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Bachelor Thesis

Statistical analysis of the use of cryptocurrencies

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Faculty of Economics and Management

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Statistical analysis of the use of cryptocurrencies

Objectives of thesis

The thesis aims to understand, analyze and find patterns in the daily behavior of the largest cryptocurrencies. It is essential to understand their behaviors to make suitable investments and bear the risks in mind. The analysis output will help make the conclusions about the mentioned cryptocurrencies.

Methodology

The theoretical part of the thesis is the collection of knowledge obtained from scientific articles and publications. The practical part focuses on analyzing the behavior of the most common cryptocurrencies using time series analysis methods. The data used for this thesis is collected from Kaggle, Google Dataset and Datahub.

The proposed extent of the thesis

30-40 pages

Keywords

Bitcoin, Blockchain, Cryptocurrency, Cryptocurrency Market, Time Series

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CAMPBELL-VERDUYN, M. Bitcoin and Beyond : Cryptocurrencies, Blockchains and Global Governance. Milton: Routledge, 2018. ISBN 978-0-4157-9214-1.

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Declaration

I declare that I have worked on my bachelor thesis titled " Statistical analysis of the use of cryptocurrencies" 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 any copyrights.

In Prague on 15/03/2023

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Orhan Fatih Dos

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Statistical analysis of the use of cryptocurrencies

Abstract

This Bachelor Thesis studied the daily prices of cryptocurrencies. The reason for their volatility and why the population still invest in them has been investigated. It took a deeper look at types of cryptocurrencies and the differences between them. It looked at the blockchain technology with the way it was implemented to the cryptocurrencies to make them a secure method of payment. Furthermore, how the emergence has forever changed the economic system of the countries and will continue to influence the future will be discussed.

For the practical part, time series analysis and other various types of analysis is used to find patterns between the prices of cryptocurrencies and to try to predict prices of these cryptocurrencies using ARIMA Models. Analysis of the uses of cryptocurrencies has been made to understand where the cryptocurrencies are mainly used at. Multiple tools will be used to clean the data and make the statistical analysis. Data is obtained from multiple sources as they are publicly available. Factors that affect the prices, how this method of payment has become popular as well as how the transactions are digitally validated and added to the blockchain will be thoroughly explained. In result, it is found that forecasting of cryptocurrencies prices can be made using ARIMA Models with a high level of accuracy. It was found that the ARIMA Model's accuracy has been between 96.52% and 95.46% depending on the volatility of the cryptocurrencies. Heteroskedasticity has been seen in the data and conclusions have been accordingly and the recommendations.

Keywords: Bitcoin, Blockchain, Cryptocurrency, Economic systems, Mining, Decentralization

Statistická analýza využití kryptoměn

Abstrakt

Tato bakalářská práce studovala denní ceny kryptoměn. Byl zkoumán důvod jejich volatility a proč do nich obyvatelé stále investují. Podíval se hlouběji na typy kryptoměn a rozdíly mezi nimi. Zaměřil se na technologii blockchain se způsobem, jakým byla implementována do kryptoměn, aby se z nich stal bezpečný způsob platby. Dále se bude diskutovat o tom, jak tento vznik navždy změnil ekonomický systém zemí a bude i nadále ovlivňovat budoucnost.

V praktické části je použita analýza časových řad a další různé typy analýz k nalezení zákonitostí mezi cenami kryptoměn. Byla provedena analýza využití kryptoměn, abychom pochopili, kde se kryptoměny převážně používají. K čištění dat a provádění statistické analýzy bude použito více nástrojů. Údaje jsou získávány z více zdrojů, protože jsou veřejně dostupné. Důkladně budou vysvětleny faktory, které ovlivňují ceny, jak se tento způsob platby stal populárním a jak jsou transakce digitálně ověřovány a přidávány do blockchainu. V důsledku toho bylo zjištěno, že prognózování cen kryptoměn lze provádět pomocí modelů ARIMA s vysokou úrovní přesnosti. Bylo zjištěno, že přesnost modelu ARIMA byla mezi 96,52 % a 95,46 % v závislosti na volatilitě kryptoměn. V datech byla vidět heteroskedasticita a závěry byly v souladu s doporučeními.

Klíčová slova: Bitcoin, Blockchain, Kryptoměna, Ekonomické systémy, Těžba, Decentralizace

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List of Abbreviations

ARIMA – Autoregressive integrated moving average

ACF – Autocorroletion Function

PACF – Partial Autocorroletion Function

XRP – Ripple

USD – United States Dollar

RMSE – Root Mean Square Error

1 Introduction

Cryptocurrency and Blockchain technologies have been trending technologies of 21st century and thus combination of these technologies together have greatly increased the trust of people because of their stability and efficiency. Cryptocurrencies use cryptographic techniques for their security, and it is worth mentioning an anonymous person named Satoshi Nakamoto who invented the first cryptocurrency called Bitcoin in 2008. Bitcoin's circulation since 2009 and its exponential growth has made people change their investments to cryptocurrencies as a result introductions of many cryptocurrencies in the market.

One of the other reasons that the interest of cryptocurrencies grew was the 2008 crisis in the world. Before the crisis many people trusted in the banks thinking their money would be safe but the problem with the banking systems was that banks also give loans and invest too. So, during this time, many banks faced many problems and some of them had go for bankruptcy. Many people lost so much money even if the National Banks try to provide the money lost but it is never the exact amount, so people wanted to invest somewhere else and with how safe blockchain is and with its' anonymity, it drew many people's attention. It also gave transaction power from institutions to individuals.

This power, anonymity and non-traceability of cryptocurrency transactions have also been a gateway to illegal transaction such as money laundering, but this is not what we are going to concentrate but rather analyse the prices of these cryptocurrencies. Bitcoin for example isn't backed by anything and it's the people that make a cryptocurrency valuable by the market cap which will also be talked about. Even the United States Dollar was originally backed by silver or gold.

We certainly can't see or know the future of cryptocurrencies because of their volatility, we can only analyse and try to understand how they might behave by analysing the previous behaviours using data analysing methods, but we can be sure about the fact that the future of financial systems will never be the same as the way it was yesterday.

2 Objectives and Methodology

2.1 Objectives

The thesis aims to understand, analyze and find patterns in the daily behavior of the largest cryptocurrencies. It is essential to understand their behaviors to make suitable investments and bear the risks in mind. The analysis output will help make the conclusions about the mentioned cryptocurrencies.

2.2 Methodology

The theoretical part of the thesis is the collection of knowledge obtained from scientific articles and publications. The practical part focuses on analyzing the behavior of the most common cryptocurrencies using time series analysis methods and forecast them using ARIMA Models with Jupyter Notebook. The data sets used for this thesis is collected from Yahoo Finance. ARIMA model is denoted by ARIMA(p,d,q). These values need to be entered before as they define the ARIMA Model. PACF plot will be used to find the best 'p' value which refers to the order of the autoregressive component of the model. Augmented Dickey Fuller Test will be used to check if the data is stationery or not. If the data is stationery, we need to difference it using the 'd' value. ACF plot will be used to find the 'q' value which also refers to moving average component of the model.

3 Literature Review

It is important to talk a little bit of how we have found ourselves where we are now with the current financial system before talking about cryptocurrencies.

