side, it was necessary to give a confirmation (certificate) for their clients confirming the presence of a particular amount of coins in a person's account in a bank. Clients were able to take their money back from the storage by the presentation of a receipt. Hence it wasn’t needed to have a stack of coins to pay for a large purchase because it was enough to give this certificate to the seller and exchange it for some product. Over time, these certificates began to have the same validity as real money as no one wanted to go around with heavy metal coins to buy anything. And this is how the first paper money appeared Ammous (2021) says. Even the word "banknote" itself comes from the English word "bank note", which means "bank record". The economic essence of the banknote is the bank's obligation to issue cash to their customers. However, now banks are not required to exchange banknotes for full-fledged natural money. The banknotes themselves are money now. Over time these "bank notes" completely replaced other types of payment.

According to Ammous (2021), the USA played a key role in the gold standard introduction and its consolidation in a global economy. In 1792, it was established in the United States that one troy ounce (31 grams) of gold was contained in $ 19.3. In 42 years, since the United States did not have enough gold reserves to support the entire volume of money they printed, one troy ounce of gold became contained in $ 20.67 and the exchange rate had to be reduced. For a while, this stabilized the dollar against the gold, however, after the First World War, the devaluation began to continue on an even larger scale. Then in 1929, there was a stock market crash in the United States. The crisis gave rise to the development of the "Great Depression" and radically changed the economic policy of the state in the financial markets. In 1934, it was already $ 35 given for 1 troy ounce of gold. But at the same time, the dollar comes out on top making the dollar zone in the countries of North and Latin America.

In the book “The Transformation of Merchant Banking” Brian O'Sullivan (2018) explained that in 1931, the crisis in England began to get worse and worse because the other neighboring countries took their money from the economy of England to stimulate their country’s economies. This ultimately led to panic in the financial market in England, which in turn led to a change in the leaders of the reserve currencies of the world. The dollar came out on top, and the British pound took a back seat. The same year GB canceled the gold reserve standard and introduced a free-floating exchange rate of the pound sterling. And in two years the US did the same. It was critically necessary, since the amount of mined money was decreasing, while the need for banknotes was increasing.

In spite of the economic crisis, according to Miao Han (2016), the United States tried to keep the dollar connected to gold, the discount rate was raised, but this did not help. However, in connection with the coming wars, gold from the Old World began to move to the New, which temporarily restored the dollar's connection to the gold. Almost at the end of the second WW, the Bretton Woods Agreement was adopted. This agreement introduced the gold dollar standard. 44 countries' currencies were tightly connected to the US dollar while the dollar to gold. With new rules, the dollar became the only currency directly connected to gold. Gold has gone from being the main currency to being a reserve currency. Through the seventies of the 20th-century dollar depreciated a few more times until in 1976, the Jamaican Monetary System was created, which officially removed the dollar's connection to gold, but the dollar remained the world's reserve currency with a floating exchange rate which remains to this day.

Out of the work of Miao Han (2016), it’s important to mention that since 1913, the Federal Reserve System (FRS), has been responsible for the production, distribution and accounting of dollars in the United States. Basically FRS acts as the country's central bank or we could say as a Worlds central reserve system**.** The amount of money generated depends on the needs of the United States. Nowadays, from one-third to one-half of the dollar mass, printed in the United States, leaves the country. According to the Department of Treasury, approximately 99% of the dollar bills and coins produced are now in free circulation. During the period from 1995 to 2005, the dollar amount in circulation increased by 89% and reached $ 758.8 billion.

Printing currency allows the government to spend without the public realizing that their money is being taken from them. Having a currency supply backed by nothing means that the government can essentially borrow from the central bank indefinitely.

However according to Miao Han (2016) in 2003-2008, with the strengthening of the euro and the accumulation of negative trends in the US economy, the dollar's exchange rate against other currencies and its role as a reserve currency declined. Since the second half of 2008, amid the globalization of the crisis in the world economy, there has been an increase in the dollar exchange rate against the currencies of other countries, since the dollar is considered a stable safe-haven currency just the same as gold was before.

3.1.2 Capital and types of investment

Before explaining the phenomenon of Bitcoin, I would like to start by talking about capital and traditional types of investments. Edward Chancellor (2016) states that in the wide sense of the word Capital – is any resource, which is made for purpose of creating a bigger amount of economic goods. In the narrow sense we could say that capital is any income-generating value. It could also be a stream of assets in the sphere of production or provision of services to further make a profit and it is called capital investments or shortly investments. There are several different types of investment and I would like to go through the most important of them and analyze what type of investment is closest to investment in cryptocurrencies.

Definition of different investment types, according to S. N. Durlauf (2018):

Stocks – is a type of investment in a specific company. Stocks represent shares of ownership, also known as equity shares. Companies usually sell shares of a company to raise cash.

Bonds – is a loan investor make to the government or a company on purpose to receive in the future some interest back. Bonds are recognized as a low risky type of investment but they also may offer lower returns. Generally, the less risky the bond, the lower the interest rate.

Bonds are fixed-income investments so investors may expect income payments on a regular base.

Mutual funds are a bit different type of investment than we've analyzed before. In case you do not consider yourself a professional investor and you don't have time to analyze the company's P&L ratio or you have no clue what is TA you can invest in a Mutual fund, they will do all the dirty work for you. Of course, you would need to pay some fee for the work done by the professional trader who will invest according to a specific strategy.

Index funds are a type of fund that follows a price index, rather than paying a manager to pick investments. In other words when you just buy some index you immediately diversify your contribution to as many companies as are included in the index.

ETF (Exchange-Traded Funds) is a type of index fund. ETF tracks a price of an index and aims to represent an index's performance. Same as index funds, they might be cheaper than mutual funds because they are not managed actively. The main difference between index funds and ETFs is that ETFs are more like regular stocks, the price can move during the day while Mutual funds and Index funds have their price once at the end of each trading day so their price stays the same during the whole trading day. ETFs also can pay dividends and some interest to investors.

Options are the most unusual and complex type of investment. When you purchase an option, you are buying a contract. The contract doesn't obligate you to buy or sell shares immediately. When you buy an option you can buy/sell shares at a specified price by a specified time or date which was agreed before. You can even sell an option contract to another investor or let the contract expire. Basically you lock your investments in the price of the stock. And they for example expected to rise in value. If you are right, you will win by buying the stock at a lower price. If this is not the case, you can refuse the purchase of stock and you will only receive the contract's value of itself.

Security Futures. Using this type of investment, you may lose a significant amount of money

in a short amount of time. As a high degree of leverage is involved, the amount you may lose is potentially unlimited.

Initial Public Offering (IPO). For a long time, businesses struggled to raise funds for their ambitious goals. During IPO a part of the company's total shares is sold to the public to increase the capital of the company. So investors can participate in IPOs as early investors with the aim of acquiring part of the company at a cheap cost and further partial or full resale at a higher price.