It all started with exchanging of goods between people. This method of payment is called barter which didn't involve any cash or coins as the goods exchanged were the medium of payment. Later, people started using gold or silver coins as a mean of payment since they are durable, divisible, and limited supply. The problem was that it was difficult to carry tons of gold from different countries and to solve this problem, cash was invented, and later credit cards were introduced to make payments even easier, and the trust model of money changed as a piece of paper can worth so many things now. The money that everybody holds or keeps in their bank account are worth the value that the controller of that currency says it is. The same controller of a country's currency is the government of that country. We can also call these currencies the government-backed currencies which are the trust of the people. (Lewis, 2021)

To send money to family members or friends have been expensive ever since as there are middlemen and banks which charge for the service of sending the money on behalf of you and they are slow as payment systems used today are outdated. People don't have power over their money. Currencies of Venezuela's or Iran's value skyrocketed for example when the government printed so much money and the value that people possessed dropped day by day. Cryptocurrencies are promising to be solutions to the mentioned problems above. (Kiana Danial, 2022)

3.1 Definition of Cryptocurrency

Cryptocurrency is a new digital currency which uses the blockchain and the cryptographic techniques for its security. Thanks to the technologies that they use, they make transactions faster and easier. Cryptocurrencies are kept in cryptocurrency wallets and to perform a transaction with a cryptocurrency, it is necessary to own a cryptocurrency wallet. (Kiana Danial, 2022)

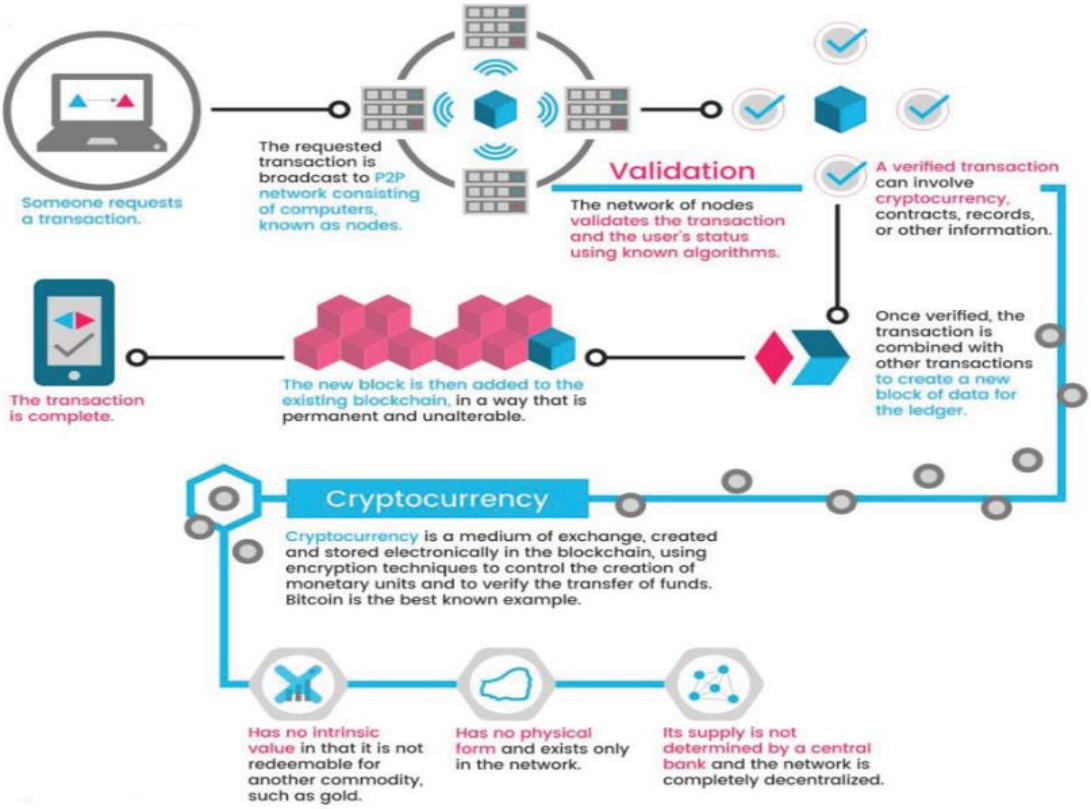
There are currently 2,322 cryptocurrencies on the market with the market value of 349 billion USD. (Shrivastava 2020). The main reason for the growth of the cryptocurrencies were the 2008 world economy crisis and investors wanted to invest in a new field. From that

point on, cryptocurrencies remained a hot top of interest with getting more attention day by day. (Gulshan Shrivastava, 2018)

Other great thing about cryptocurrencies is that the system that cryptocurrencies are built on cannot be controlled in a way by governments but can only accept it as a legitimate method of payment or trading since they are so difficult to control them in any way. (Milutinovic, 2018)

Some countries have completely banned cryptocurrencies from trading while some countries have partially allowed the trading, and some have completely made it legal. Countries have mixed feelings about adopting cryptocurrencies because they are worried that in case of a need to interfere would make it impossible to steer the economy in crisis times and it can affect thousands of families and direction of a countries economy since these systems are so difficult to control as mentioned above but the fan number of it are increasing in an exponential growth. (Milutinovic, 2018)

Figure 1*:* How miners create coins and confirm transactions



Source: (Milutinovic, 2018)

The whole system of a cryptocurrency is based on a simple principle called peer-to-peer technology. Every peer has a record of the past transactions that were made. When a new transaction is made between two parties, the file consisting of the transaction will be sent together with a private key and broadcasted into the network once it is signed so that it can be passed on from one peer to other peers. There is a period for a transaction to be confirmed depending on the amount of the coin. Confirmation is a very important part of this process as confirmation of peers of a transaction is one of the most important parts of the cryptocurrency transaction and once it gets confirmed, it will be written in the historical transactions of the blockchain and spread through the network by the miners. Miners get pain in the cryptocurrency that they are mining for the work that they have done. (Milutinovic, 2018)

3.1.1 Bitcoin

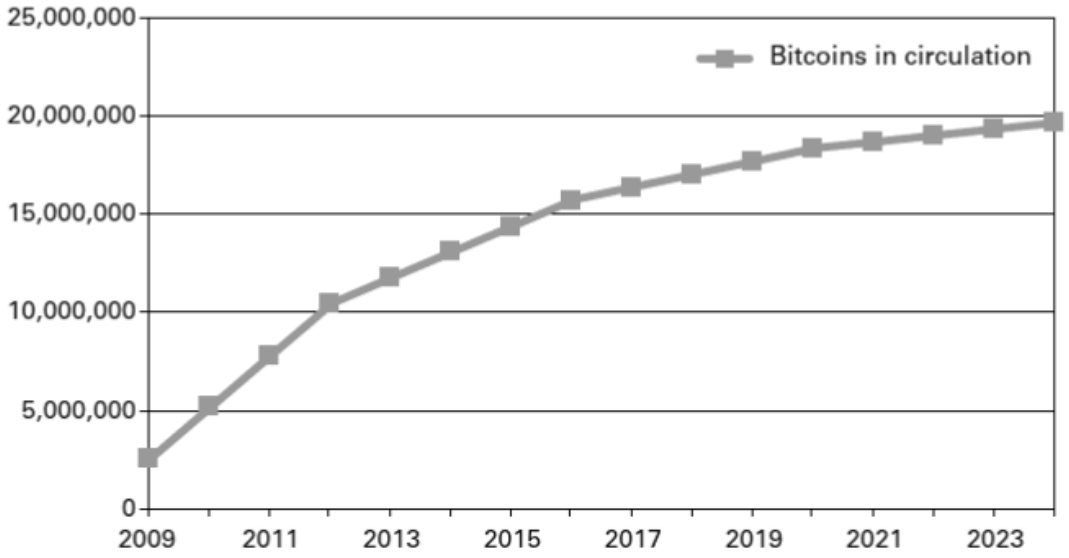
First thing that can be said about Bitcoin is the popular meme „There is no CEO of Bitcoin!“. It was a manifesto that was published by an unknown person Satashi Nakamoto from Japan. This is the name behind the creation of Bitcoin. It is believed to be either a person or an anynymous organization that believe that people should have the power to send online payments to eachother without going through a financial institution. He believes that proof is rather more important than trust in an electronic payment system. He mentions in his 9 paged manifesto that financial institutions which are believed to be trustworthy are prone to hacking thus many people's personal information are stolen and on top of that he mentions the fact that financial institutions accept a certain percentage of fraud as unavoidable. He also states the sad truth that the only way to avoid this is using physical currency and that there is no communication channel to make payments without a trusted party and he introduces the technology behind Bitcoin in this very same manifesto. (Nakamoto, 2018)

Huge companies has spent and will continue to spend millions of dollars, hire thousands of people to safeguard their customers but yet they still get hacked as everything is hackable but the exception is Bitcoin. No one ever sat down in a conference hall and try to come up with an idea to develop Bitcoin or ever hid away its source code but everything has been publicly available and yet Bitcoin has still not been hacked. Bitcoin is not secured by an organization, government or a financial institution. Bitcoin security system is in its code and this something which many people believe can not be done by one person and that

is why it is also believed that Satoshi Nakamoto is an organization that voluntarily created Bitcoin. (Lewis, 2021)

The total amount of Bitcoin that will ever exist will be 21 million. Currently two thirds of Bitcoin already exist and the last mined Bitcoin will be somewhere around 2140. The Bitcoin network issues new Bitcoins every 10 minutes and every 4 years, the issuance of Bitcoins gets halved. By doing this, the value of the bitcoins get more valuable. This halvening is automatic. When Bitcoin first came to existence, the network used to issue 50 bitcoins every 10 minutes and this first got halved in 2012 to 25 and the next one was in 2016 from 15 to 12.5. This value even dropped to another half in 2020 to 6.25 Bitcoin per block and the next halvening period will be in 2024 and this amount will drop to 3.125 Bitcoins and this will increase the value of Bitcoin even more since there will be less Bitcoins than the demand. (Lewis, 2021)

Figure 2: Bitcoin Issuance Schedule



Source: (Milutinovic, 2018)

This scheduled halvening is one of the reasons that influence the value of a bitcoin. It is important that this is not the only factor that influence the price of a Bitcoin so this can not be directly the cause of price change. We can observe from the chart that we are almost at 20 million and the other 1 million of Bitcoins will be issued in the coming 120 years.

3.1.2 Alternate Cryptocurrencies

Alternate Cryptocurrencies also known as Altcoins are all the other cryptocurrencies other than Bitcoin. These are cryptocurrencies that are inspired by Bitcoin. We can also say that some of them are modified version of Bitcoin. The first cryptocurrencies that were created after Bitcoin were mainly scams to try to give empty hope to people and most of them only took 1-2 weeks for them to disappear into the cryptocurrency graveyard. Some of them have interesting technologies and ideas behind them that could also be used to support other features of global payments. As there are thousands of altcoins in the past and currently that we are only going to be talking about a few of them. (Lewis, 2021)

There are many alternative cryptocurrencies out there now but the ones that are worth mentioning are:

- **Ethereum:**

  This alternative cryptocurrency was created by Vitalik Buterin a Canadian-Russian crypto-genius. He is a big fan of Bitcoin. There are many similarities between Bitcoin and Ethereum as they use the same decentralized public track and blockchain technology. This cryptocurrency was first publicly available in the middle of 2015. Vitalik used the code of Bitcoin as its coin is publicly available. They use the same technology, but they are completely different in terms of design and their usage in the real world. Ethereum is programmable in a way that it can host many projects(applications) within its network and provide many services with a few tweaks while Bitcoin is only a payment network is Ethereum received huge attention from many corporations because of Smart Contracts. Smart Contracts are algorithms that automatically fulfils the terms of the contracts once the conditions are met. Other aim of Ethereum is to build and be the internet of its own. It also hosts other Tokens within its blockchain network, currently circulating Ethereum is 122,581,661 according to coinmarketcap which is one of the biggest cryptocurrencies and NFTs trading website on the internet. There are many people that people believe in Ethereum as it has big potential to be even bigger than its current size. It is the second most valuable cryptocurrency right after Bitcoin. (Lewis, 2021)

XRP:

XRP is a cryptocurrency which was released in 2012 by Ripple Company. XRP is the cryptocurrency which uses Ripple's payment network. Ripple Company is the owner of XRP. This is what makes XRP interesting than the other altcoins. It is a cryptocurrency which uses the same technologies as Bitcoin which is peer-to-peer technology, but the interesting thing is that source of XRP is privately owned by this same very company. Its aim is also to be able to make payments globally without financial institutions. The question arises how it can serve the same purpose of Bitcoin. Well, the answer to this is that Ripple's network can be run without the Ripple Company. It has validators such as companies, internet providers and Massachusetts Institute of Technology. This cryptocurrency has been in the market for almost 10 years now and it can be confidently said that its one of the most popular alternative cryptocurrencies out there in the cryptocurrency world. Many banks use Ripple's technology as a basis to their own settlement infrastructure. We can say that Ripple is a new version of Bitcoin as it has tried to eliminate the shortcomings of Bitcoin. (Jani, 2018)

It has its transactions verified by its members rather than miners like in Bitcoin. It also uses less electricity than Bitcoin and faster than Bitcoin. Because of their fast instant payments, Ripple's transactions fees are much cheaper than of Bitcoin. To make Ripple secure, Ripple depends on independent validating servers which validate the transactions and constantly compares each other's records. With the Ripple's technology, you can transfer literally nay types of currency such United States Dollars, Euros or even Airlines miles and of course XRP transaction fees are much cheaper than other currencies transfer fees. For non-native currencies transactions, Ripple charges transaction fees to protect the network from hackers flooding the system to make it much more expensive for them to do such a thing which will harm the eco system of Ripple. (Jani, 2018)

One of the greatest things of Ripple which is the founding of XRP is that it has enabled financial institutions to communicate and make payments with each other directly rather than depending on other banks too. Only 100 billion XRP were created to make it a scarce cryptocurrency. It is also the only native digital asset of Ripple network. Compared to Bitcoin, an XRP transaction take less than 4 seconds while a Bitcoin transaction average 70 minutes to be cleared. (Jani, 2018)

- **LiteCoin:**

  Litecoin was first presented to the public in 2011 by Charles Lee who is a former employee of Google and the creator of Litecoin. It is peer-to-peer internet currency that uses the same technology as Bitcoin. Its main goal is to provide a decentralized global payment network. It is very similar to Bitcoin and just like other cryptocurrencies, it is slightly improved version of Bitcoin. LiteCoin. (Milutinovic, 2018)