Alternative and Complex Products are types of investing that offer alternatives to usual stock and bond investments. These type of an asset is referred to a non- conventional investments or structured products. They tend to be more complex—and more risky—than traditional investments at the same time, and this type looks the most similar to what crypto investments look like nowadays.

Initial Coin Offerings**.** Just the same as a Public Offering of a company shares works for Crypto-Coin Offerings. Investors can participate in ICO in order to receive higher returns as an early investor. Same time they are taking a higher risk as none of the cryptocurrencies is supported by the government and law in particular.

Over the past few years, the cryptocurrency has been gaining momentum, attracting more and more investments, from both large and individual investors. The same time crypto market is still difficult for understanding and too volatile for most investors. Digital assets like cryptocurrencies with billions of dollars in financings, are rapidly changing markets. By analyzing the given above types of investment, we can say that the cryptocurrency and its protocols have taken most of the investment features, improved them and made them more accessible for a common human being.

3.2 Internet

Now I would like to step back a bit from the traditional investments and tell you more about the concept of the web that appeared along with the Internet because I believe that it is impossible to talk about Bitcoin and blockchain technology without talking about the emergence of the Internet and its stages of evolution.

Nupur Choudhury (2014) in his article defines the Internet – a global network that connects a multitude of smaller networks. In aim to run the internet with a big amount of information and users in it, a big amount of servers were also needed.

According to Nupur Choudhury (2014) World Wide Web (WWW) – is a combination of all resources and users of the Internet that are using the Hypertext Transfer Protocol (HTTP). If to compare the Internet to the Web, WWW is just a communications tool that, through HTTP, enables the exchange of information over the Internet. To put it simply: the Internet is a net that connects every user and server using a communication protocol – The Web.

3.2.1 WEB 1.0

At the very beginning of internet it wasn't the same as we know it nowadays. It was defined as a web of information connections. The innovator of the World Wide Web, Tim Berners-Lee(Berners-Lee, 1998) considers Web 1.0 as a "read-only" Web. At that time Web provided a very small interaction or content contribution of a user. The first role of the web was very passive. The first generation of Web was an era of static pages and content delivery purposes only. In other words, Web 1.0 allowed us to search for information and read it only.

But everything changed in 2000. The Dot-com bubble happened. Basically what happened according to Vogel (2021) was that every small and big investor or businessman had seen imminent profits in internet companies that appeared with incredible speed and at that time it seemed that nothing would stop it. At that time, the Internet was just developing and not all

Internet companies were worth something. Most of these companies and investors simply floated on a rapidly gaining momentum, which, as a result, turned into an avalanche and claimed the lives of most of them. Companies turned out to be highly overvalued and large speculators were able to take advantage of this by leaving the market, taking with them the maximum profit, thereby bringing down the market of fake companies. However after the fall, some of these internet companies were able to recover and give even more growth because they had a real idea or some revolutionary product. In practice, that bubble gave investors and entrepreneurs the understanding that the Internet is not just a platform where you can place data about a company or service, but that it is much - much more.

3.2.2 WEB 2.0

Then Tim O'Reilly (2006) came up with the idea of Web 2.0 and he define it as a read-write web. The technologies of web 2.0 allow assembling and managing large global crowds with common interests in social interactions. Web 2.0 is the business revolution in the computer industry that caused by the great development of the internet as a platform, and an attempt to understand the rules for success on that new platform. In other words, the user of web 2.0 has more interaction with less control. Also User Experience itself developed and this meant that soon the Internet would become publicly available in terms of the benefits that all people can get, regardless of their nationality, income or employment. Since then literally everything could be done via the Internet. Before we start looking into the concept of Web 3.0, let's finally figure out what Bitcoin is. After all, he appeared at the junction of Web 2.0 and Web 3.0. Or we can say that Bitcoin became an incredible impetus for this transition. In 2008 not only a huge economic crisis happe. That year Bitcoin was also born. No one still knows the real creator (or group of creators) who made this technology. But back in 2008 almost no one had an idea what changes this technology would bring to the global economy.

3.2.3 Bitcoin or great transmission from WEB 2.0 to Web 3.0

In the book The Bitcoin Standard: The Decentralized Alternative to Central Banking, Saifedean Ammous (2018) considers cryptocurrencies as a fairly new investment option and well-known Bitcoin is the most famous cryptocurrency, but there are many more of them. These digital currencies don't have any government backing. You can buy and sell them on cryptocurrency exchanges. These currencies considered as very volatile type of an asset however it is used by some investors who also want to diversify their portfolio beyond stocks and bonds. It was some time ago, however, what we can observe now is that some of these cryptocurrencies have already begun to adopt and even improve the investment mechanisms we are used to. Nowadays, crypto currencies is not just a digital money just like money on your bank account. Most of the crypto currencies bring you some new technology. Those technologies named protocols and they allows you to do almost everything you can do in a traditional market world, and all this without government management or supervision. When you buy some kind of cryptocurrency, you buy not just a currency itself, but a key to use a technology provided by the developers of this currency which is based on specific blockchain technology.

How it works? According to Ammous (2018) Bitcoin is a peer-to-peer payment system. P2P network means an overlay computer network based on the equality of participants. Often in such a network there are no dedicated servers, and each peer is both a client and performs a server function. Unlike a client-server architecture, P2P one allows the network to remain operational for any number and any combination of available nodes. All nodes are members of the network. That means that no servers or centralized regulators are needed anymore. Of course the scalability of the network plays an important role here - the amount of transactions that could be processed by the system per minute. To ensure the functioning and protection of the system, in the P2P system cryptographic methods are used, but at the same time all information about transactions between system addresses is available and open for everyone. Hence normal electronic transaction still involved conventional money, BTC is decentralized meaning that it's distribution and exchange aren't in control by a government or any other authority. Ammous (2018) also noticed that traditional currency goes through a central payment process like your credit card company, while all your BTC transactions a processed by a large distributive computer running special software. Whenever transactions occur the

network records the SENDER'S and RECEIVER'S bitcoin addresses and the amount which was transferred and then entered this information into the end of the ledger or record called a BLOCKCHAIN. Blockchain is updating over a 100 times during the day and is sanded to all computers that are involved in processes of BTC transactions. Each transaction is encrypted with a public cryptography key and verified by multiple points in the network to ensure that every computer that processes BTC is using identical correct copies of blockchain and it's technically impossible to controvert it. Nowadays there are variety of different BLOCKCHAINs that differ in their scalability of the network and Bitcoin's network is not the best in this sense.