  Traders can trade greater amount than Bitcoin with LiteCoin and it aims to process the payments in 2.5 minutes compared to Bitcoin which is 10 minutes meaning faster transactions confirmation. LiteCoin uses script algorithm for the miners to mine Bitcoin and LiteCoin at the same time. LiteCoin can have a total of 84 million LiteCoin. It is important to mention that miners are rewarded with LiteCoins as transaction fee. LiteCoin is considered a younger brother of Bitcoin and it is a backup of Bitcoin just in case Bitcoin fails. (Tobby Gibbs, 2014)

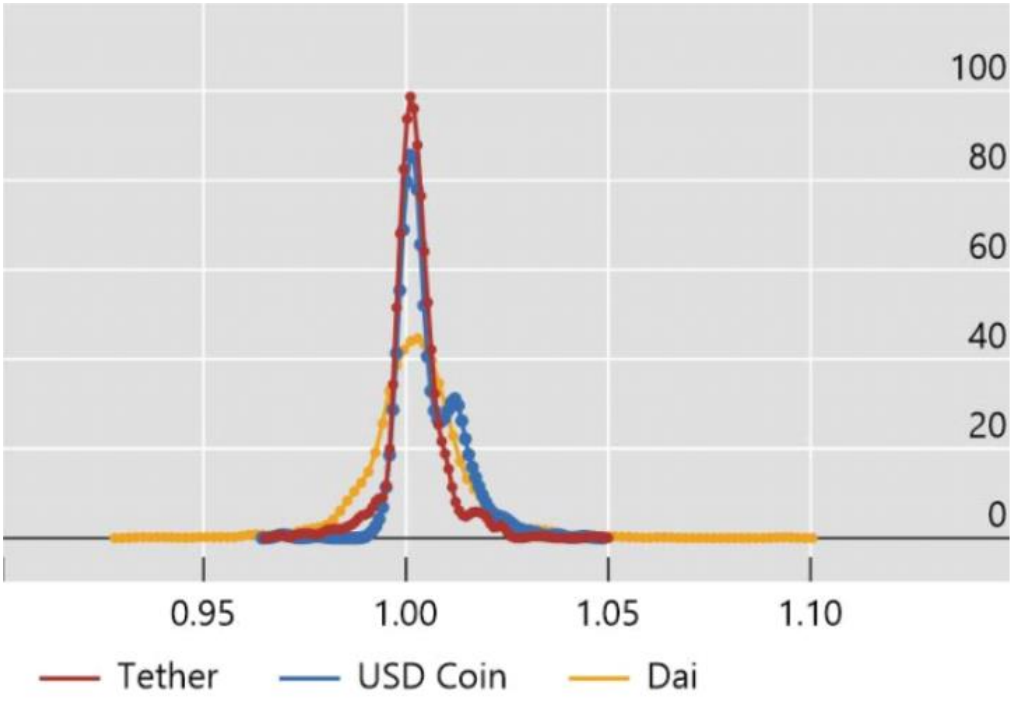
3.1.3 Stable Coins

Stable coins are digital assets that are stable value against one or more fiat currencies. Fiat currencies are currencies which are government backed and issued currencies. Stable Coins were first introduced when Bitcoin and other altcoins had their first high price volatility. One of the most popular stable coins at the market are Tether and USD Coin.1 Tether United States Dollar for example is equivalent to 1 United Stated Dollar. These very same stable coins instead are used as digital forms of the fiat currencies now like the United States Dollar (USD) or Euros since there were no digital forms of the fiat currencies at the time. They are the support between crypto-assets and fiat currencies. Due to this reason, Cryptocurrencies especially Bitcoin started to be used as an asset investment and an instrument of trade due to its high volatility instead of decentralized payment method. Stable coins have been generally the most common means of putting funds in and out of the crypto trading platforms such as Binance, Crypto.com and Plus500. One other use of Stable coins is transferring fiat valued currency without a centralized network which makes it cheaper and faster. Stable coins have the potential to challenge the current card payment systems too. (Douglas Arner, 2020)

To achieve these goals though, stable coins must have a stable value. Stable coins though had their ups and downs to when they didn’t value the fiat currencies value at the

time, but they are still much less volatile than cryptocurrencies. Some policymakers though consider stable coins neither stable nor coins. Even if they haven't been so accurate with their stability, in mid-2018, 80% of Bitcoin transactions involved one side of trading using Tether. (Douglas Arner, 2020)

Figure 3: Days traded at each price



Source: (Douglas Arner, 2020)

Figure 3 shows stable coins daily traded prices to how many days these prices were traded for in 2018 and we can read from the histogram that stable coins didn't have a stable value during the whole year. Tether for instance had 100 days of the value 1. Dai coin had 40+ days and USD Coin had close to 90 days and other than that some days these coins were traded at 0.97 or 1.05.

Although they haven't been so stable, they have been trusted by traders because of its small volatility. But we can understand from the histogram the aim of stable coins. When compared to cryptocurrencies, they have a very small volatility which is why the market cap of these coins are 152.19 billion Dollars according to Statista.com (Douglas Arner, 2020)

3.2 Blockchain

Blockchain technology is a tamper resistant technology digital ledger which are publicly available and is not controller by a central authority. Simply put, it is a digital shared ledger which enables a community to record its transactions and under normal operations of the ledger, a transaction cannot be changed once published. (Dylan Yaga, 2018)

It is not controlled by any one and in 2008, this idea was combined along with other technologies to create a cryptocurrency. It was protected by cryptographic mechanisms and not by a central authority. (Dylan Yaga, 2018)

In Blockchains, an information is attached to a digital address in the bitcoin and when a user transfers the to another user, all other users are informed about this change, and they verify the change independently. This idea behind the blockchain makes it a tamper resistant digital ledger trusted by millions as of today. There is a new trend of Blockchain technology is being tried to develop into applying into every sector today, but it cannot be denied that the most common use of blockchain technology is in the cryptocurrency sector. It is also important to acknowledge that blockchain technology usage in the cryptocurrency technology is just a part of a component. (Dylan Yaga, 2018)

There are 2 types of high-level approaches of blockchain. From the word itself, it is possible to derive a meaning from it. Even though there are many approaches to the blockchain technology, most blockchain networks use a common core concept which is a blockchain network is a distributed ledger which contains blocks. Each block contains a block header with contains a metadata and the block data contains information about transactions with the header also containing a cryptographic to the previous block. (Dylan Yaga, 2018)

- **Permissionless**:

  Permissionless blockchains are decentralized ledger platforms which are accessible by anyone and can be accessed by agreeing to download it. In permissionless blockchains, anyone who can access the blockchain can read or issue transactions without the permission of an authority. Due to the freedom that permissionless blockchains provide, malicious transactions may be entered that may result in malicious users publishing transactions to subvert the system. To avoid this, permissionless blockchain use a system called consensus or multiple agreement which is the process of other users or the so-called miners to approve the block

entered by a user and maintain it. Thus, this makes it very hard for the same malicious user from entering false transactions. By doing this, users get motivated to maintain the network and enter non-malicious blocks and reward with the native cryptocurrency of the network. (Dylan Yaga, 2018)

- **Permissioned**:

  Permissioned blockchain networks are the ones' where only authorized users are allowed to either read, access, or write to the network. It depends on the permission that they are given by the controlling people or authority of the network. These networks can either be decentralized or centralized but there always must be an organization, group of people or a person being owning the permission of the network to main the network. These type of blockchain networks are great for organizations or companies that want to use the blockchain technology. Users of these networks are not anonymous since they need to be authorized to see, send, or receive transactions. In this matter, it is easy to punish the offenders as the network maintainers are aware of the user who caused the damage to the network. (Dylan Yaga, 2018)