Ammous (2018) defined miners as keepers of a copy of the leger itself, which contains all transactions of BLOCKCHAIN. When a computer successfully processed and created a new block it is added to the Blockchain network and the system generates a new BTC that goes into the miner's digital wallet as a reward. Mining software works by gripping recent transactions into BLOCKS which are only accepted by the rest of the network if the block is hashed correctly. In case when the block was hashed incorrectly and some user finds it out, then he could declare about that so it will be changed soon by validators. In some other BLOCKCHAINS, users who mentioned this even could receive a reward for it. This process of creating a new block requires computers to find a correct numerical value and it is a time-consuming and compute - intensive process. It takes a lot of processing power to generate an appreciated amount of BTC. And since the system is designed to take about 30 minutes to successfully process of block the difficulty of mining generally increases as more nodes join network. It should be noted that this approach doesn't necessarily apply to other cryptocurrencies.

So it's obvious why people mine BTC (there is profit to be made), but why do other people want it? Ammous (2018) has seen that some people are mistrustful of banks and governments to keep their money secure and have a lot more faith in a blockchain system. Especially as more and more retailers begin to accept cryptocurrency. Others are looking for the anonymity that BTC offers. The only thing that necessarily connected you to a particular BTC address is an inscription key however you could have a new address for each transaction every time.

Some people may look at Bitcoin as an investment. But you should be very careful here because BTC is completely unregulated so there is no guarantee of its value. What can be even worse is that for example if you sent a certain amount of coins to your friend's wallet and incorrectly indicated the network parameters or address of the wallet that may even not exist. Or for example, you just forgot the password of your wallet – since then you cannot reverse the transaction or restore the wallet with a lost password and get your money back. Compared to traditional banking there is no customer support to help you with this, it is technically impossible. From one side it is a very risky step you should take to participate in this but from another this is a fair cost you should pay to get rid of regulatory oversight and control. So investing a lot of money into bitcoin, at least for now, is considerate as a "speculative" level of risk. However the BLOCKCHAIN system of Bitcoin is designed so by the year of appx. 2140 no new BTC will be produced. And it's making some believe that down the line it will be more secure virtual commodities of sorts that will provide a hedge against inflation of traditional currencies. For the same reason people invested in gold bars in the past. That sounds cool in theory but right now BTC seems to be a highly volatile asset that turns off not just mass consumers but also large market players. Bitcoin quote depends only on the balance of supply and demand, it is not regulated by anyone and no one can print as much Bitcoin as they want just like FRS did with USD in past years. Bitcoin, by its nature is a deflationary asset. That means that over the long-run series its cost will grow more and more as demand will grow. Of course it will be possible only if humanity will need this asset. The deflationary nature is a main advantage of Bitcoin compared to other world currencies and assets. Also just like purchasing a stock or even easier you can buy some crypto coins and use them in their protocol to lend/borrow or so-called stake (deposit) for a particular time. Also first Bitcoin ETFs appeared not long ago.

3.2.4 WEB 3.0

Web 3.0 is the upcoming update of the Internet, Nupur Choudhury (2014) states. This new type of Internet will be just the same as we see it nowadays except for some major changes. It will use technologies such as machine learning (ML), big data, **decentralized ledger**

technology (DLT), data will be interconnected in a decentralized way. All services will be transformed, supplemented and improved**.** We could say that the two cornerstones of Web 3.0 are the Semantic Web and Artificial Intelligence (AI). New technologies such as Blockchain and many protocols built on it will be interoperable, easily integrated, automated with smart contracts, and used to power anything. Considering how smart devices, such as phones and computers, have already changed our lives we could say that Blockchain technology and Bitcoin itself will radically change it in the next decade again.

Four key features of Web 3.0:

1. Ubiquity
2. Semantic web
3. Artificial Intelligence (AI)
4. 3D graphics (VR, AR)

3.3 Methods of time-series analysis

3.3.1 Behavioral economic and Behavioral Finance

Now I would like to consider the most important (popular) theories and hypotheses of the market analysis. It is useful to know these theories, however it is also important to remember that no unified theory can explain the financial world. During certain periods, one theory seems to hold sway only to be toppled soon after. In the science world, change is the only true constant. To understand the best way to analyze the quotes of Bitcoin we have to figure out the methods and economic theories that were used for time series analysis before its appearance and determine how they fit in the analysis of modern assets, in the era of Web 3.0.

Shinsuke Ikeda (2016) in his book dedicated to Behavioral Economics explains the term as a study of psychology related to the decision-making processes in economics to explore why people might make irrational decisions and why their behavior doesn’t follow the predictions

of regular economic models. He was saying that traditional rational choice theory states that people are can make rational and optimal decisions by effectively weighing the cost and benefits of each available option. In order of scarcity people would choose the option that maximizes their satisfaction. However Behavior Economics argues the opposite. It states that human beings are not rational much and they instead incapable of making rational decisions. And Behavioral Finance works the same way by analyzing the decision-making processes of investors in the world of financial markets. The theory looks at the irrational human tendency to quickly achieve profits by selling the title and to postpone accepting losses by preserving the asset. The fusion between classical financial analysis and behavioral finance can help investors and financial analysts to better understand the market mechanism of functioning.

3.3.2 Modern Portfolio Theory

Modern Portfolio Theory (MPT) or mean-variance evaluation, in keeping with Mayes (1983) is a famous method primarily based totally at the evaluation of predicted returns and versions of random variables. The idea shows that buyers will continually decide upon a much less unstable portfolio while a given degree of predicted go back is unstable. In addition to the precise danger inherent in every asset, Modern Portfolio Theory specializes in the interplay among property in a portfolio. It takes benefit of the truth that a negatively correlated asset can replacement for losses in any other asset. At the equal time, MPT is an extension of the diversification approach in investing, i.e., the concept that proudly owning specific varieties of monetary property is much less unstable than proudly owning handiest one type.

According to Mayes (1983), best high quality correlation among property inside a portfolio increases the portfolio's fashionable deviation and, as a result, its danger. The key to a well-assorted portfolio is to maintain property that aren't flawlessly undoubtedly correlated with one any other. He additionally said that, at the same time as all property bring a few diploma of danger, a few property, which includes treasuries, that have low dangers and glued returns through default, are taken into consideration danger-loose property.

3.3.3 Diversification strategy

In the e book relating Modern Portfolio Theory and Financial Institutions Mayes (1983) defines diversification as a portfolio allocation approach that objectives to minimizing risk and danger through maintaining a portfolio of property that aren't flawlessly correlated. There are varieties of danger: systematic danger refers back to the danger that is not in unusual place to the whole marketplace, not like idiosyncratic danger, that is unique to every asset. Diversification can't decrease systematic danger due to the fact nearly all property bring this danger. Simply correlation is the connection among variables, and it's far measured the use of the correlation coefficient, that is among $-1 \leq \rho \leq 1$.

• If the correlation coefficient is near or identical to -1 then it suggests a really perfect poor correlation among property. It approach that a high quality motion in a single is related to a poor motion withinside the other.

• If the correlation coefficient is near or identical to one then it suggests a really perfect high quality correlation. Both property circulate collectively withinside the equal course in reaction to marketplace movements.

According to Mayes (1983), best high quality correlation among property inside a portfolio increases the portfolio's deviation and, as a result, its danger. The key to a well-assorted portfolio is to maintain property that aren't flawlessly undoubtedly correlated with one any other. He additionally said that, at the same time as all property bring a few diploma of danger, a few property, which includes treasuries, that have low dangers and glued returns through default, are taken into consideration danger-loose property.

3.3.4 Efficient Market Hypothesis

For the first time EMH was invented by Eugene Fama (1965) and defined by Malkiel (1989) as a theory, which postulates that the price of any asset reflects all publicly available information about this asset. So all market movements at the current moment are instantly reflected in the quotations of securities and fully reflects their true inner value. If the market is effective about any informational message, then this information will instantly be reflected in the rate of exchange-traded assets. Let’s specify: according to the EMH, assets always trades on exchanges and represent their fair value, making it impossible for investors to beat it from

the performance perspective over a long run, unless you have some illegal inside information. In other words this theory states that investors can't buy undervalued stocks or sell stocks for inflated prices.

Simply accordingly to Malkiel (1989) EMH postulates - as much risk investors are willing to take as higher returns they can achieve. And hypothesis does not negate investors who want to have a higher return and are willing to take risks to get there. But what it is saying is that over the long run asset price reflects all publicly available information and therefore since we all have access to the same information no one can consistently beat the market. However there've been multiple studies that have proven that private information can allow investors to consistently beat the average returns of the market, hence it is a reason why insider trading is illegal in developed markets.

Fama (1965) divided the theory of the Efficient Market into different types that differ from each other by the amount of information in the price reflection. And he called them "weak-form", "semi-strong-form", and "strong-form" tests.

Table 1. Forms of Efficient Market by the amount of the information in the price reflecting.

Weak form	Supposed to refer all currently available information for a particular asset and therefore TA will never work because it essentially relies on historical repeating. Although fundamental analysis can make it possible to make a correct prediction based on a global fundamental analysis of all available information.
Semi-strength	This form also studies information (beyond historical prices) which is publicly available. At that level the price of an asset is quickly adjusted based on new information. Either way asset price reacts quickly to the information from any source. So fundamental analysis can't be used to achieve risk-adjusted returns. This type of EMH is the closest to reality scenario. In this situation the advantage is obtained by traders and investors who possess information that is not publicly easily accessible (insider information).
Strong	And in the case of a strong EMH all information (public/private or direct/indirect) which is related to our asset is immediately reflected in the movement of quotations. So none of the investors, traders, arbitrageurs or even insiders can influence the general course of the price over the long run.

3.3.5 Relevance of market efficiency

The EMH hypothesis provides all participants with equal chances and trading opportunities. However, Dhankar (2016) by studying the impossibility of artificially overcoming information efficiency, mentioned that traders and investors can look for ways to obtain sustainable profits in more subtle operations, for example, in arbitrage schemes. On the other hand, 100% market efficiency will never come, which constantly creates opportunities for earning money in a momentary situation. Nowadays many economists deny the possibility of using the Efficient Market Hypothesis (EMH) for Financial Markets analysis while all classic financial theory is based on EMH and on assumption that price changes are normally distributed.

3.3.6 Random walk motion hypothesis

This famous mathematical model, is applied in the stock market. Regarding Moinak Maiti (2021) this hypothesis states that the price of a stock can never be predicted in advance. This hypothesis puts at the front the chaotic dependence of quotes on any random information.

Mandelbrot (2006) find out that most of economists nowadays deny the possibility of using the Efficient Market Hypothesis (EMH) to analyze financial markets. While in fact all classical financial theory is based on the efficiency of the markets and the assumption that changes in asset prices are normally distributed. When Eugene Fama put forward the Efficient Market Hypothesis (EMH) in the 1970s, he illustrated that if a market satisfies this hypothesis, then it is efficient.

In the finance world regarding Mandelbrot (2006), there are two main approaches to analyzing the market which are based on mean-reversion or on momentum strategies. Both of these approaches are based on an assumption that we can find some kind of pattern or parameter in the data to predict the future value of an asset. But first we need to determine if the asset is trend-continuous or rather Momentum-based.

- Momentum-based is the strategy when investors try to use the continuous trends of the market. For example investor thinks that the price of a specific asset will show growth/fall soon and investor has an opportunity to open a long/short position.
- Mean-Reversion is a strategy when investors determine that the different specifications like volatility or stock returns will gain over time. In such cases, investors can assume that the stock price will follow the long-term pattern after some extreme event which might be either positive or negative and make money based on this.

3.3.7 Time series

Mandelbrot (2006) determined Time series as an ordered sequence of data points spread over some time. Here, time is generally an independent variable while the other variable/s keep changing values. The time-series data is monitored over constant temporal intervals. This data can be in any measurable and quantifiable parameter related to the field of business, science, finance, etc. While time series analysis refers to identifying the common patterns displayed by the data over a period of time. What differentiates time series data from other data types is that the analysis can show how variables change over time. In other words, time is a variable that shows how the data adjusts over the data points as well as the final results. It provides an additional source of information and a set order of dependencies between the data. Time series analysis typically requires a large number of data points to ensure consistency and reliability. An extensive data set ensures you have a representative sample size and that analysis can cut through noisy data. It also ensures that any discovered trends or patterns are not outliers and can account for seasonal variance. Time series data can be used for forecasting—predicting future data based on historical data. The first question Mandelbrot (2006) wanted to answer in his studies was whether the time series under study is predictable. And if the time series is random, all methods are expected to fail.

Mandelbrot (2006) identified key characteristics of a stable market: first of all it should be made up of investors with different investments opportunities. This ensures high liquidity in financial markets. Also trading volume should not be associated with Financial market liquidity. Accordingly Mandelbrot (2006) liquidity means the ability of the market to amortize

sharp changes in supply and demand so that they do not cause significant price fluctuations in the market. Simply, liquidity is the number of people willing to buy or sell an asset at a certain time by the closest to the real-time cost of an asset, so as higher the number of buyers/sellers as higher the liquidity. The source of liquidity in financial markets are investors themselves with different investment horizons, different information sets and, therefore, different ideas about fair prices of assets. Since investors with different investment horizons evaluate information differently, depending on the investment period, the dissemination of information in the market will also be uneven. Therefore, we can say that the importance of information in the financial markets is determined by the investment horizons of the majority type of investors. If there are investors with long-term investments who stop participating or become short-term investors in the market then financial markets become unstable. Prices are formed under the influence of information based on both technical and fundamental analysis.