3.2.1 Consensus Models

An important part of blockchain technology is deciding who is going to add the next block. The reason for this is, whoever adds the next block first is the user who gets the reward or so called the transaction fee. Many publishing nodes compete for this and even though these nodes. These users usually don't know each other except from their public addresses. Blockchain technologies use the consensus model to enable group of competing users to work together for the blockchain. (Dylan Yaga, 2018)

There is always the genesis block which is pre-determined by the creator of the blockchain network. All the other blocks are added after this very same genesis block and thus users accept the state of the system. Users that join the network must accept the current state of the system and continue from there and to earn rewards, they need to be verifying transactions and whenever there are 2 valid chains, the

system will choose the chain with the longer chain because that is the chain with the one where the most work is put into. (Dylan Yaga, 2018)

3.2.2 Proof of Work Model

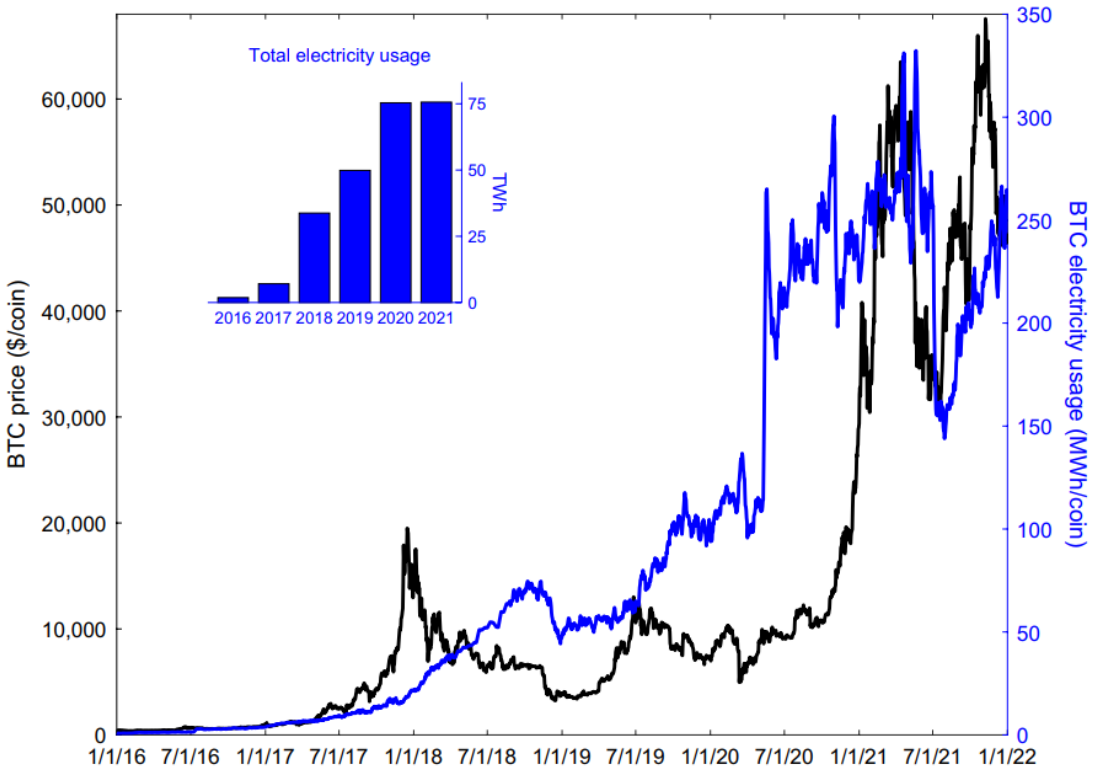
In the proof of work model, users or so-called miners try to solve complicated computationally intensive problem to publish the next block. By solving the puzzle is proof of work that the user worked to solve the problem. The problem is hard to solve but it is easy to verify if the solution solved is correct or not. If a miner solves the block problem and solves the problem and if the solution is wrong, proposal to add the block will be rejected subsequently. (Dylan Yaga, 2018)

One of the puzzle methods that make the mining process a computationally intensive process is to require the block header hash digest to be less than the target value and every time these nodes make small changes to the block header, they are supposed to compute for the entire block header. As technology improves and higher computational power is achieved but the problem that arises is that blockchain increases the difficulty of the puzzle problems every 2016 blocks to main the publication of blocks to every 10 minutes and to make it difficult for no entity to take over the block production. (Dylan Yaga, 2018)

3.2.3 Energy Consumption of Crypto Mining

One of the issues of cryptocurrencies are the crypto mining are the energy consumption. The process that are explained above require lots of energy. There are researchers made to understand the real impact of crypto mining to the world but especially Bitcoin mining since Bitcoin make up most of the Market Capitalization of 40% as of October 2022 according to coinmarketcap.com and this value was higher before the emergence of many other alternative coins and due to this Bitcoin itself made up more climate damage than all the alternative coins together. (Benjamin A.Jones, 2022)

Figure 4: 7 days averaged daily usage of mining activity per coin



Source: (Benjamin A.Jones, 2022)

We can depict from **Figure 4** that the electricity usage of Bitcoin mining is extremely high. In 2022, electricity usage goes up to 250 MWh per coin. This is equivalent to 250.000 KWh. This sounds a lot, and we cannot refuse that it is a high electricity consuming industry and Power of Work model of bitcoin network is one of the culprits of this electricity usage, but we cannot also look over the fact that market capitalization of Bitcoin had an approximation of 960 billion Unites States Dollar by December 2021. One of the other reasons for this much of energy compensation is because of the competition between the miners. Miners use as much as computation power that they can use to get the reward for adding a block and as discussed earlier, for a block of code to be added to the blockchain, they need to be quick and solve the puzzle problem as fast as possible and it creates this winner takes all type of rivalry. (Benjamin A.Jones, 2022)

Figure 4 estimates have been generated by using the network hash rate data and data on equipment power consumption and efficiency. (Benjamin A.Jones, 2022). According to this estimate, bitcoin mining used a total of 75.4 TWh yr-1 in 2020 which is more energy used by Austria and Portugal (69.9 TWh yr-1 and 48.4 TWh yr-1). (Benjamin A.Jones, 2022)

According to estimates of Cambridge University, 61% of mining energy comes from non-renewable energy sources such as gas and coal while only 39% of energy sources come from renewable energy sources and each Bitcoin created resulted to 11.314$ of climate damage with all cryptocurrencies included resulted in 3.7 billion Unites States Dollar in 2021. It is important to note that these values are only estimates as there are no direct data to be worked on and analysed. The reason why these values have so high in terms of use of non-renewable energy sources are because of China banning the mining of cryptocurrencies in 2021 since it is assumed that Chinese miners used mainly renewable energy resources and their exit have made the estimates different as suggested that energy sources consumption might have been different and when compared to other commodities, Bitcoin is once again clearly shown its energy consumption. (Benjamin A.Jones, 2022)

4 Practical Part

In this section, ARIMA model is used to forecast the 4 cryptocurrencies that were previously explained in details. These cryptocurrencies are Bitcoin, Ethereum, LiteCoin and XRP. The datasets have been downloaded from www.yahoofinance.com. ARIMA model are popular time series modelling techniques and are widely used in the financial markets.