An important role in time series analysis plays Long-term memory and it is defined by Mandelbrot (2006) as a storage of information over an extended period of time. This type of memory is quite stable and it can be stored for a very long time - often for years. While studying the Mandelbrot set he established the fact of persistence of financial markets and market prices. Persistence means the ability of a certain trend in the market to last longer than the process that created it. Based on the results of his analysis we can say that financial markets have a long-term memory, which is expressed either in persistence or in antipersistence of time series of prices. He stated that in the antipersistent ($0<H<0,5$) stochastic process, after an increase in the variable, it usually decreases, and after a decrease, an increase. An antipersistent process is characterized as “mean-reverting”, which means an up value is more likely followed by a down value, and vice versa. Therefore, Mandelbrot suggested using the Fractal Market Hypothesis (FMH) instead of the Efficient Market Hypothesis (EMH) in financial market analysis. Hence financial markets may be characterized by varying degrees of plasticity, which can be defined as the ability to take and maintain shape. This means that markets can significantly change in terms of their form and function for a certain “long” time.

Mandelbrot (2006) find out that financial market plasticity is a twofold construct and it provides for both: the ability to change and the ability to keep (maintain) shape for a long

period of time. All markets are plastic, but the degree of their plasticity can change. Studying the relationship between volatility and stability will provide a better understanding of market dynamics. He distinguishes two types of plasticity: structural and organizational.

- Structural plasticity refers to the ability of financial markets to move towards greater congruence. In other words, with the Structural plasticity of the chart, the asset price will move along an equal deviation.
- Organizational plasticity refers to the ability of a system to neutralize external structural changes through its internal structural changes.

The main aspects of the plasticity of financial markets regarding Mandelbrot (2006) are: the ability to accept, maintain, transfer, destroy form and change functions.

3.4 R/S analysis overview

Mandelbrot (2006) discovered the main method for studying the fractal structure of financial markets - R/S analysis, or the normalized range method. It was developed by the English hydrologist Harold Edwin Hirst. He was observing the flow of the Nile River back in 1951 and after studying 800 years of records in conditions of unpredictable rains and droughts that were observed over a long period of time he discovered that it was not random, but patterned. Hurst defined a constant, K, which measures the bias of the fractional Brownian motion. Further Mandelbrot and Wallis elaborated on the method. In 1968 Mandelbrot defined this pattern as fractal. There are many algorithms to calculate fractal characteristics such as fractal dimensions, which is a number that quantitatively describes how an object fills its space. Also Mandelbrot renamed the constant K to H in honor of Hurst. The form can be understood as the structure of various financial assets or products, which adapts to various external conditions. The structure of the financial markets themselves is determined by the structure of financial products, which are regulated by financial institutions. The more diverse the financial products, the more stable the financial markets. Various types of financial products form the fractal structure of the market. In other words R/S analysis is a method used for distinguishing

a completely random time series from a correlated time series. Namely to determine if some specific time series is mean-reverting, trending or random. The Hurst exponent (H) is a statistical measure which is used to classify time series. It provides a measure for long term memory and fractality of a time series. Also it has broad applicability for time series analysis.

Mandelbrot (2006) explained that Hurst exponent values are always ranged between 0 and 1. Based on its value we can classify the given time series as:

- For H < 0.5 – Mean-Reverting (anti-persistent / anti- trend) series. As smaller the value and as it's closer to 0 as stronger the pattern of the mean-reversion process. In practical situations, it means that after a high value will be a lower value and vice versa.
- If H = 0.5 – then it's a Geometric Random Walk. This means that it can go either way and there are no clear tendencies possible from the given parameters. In this case we can say that the closer the Hurst exponent to 0.5 the more efficient the market are. Often this happens as a result of a large number of participants in the market.
- For H > 0.5 – Sequences are considered persistent (Trending). A value that is closer to 1 means that the trending pattern is strong and the trend will continue. They retain the existing trend, that is, future growth will more likely be driven by past growth and vice versa. With H>0.5 most of the economic and financial time series are persistent.

Studies by many scientists including Mandelbrot (2006) show that Hurst (H) indicators which correspond to the dynamics of market prices are much more than 0.5. It shows us that the dynamics of market prices are not random at all. This could be due to two main reasons:

1. Market information is not immediately priced because investors do not have equal access to information. (Market is not efficient)
2. After a certain period, the influence of information on the prices of financial assets decreases. This is expressed in the market due to well-known psychological phenomenon - the memory of the market.

4. Practical part

4.1 Data analysis

To determine whether the price forming of Bitcoin follows a random walk or exhibits antipersistent or persistent behavior Hurst exponent will be used as a statistical measure of long-term memory of a time series.

It is useful to distinguish between random and nonrandom data points/time series. According to Mandelbrot (2006) if H equals 0.5, then the data is determined to follow a random walk. If the H value is less than 0.5, it represents an anti-persistence, meaning, if the signal is up/down in the last period then more likely it will go down/up in the next period respectively. In case the H value varies between 0.5 and 1, this represents persistence which indicates long memory effects. basically if the signal went up/down in the last period, then most likely in the next period the signal will continue going up/down respectively. This also applies to the trend: meaning that the increasing trend in the past implies an increasing trend in the future and vice versa.

4.2 Rescaled range (R/S) analysis

For a chosen asset a Hurst exponent was estimated to minimize the risk of bias selection. The Hurst exponent was estimated for the roughly a 7-years period with 2560 daily returns. 7-year periods was chosen instead of the traditional 10-year period due to the fact that the crypto market, unlike traditional markets, is open and trading 24/7.

After a careful review and data analysis I decided to add another estimation range with smaller sample size. With 2560 daily returns I was also estimating 1280 trading days. This range is two times smaller and it represents 3,7 years of daily returns instead of the 7 that was estimated before. It was made to study more cryptocurrencies and compare their behavior with quotes of Bitcoin. It was also almost impossible to find relevant data for cryptocurrencies

before the year 2018, regardless of the date of creation (appearance) of this cryptocurrency in the financial markets. The period during which the strategies were experimental implemented was different and it showed a different outcome. The period of 7 and 3,7 years was taken so that the length of the studied series is X observations which are sufficient enough to make the series divisible by 2 and it is long enough to split it into shorter time windows during the H-exponent estimation process. It also guarantees that there will be enough observations in the shortest time span.

Data itself was generated from Yahoo finance. As was mentioned before BTC – is a cryptocurrency which uses a peer–to–peer technology to operate with no central authority or banks. Transactions are managed and carried out collectively by the network. Many other crypto currencies are working the same way but not all of them.

Hurst exponent will be calculated by using rescaled range (R/S) analysis. For a time series, X = X1, X2, … Xn. The original rescaled range (R/S) analysis was used.

4.3 R/S analysis steps

1. After picking an asset that we will observe we should choose a range that we will estimate. Rescaled range analysis depends on multiple lengths of time (time windows). In our case there are two types of estimations: 2560 and 1280 daily returns. For a clearer calculation of the Hurst parameter the whole series of log returns was split up into non-overlapping time windows of length $\tau(i)$. The number of boxes 2^n was applied, where n ranges from 1 to 7, i.e. the original series of 2560 observations was split into 2 and up to 128 subperiods with the length ranging from 1280 to 20 observations. And 1280 observations were split into 2 and up to 128 subperiods with the length ranging from 640 to 10 observations.