The ARIMA models have its' weaknesses and strength. Comparisons are to be made on how well they will be used to forecast the prices of these respective cryptocurrencies.

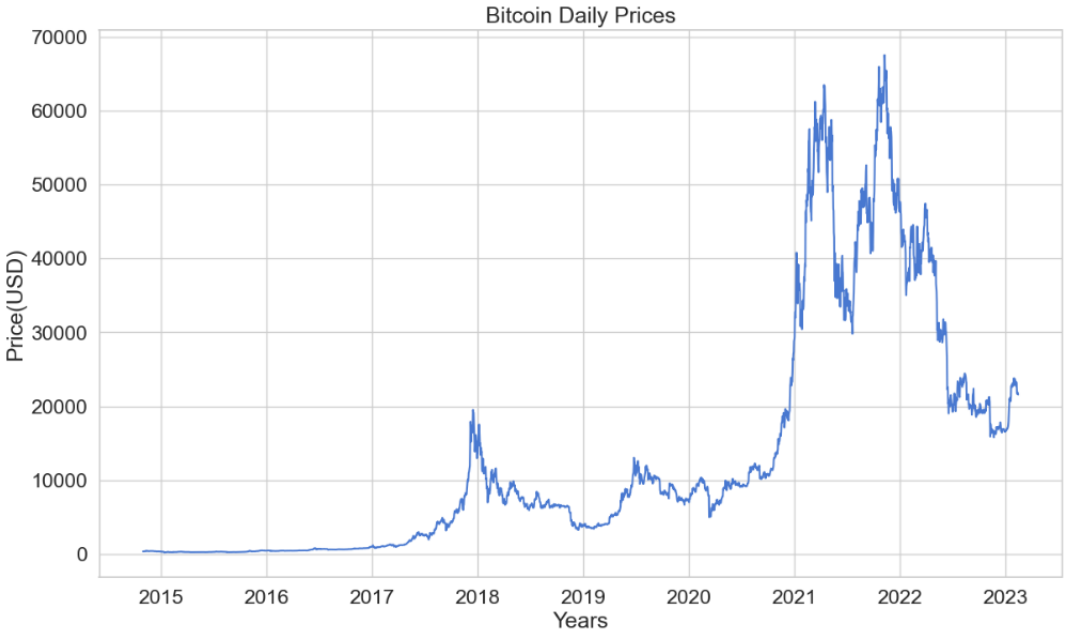
4.1 Datasets

4.1.1 Bitcoin Dataset

Daily Bitcoin prices is between the dates 01/11/2014 and 13/02/2023 which makes it a length of 3027 rows without any missing data so it is ideal for forecasting as missing data will allow more accurate forecasting and reliable analysis. The closing price in the first point of the dataset is 325.748 USD while the closing price of Bitcoin in the last day of the dataset is 21568.197 USD and just from here it is worth mentioning there has been a positive linear relationship between time and the price of Bitcoin and how volatile it is.

All-time high price of Bitcoin so far is 67566.828 USD and all-time low price is 178.102 USD in the dataset. The current growth rate of the dataset is 6548.75% as it was calculated using the first price of the dataset and the last. This shows that the value of the Bitcoin increased by over 66 times. All time high growth percentage can give a more different percentage. It is also worth mentioning that until the mid of 2017, Bitcoin prices were still not increasing as much as it would in the coming years from 2017.

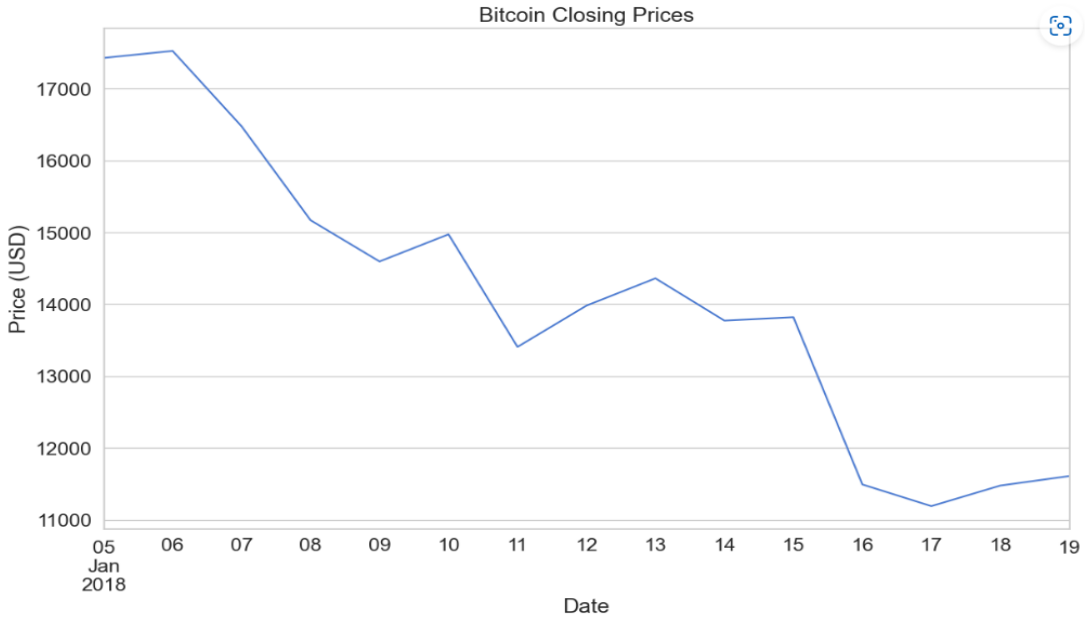
Figure 5: Bitcoin Daily Prices



Source: Yahoo Finance, own work

One of the years when Bitcoin really had an increase was in 2017 when the closing price in January was in the range of 900 USD while the closing price in the last day of 2017 was in the range of 14000 USD. Prices continued to soar in the first month of 2018 until 17500 USD when by the end of January, the closing price was 10200 USD. Between the dates 05-01-2018 and 19-01-2018, the price of plummet by 33.40% as this downward trend can be seen in **Figure 5.**

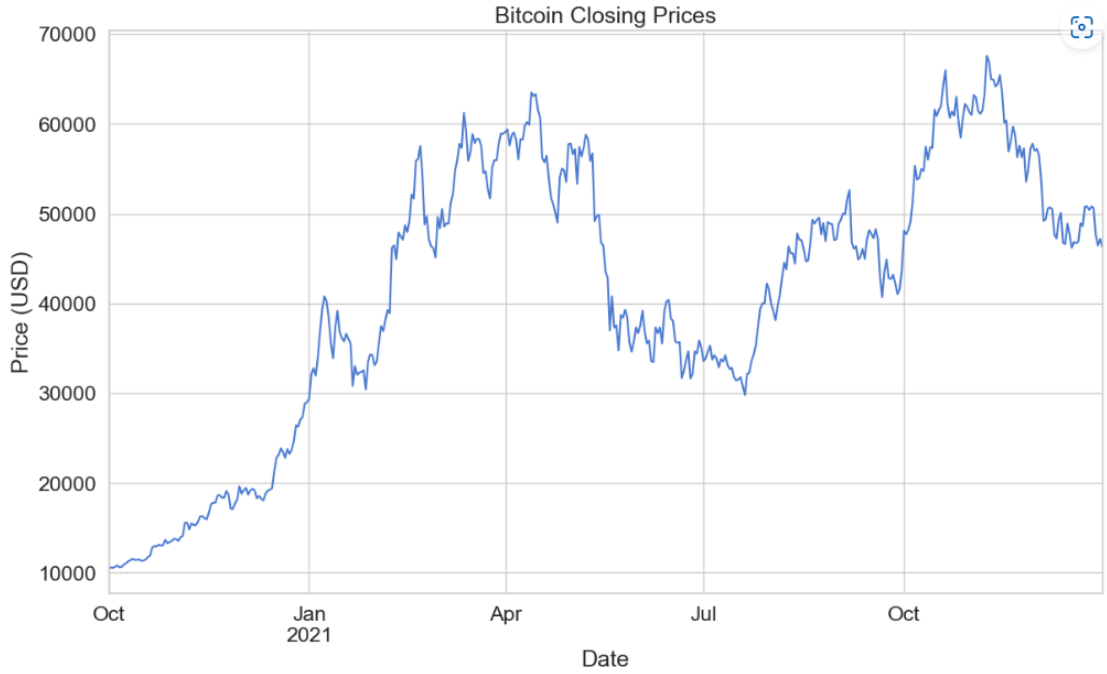
Figure 6: Bitcoin Closing Prices between 05/02/2018- 19/01/2018.



Source: Yahoo Finance, own work

Just within 3 months which were the months of October,November and December of 2020, the prices soared from 10619 USD to as much as 29374 USD which gives a growth rate of 176.61%. The upward trend didnt end here but continued also until the 60000s then dropped to the range of 30000 USD by June of 2021 and started to follow the upward trend with prices all the way up to 67506 USD after going down all the way to 33114 USD by the end of 2021. It is worth mentioning that last months of 2020 and the whole year of 2021 has been a rollercoaster just like all other years but this time with very high values as it is clearly shown in **Figure 7**.

Figure 7: Bitcoin Closing Prices between 01/10/2020- 31/12/2021.



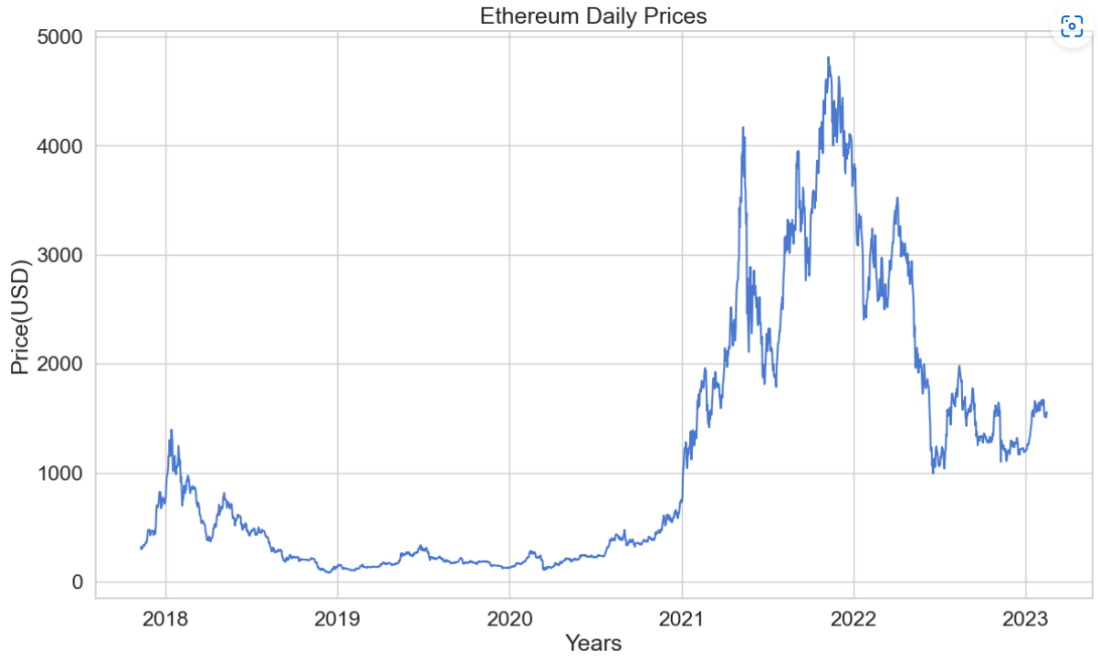
Source: Yahoo Finance, own work

4.1.2 Ethereum Dataset

Daily Ethereum prices ranges between the dates 09/11/2017 and 15/02/2023 which makes it a length of 1925 rows without any missing data. The closing price in the first point of the dataset is 320.884 USD while the closing price of the last point dataset is 1547.332 USD.

All-time-high price of Ethereum so far is 4812.087 USD and all time all time low is 178.102 USD in the dataset. The current growth percentage of the Ethereum closing price in the dataset is 382.20% as it was calculated using the first closing price of the dataset and the last. This shows that the value of the Ethereum increased by almost 4 times.

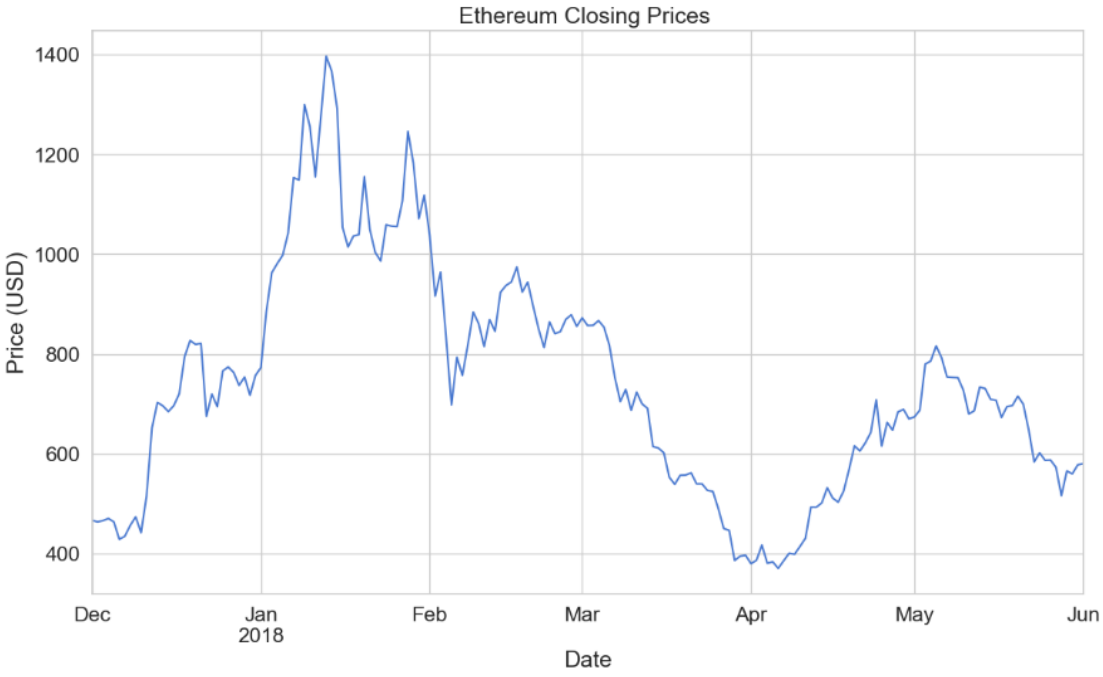
Figure 8: Ethereum Daily Prices



Source: Yahoo Finance, own work

The closing price of Ethereum in the year end of 2017 was 756.73 USD while Ethereum traded at 486.54 in the beginning of December 2017. This shows a growth of 55.53% only within one month. This upward trend continued only until the end of January 2018. An all-time high price until that time was seen in 13th of January 2018 which was 1396.41 USD according to the dataset obtained as it can be in **Figure 9**.