To understand how it works let's have a clear example of both types of estimated periods:

a) Size of each range is 2560/2 = 2 ranges of 1280 daily returns

The size of each range is 1280/2 = 2 ranges of 640 daily returns

b) Size of each range is 2560/4 = 4 ranges of 640 daily returns

The size of each range is 1280/4 = 4 ranges of 320 daily returns

c) Size of each range is 2560/8 = 8 ranges of 320 daily returns

The size of each range is 1280/8 = 8 ranges of 160 daily returns

d) Size of each range is 2560/16 = 16 ranges of 160 daily returns

The size of each range is 1280/16 = 16 ranges of 80 daily returns

e) Size of each range is 2560/32 = 32 ranges of 80 daily returns

The size of each range is 1280/32 = 32 ranges of 40 daily returns

f) Size of each range is 2560/64 = 64 ranges of 40 daily returns

The size of each range is 1280/64 = 64 ranges of 20 daily returns

g) Size of each range is 2560/128 = 128 ranges of 20 daily returns

The size of each range is 1280/128 = 128 ranges of 10 daily returns

2. In the next step we need to calculate a mean deviation for each of the ranges we get in the previous step.

$$m_s = \frac{1}{n}\sum_{i=n}^{n} x_i \qquad (1)$$

Where:

n – is a size of a range for which we are calculating the mean (Mandelbrot, 2006)

s – is a series (2, 4, 8, 16, 32, 64, 128)

x – is a value of one element in a range

In this step we are finding an average of a picked time – window to calculate it from each daily- return to a mean. We can do that by subtracting the mean from a daily – the return

value. After we have a mean difference calculated for a whole data set we should create a series of deviations for each range by creating a time series of deviations using the mean for each range. We should calculate a cumulative summations (mean deviations). And this can be done by summering mean differences with all previous ones.

3. Then after creating a new time-series of mean deviations we can calculate a mean adjusted deviation

$$Y_t = x_t - m \tag{2}$$

Where:

Y – is a new time series adjusted for deviation from the mean (Mandelbrot, 2006)

x – is a volume of one element in the range

m – is a mean of the range which was calculated in a previous step

4. Next step will be a creation of a series which is running the total of the deviations from the mean. As we already calculated a series of deviations from the mean for each range in this step we need to calculate a running total for each range's deviations from the mean.

$$= \sum_{i=1}^{t} y_t \tag{3}$$

Where:

y – is a running total of the deviations from the mean for each series (Mandelbrot, 2006)

Y – is a time series adjusted for deviations from the mean

5. The next step is to calculate the widest difference in the series of deviations. It can be done by finding both the MAXIMUM and MINIMUM values in the series of deviations of adjusted means for each range. Then to calculate the widest difference we need to take a difference between the max and min.

Widest difference range (R) can be calculated a:$R_t = \max(y_1, y_2 \dots y_t) - \min(y_1, y_2 \dots y_t)$

(4)

Where:

R – is the widest spread in each range (Mandelbrot, 2006)

y – is a value of one element in the deviation from the mean range.

6. Then with the use of standard deviation which was calculated for each range the R/S statistic can be calculated considering of the ratio of the range and standard deviation.

$$S = \sqrt{\frac{1}{2}\sum_{i=1}^{t}(x_i - m)^2}$$

(5)

Where:

m – is a mean of the range (Mandelbrot, 2006)

x – is a volume of one element in the range

7. By calculating the rescaled range for each range in the time series we create a new measure for range in the time series that shows how wide is the range measured in standard deviations.

$$(\frac{R}{S})_t = \frac{R_t}{S_t}$$

(6)

Where:

R/S – rescaled range for each range in the time series (Mandelbrot, 2006)

R – is a range which was created before

S – standard deviation for the range

8. To summarize each range the average of rescaled range values need to be calculated. The arithmetic average of R/S statistics is the relevant R/S characteristics of a given a step of decomposition (R/Sτ). The Hurst exponent can be estimated by plotting log(R/S_t) against log(t) as a slope of the regression line. So basically we need to calculate R/S values for each region.

For each time slot following parameters should be calculated:

1. Average RS – is an average between RS values in a chosen time slot
2. log2(n) – is a square logarithmic value for a specific range (n) of observations
3. log2(R/S) - is a square logarithmic value calculated from the Average RS

9. In the next step Hurst exponent (H) can be found by plotting log (R/S) against log (τ /2), the slope of the resulting straight line is the Hurst exponent. The Hurst exponent gives a measure of the smoothness of a fractal object where H varies between 0 and 1. Low 'H' values indicate high levels of roughness or variability. High values of H indicate high levels of smoothness.

To calculate a Hurst exponent given steps should be followed:

- Calculate logarithmic values for the size of each region and for each region Rescaled Range.
- Plot the logarithm of the size (x-axis) of each series versus the logarithm of the rescaled range (y-axis).
- Calculate the slope of the data to find the Hurst exponent. Hurst is the slope of the plot of each ranges log (R/S) versus each ranges log (size)

The Hurst exponent is estimated by fitting the power-low to the data. This is done by taking the logarithm of both sides and fitting a straight line. The slope of the line gives H. Hurst used a dimensionless ratio R/S where S(τ) is the standard deviation as a function of τ (R/S)=(τ/2)^H

The Hurst exponent can be calculated using the following formula:

$$R\backslash S = (aN)^H \tag{6}$$

or

$$\mathrm{H} = \frac{\log(R\backslash S)}{\log(aN)} \tag{7}$$

where

- S - standard deviation of “x” series observations; (Mandelbrot, 2006)
- H - Hurst exponent;
- R - range of the accumulated deviation Zu;
- N - number of observation periods;
- a - given constant, a positive number. Hurst empirically calculated this constant for a relatively short time series of natural phenomena as 0.5. However, if the constant is equal 0.5 then with a small number of observations N, the Hurst indicator tends to evaluate them as persistent (trending) on random series, overestimating H. Therefore, for further research of market series, it is necessary to use the constant a = p / 2.

4.3 Results

Random walk is the fundamental assumption of EMH and modern portfolio theory (MPT), which are still widely applied in practice because of the nice and simple math behind them.

And that in positivists' interpretation, makes them powerful tools to understand the underlying data-generating mechanism of asset prices. However expected return and volatility cannot be estimated using the mean and standard deviation since it would lead to a serious underestimation of possible losses.

The Hurst exponent for crypto currencies was estimated. In two ways. In the range of 7 years and for 3,7 year period. First of all let's have a look at what values of Hurst exponent at different time intervals Bitcoin showed to us.

Table 2. Hurst exponent results for Bitcoin.

Coin	Time interval	Years	Hurst
BTC	3,7	2012-2015	0.72
BTC	7	2012-2018	0.67
BTC	3,7	2015-2018	0.6
BTC	7	2015-2021	0.61

As we can see in the table above the Hurst exponent decreased over time. From Hurst equal 0.72 in 2012-2015 to 0.61 in 2015-2021. The reason for this will be discussed further. The highest value of Hurst was found for the earliest period in which Bitcoin was studied.

In April 2013 the whole capitalization of Bitcoins was 1.54 billion U.S. dollars. It is such a small number compared to its capitalization nowadays - 746.82 billion U.S. dollars. It has almost 500 times increase in capitalization during the last ten years. The highest capitalization of Bitcoin currency was in November 2021 at the historical highs of Bitcoin's price. And it was an incredible 1.26 trillion U.S. dollars. Of course compared to a traditional market or real estate market with an approximate total (worldwide) capitalization of 300 trillion U.S. dollars the capitalization of crypto currencies and especially Bitcoin is not that big. But let's clarify that Bitcoin is just 13 years old.

It is very important to mention a Bitcoin's dominance in the crypto market. First crypto currency keeps the dominance of a whole crypto market on a quite high values. For example till the end of 2016 the dominance of Bitcoin didn't fall below 95%. We all might know what happened to the price of Bitcoin in 2017 - the great reckless growth. Just in one year of 2017

Bitcoin price went from 1000$ per coin in January to more than 19 thousand U.S. dollars in December 2017. At the same time the dominance of Bitcoin roughly fell to the mark of 40% of the whole crypto market capitalization and it keeps the same dominance value nowadays. This is happening the same way as in traditional markets. When the Firs crypto is growing, smart investors are trying to minimize their risks with diversification of their Portfolio. And I'm not talking about a global diversification here like in stocks or real estate. You can still diversify your crypto asset portfolio with different coins in it. It is quite logical for investors to see an opportunity in other crypto coins except for Bitcoin. If Bitcoin did that why another crypto can't. Especially when there is not any economic or global crisis on the market.

Of course when the dominance of Bitcoin is very high, just like in 2016 it's doesn't matter how you will diversify your crypto assets because the prices of crypto coins will follow the First crypto's behavior. But since the dominance of Bitcoin fell to the range between 40 and 70% it made it possible for other coins to develop and grow. There is even a special term for some time in the crypto market when the price of Bitcoin decreases slightly, or even simply corrects due to diversification of crypto assets (flow of funds from bitcoin to other currencies). It is called an altcoin season. Altcoin – is a shot form of Alternative (to Bitcoin) coins.

Since now we live in relatively low Bitcoin dominance on crypto market we can observe other crypto currencies regardless of Bitcoin's price. In our case, an attempt to predict the behavior of crypto assets may show the different result of Hurst exponent estimation in different crypto coins. But first let's have a look on so-called heat map of crypto assets correlation because it is important to see which of the coins have a high correlation with Bitcoin and which are not. This will show which of the coins might have very close results of Hurst exponent to Bitcoin. However, the correlation of assets does not always mean that the Hurst exponent will be cardinally different.

4.4 Correlation of crypto coins

In the heat map of crypto assets which I did by myself I added only those coins that were estimated by me and I tried to include as popular ones and old but still undervalued coins. To create this map of correlation I used a Spearman correlation type with a correlation window of

one week. Spearman correlation coefficient was used as an alternative to parametric Pearson correlation coefficient since the underlying data behavior was not checked and I do not apriori assume the data follow Gaussian probability distribution.

A basic principle of how the correlation of assets works was described in the chapter Diversification. Simply correlation is the relationship between two variables, and it is measured using the correlation coefficient, which is between $-1 \leq \rho \leq 1$.

- If the correlation coefficient is close to or equal to -1 then it shows a perfect negative correlation between two assets. It means that a positive movement in one is associated with a negative movement in the other.
- If the correlation coefficient is close to or equal to 1 then it shows a perfect positive correlation. Both assets move together in the same direction in response to market movements.
- If the correlation coefficient close to or equal to 0 – then there is no any type of correlation between the assets.

Table 3. Correlation map for a chosen crypto coins.

	ADA	BNB	BTC	DASH	ETH	LTC	NEO	XLM
ADA	X	0.52	0.4	0.6	0.6	0.63	0.35	0.6
BNB	0.52	X	0.4	0.58	0.62	0.46	0.33	0.51
BTC	0.4	0.4	X	0.56	0.59	0.57	0.4	0.58
DASH	0.6	0.58	0.56	X	0.55	0.49	0.65	0.4
ETH	0.6	0.62	0.59	0.55	X	0.53	0.39	0.62
LTC	0.63	0.46	0.57	0.49	0.53	X	-0.1	-0.6
NEO	0.35	0.33	0.4	0.65	0.39	-0.1	X	0.016
XLM	0.6	0.51	0.58	0.4	0.62	-0.6	0.016	X

Table 4. General rules of interpreting the correlations.

Size of Correlation	Interpretation
0.9 to 1 (-0.9 to - 1)	Very high positive (negative) correlation
0.70 to 0.9 (-0.70 to -0.9)	High positive (negative) correlation
0.5 to 0.7 (-0.5 to -0.7)	Moderate positive (negative) correlation
0.3 to 0.5 (-0.3 to -0.5)	Low positive (negative) correlation
0 to 0.3 (-0 to -0.3)	Negligible correlation

From the table above we can assume that most of the compared crypto coins have a correlation coefficient value between low positive and Moderate positive. By this we can say that most of the picked coins are rather correlated with a Bitcoin than not, but at the same time their correlation is not that high nowadays. And only in some cases we can observe a negative and sometimes a negligible correlation between some assets. At the same time I could say that when the dominance of Bitcoin was on its heights the correlation was rather high than low.

4.5 Hurst exponent for altcoins. Comparison with Bitcoin

Hence, we can say that altcoin will rather repeat the behavior of the first crypto currency than not. Now let's see what values of the Hurst exponent we got for these currencies and some of the traditional assets to have something we can compare Bitcoin with. Again, I made my research with the same time windows for crypto and 10 year time- windows for traditional markets, like NASDAQ and GOLD that have been analyzed. For a simplicity I separated a table into two parts: with short time window and with a big one.

Table 5. Hurst exponent results for different crypto coins. 3,7-year time – window.

Coin	Time interval	Years	Hurst
BTC	3,7	2012-2015	0.72
BTC	3,7	2015-2018	0.6
LTC	3,7	2015-2018	0.66
DOGE	3,7	2018-2021	0.54
BNB	3,7	2018-2021	0.63
NEO	3,7	2018-2021	0.55
ADA	3,7	2018-2021	0.64
ETH	3,7	2018-2021	0.6
DASH	3,7	2018-2021	0.59
STELLAR	3,7	2018-2021	0.53

Table 6. Hurst exponent results for different crypto coins. 7-year time – window.

Coin	Time interval	Years	Hurst
Peercoin	7	2015-2021	0.6
LTC	7	2015-2021	0.62
BTC	7	2012-2018	0.67
NASDAQ	10	2008-2017	0.52
GOLD	10	2011-2021	0.55

As we can see on the above tables a smaller time-window of a 3,7 years shows much bigger spread of outputs. During 2018-2021 most of the observed cryptocurrencies showed a value of Hurst exponent between 0.53 and 0.66 which means that it is still very close to a random walk but not really. Roughly speaking the whole range of Hurst exponent values can be divided into three groups:

- From 0 to 0.33 – is an anti-persistent series. In this range the possibility to have a mean-reversion process is incredibly high. As we see none of the observed currencies showed such behavior.
- From 0.33 to 0.66 – is a random walk series. That means that it can go either way and there is no clear tendencies possible from the given parameters. It is important to mention that often this happens as a result of a large number of participants in the market.
- From 0.66 to 1 – is a persistent behavior and this means that the trending pattern is strong and the trend will continue, no matter if it's a down trend or an up to one.

In the case of this classification we can assume that all of the observed values are under the random walk range. However, I would also like to demonstrate a similar system for dividing the values of indicators, and this time not into three, but into five groups: from 0 to 0.2, from 0.2 to 0.4, from 0.4 to 0.6, from 0.6 to 0.8 and from 0.8 to 1. Firs and last case we can slightly overlook because those are extreme values which are quite rare in the markets nature. And now when we have three ranges left we can divide them into the same classification: likely anti-persistent series (0.2-0.4), random walk series (0.4-0.6) and likely persistent behavior

(0.6-0.8). After applying this classification we can observe that even for that small range of a time window the values of Hurst are acting with likely persistent behavior.

Cryptocurrencies that exhibit the lowest estimate of H exponent in the period 2018-2021 are Stellar (XLM), DOGE and NEO. They are all old enough and all of them appeared in 2014. Values of Hurst for these currencies are 0.53; 0.54 and 0.55 respectively. They are followed by other currencies which are also quite old enough, their date of birth is 2014 as well but they tend to be more popular as the technology behind them is very useful. ETH – a basic protocol of layer two of BLOCKCHAIN which aims to create decentralized applications (dApps). DASH is a decentralized payment system. BNB – is the most famous cryptocurrency exchange with many other tools and applications. It also has its own ecosystem. ADA is a system that is focused on launching smart contracts, decentralized applications, side chains and multi-party computing. Their values of Hurst are 0.59; 0,6; 0,63 and 0,64 respectively. They exhibit the middle estimate of the H exponent in the period 2018-2021.

Let's see which currencies and in what period of time showed the highest value of the Hurst. LTC is an update of a bitcoin BLOCKHCHAIN ecosystem which is designed to increase the number of possible transactions and its simplicity. During 2015-2018 LTC showed a Hurst exponent value of 0.66. And this is almost the closest value of the Hurst exponent to a persistent series behavior in the observed currencies. And finally, the Hurst exponent value for the BTC during 2012-2015 and it is equal 0.72 which is highly persistent behavior.

4.6 Explanation of Bitcoin’s Behavior

All of the chosen cryptocurrencies showed a value of Hurst exponent much greater than 0.5 (random walk). That means that all of them can be considered as persistent. Especially if we will compare those results with traditional market assets which I also applied.

The biggest and the most famous indexes that were observed in early studies were S&P 500 and Nasdaq. These indexes includes biggest USA companies. S&P 500 include a bit more than the 500 biggest US companies and we also can say that these companies are the biggest in the

world. And Nasdaq include the biggest technology companies of the world. Here I'm talking only about the indexes prices but not about everything they have under the hood. And all of them showed very close values to a random walk. 0.5 and 0.52 respectively regarding Hurst value. Also I observed a GOLD as it is the world's most famous reserve type of an asset. That means it is also has a huge popularity in the world. Value of the Hurst exponent for GOLD for 2011-2021 was 0.55. It shows not that random behavior due to its reliability.

The basic explanation for why all the largest indexes and other famous assets like gold or silver show a Hurst value close to random walk behavior is that they are very popular. Those indexes are ruled by the most experienced and clever people in the sphere so even in tough times indexes prices might grow over time. The random walk behavior means that there are that many participants on the market with different investments horizons that none can beat a market in a long-term scale. Of course a lot of different causes may impact in it just like we have right now, but in a long-term perspective these indexes and companies that are under those indexes was shown a great stable growth over time.

Now let's return to the cryptocurrencies. Generally cryptocurrencies have the same as traditional markets behavior nowadays. Mostly cryptocurrencies show a persistent behavior and that means that the trend tends to be followed. Unfortunately as more popular the cryptocurrency became the more random its behavior is. As more participants buy or hold Bitcoin the more stable this asset became. From my point of view we are still in a quite early stage of crypto development and crypto integration into a world market. However the value of the Hurst exponent showed to us that this market is popular enough to have its place in your portfolio.

5. Conclusion

This bachelor thesis deals with a problem of selecting a proper analyze the method of a time-series which is applicable for Bitcoin-quotes analysis. Throughout history, many different theories have been presented to better understand the behavior of time series and market quotes prices. The outdated hypothesis of Efficient markets (EMH) is no longer popular such as it used before. Currently the most applicable theory is the Fractal market hypothesis

developed by Ed Peters in his 1994 book Fractal Market Analysis: Applying Chaos Theory to Investment and Economics and extended by Benua Mandelbrot. This theory uses traditional quantitative methods and other theories to explain the behaviors on investors and market participants when there are chaos and anomalies in the market. The purpose of this thesis was to find a suitable alternative to outdated theories for time series analysis and use it in practice for such relatively new assets as Cryptocurrencies, in particular Bitcoin. A sufficiently long period of Bitcoin price values was taken and after various calculations in excel with the use of statistical formulas and the indicator of Hurst, as the main parameter of the long-term memory analysis, a conclusion was made. Rescaled range (R/S) analysis was used to calculate the Hurst exponent. This method is used to identify whether the amount of persistence, randomness, or mean reversion in financial markets' time series data.

Calculations showed that from the year 2012 to 2019 the value of the Hurst exponent for Bitcoin was equal to 0.67. Although Bitcoin for some investors is a protective (hedge) asset against worldwide currencies inflation, the Hurst indicator for it is closer to a random walk. If we divide the Hurst exponent range into thirds — 0.00 to 0.33 for mean reverting, 0.34 to 0.67 for random walk, and 0.68 to 1.00 for persistence — a strong statement can be made that Bitcoin nowadays is right between random walk and persistent behavior. This is happening because more and more large investors, small speculators and real market whales (big money) are being considered for this not so raw and not so underdeveloped technology as Blockchain and in particular Bitcoin. More and more people enter the cryptocurrency market in the hope of not being left on the sidelines of real opportunities and entering possibly the future of the entire financial sector. As a result, the Hurst exponent of Bitcoin tends to random walk as he gains his popularity.

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