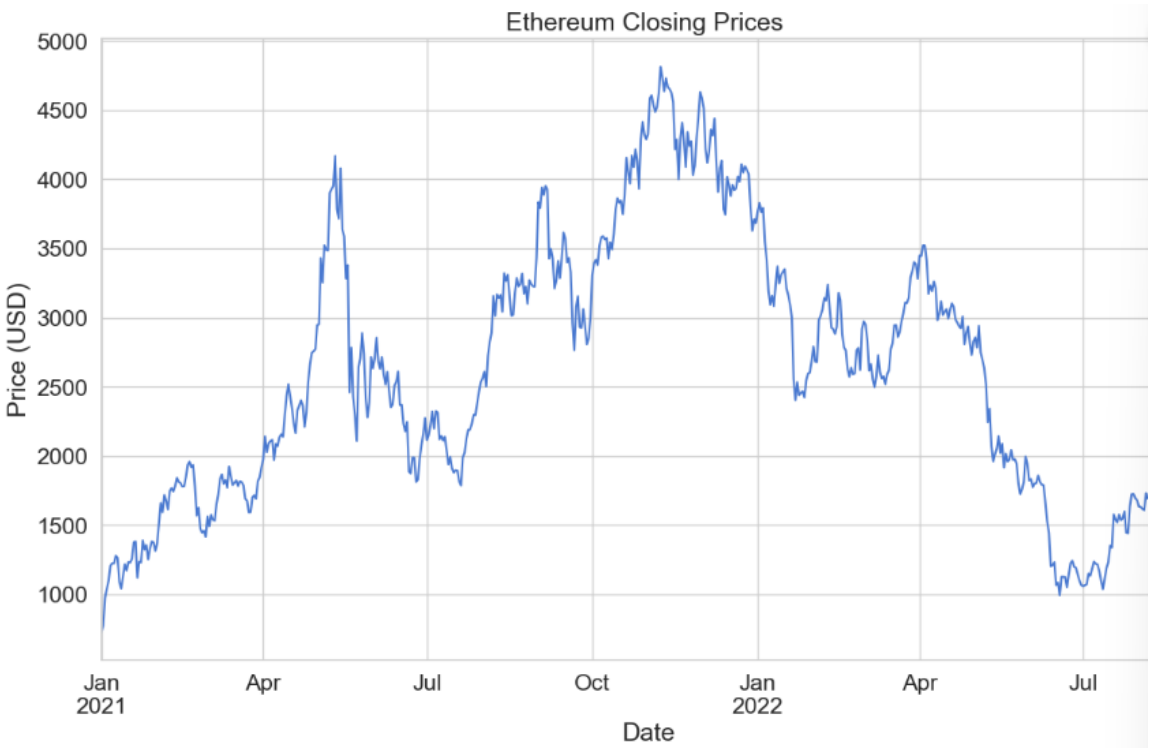
Figure 9: Ethereum Closing Prices between 01/12/2017-01/06/2018.



Source: Yahoo Finance, own work

Prices started to soar again, this time in the beginning of 2021 until the end of 2021. Prices went up all the way rom the ranges of 500 USD to 4100 USD till middle of May then went down till the range of 2000 USD once again in the last days of May. The prices started to soar in the mid of July until mid of November when the all-time high value was recorded in the whole dataset on 8th of November 2021 with a closing price of 4812.08 USD.

Figure 10: Ethereum Closing Prices between 01/12/2017-01/06/2018.



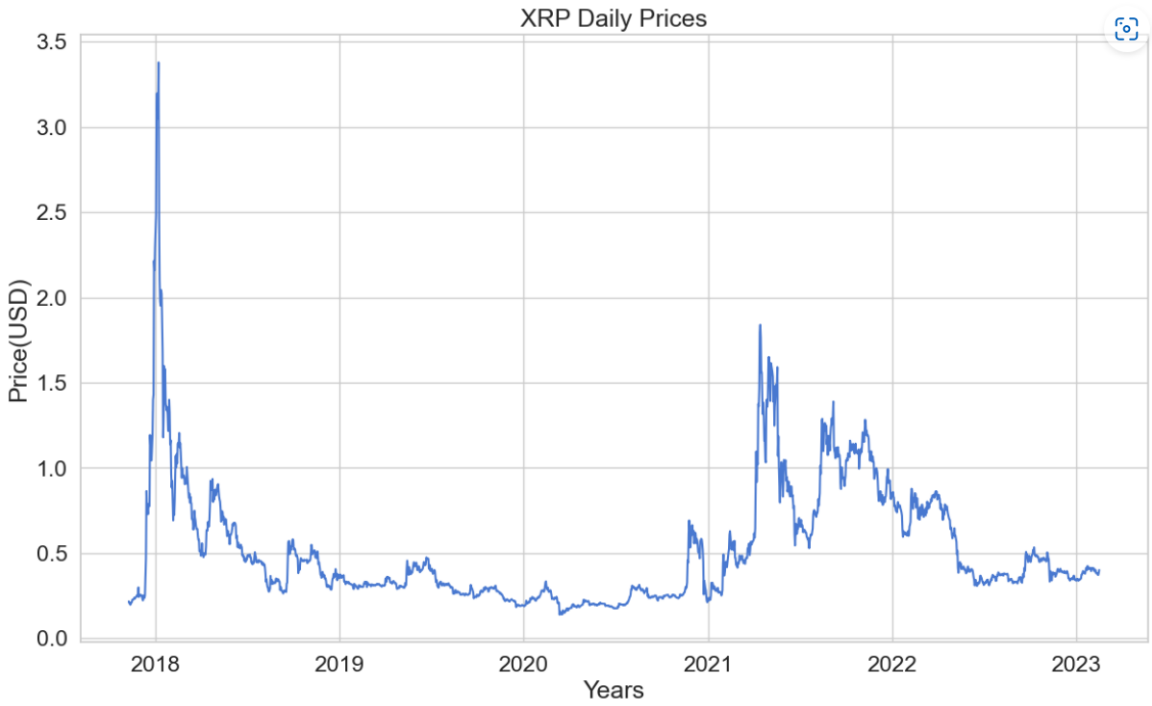
Source: Yahoo Finance, own work

4.1.3 XRP Dataset

Daily XRP prices ranges between the dates 09/11/2017 and 15/02/2023 which makes it a length of 1925 rows without any missing data. The closing price in the first point of the dataset is 0.2174 USD while the closing price of the last point dataset is 0.4014 USD.

All-time-high price of XRP so far is 3.377 USD and all time all time low is 0.1396 USD in the dataset. The current growth percentage of the XRP closing price in the dataset is 84.63% as it was calculated using the first closing price of the dataset and the last. This shows that the value of the XRP increased by almost 0.8 times.

Figure 11: XRP Daily Prices



Source: Yahoo Finance, own work

Thus far in 2021, both Ethereum and Bitcoin have recorded all-time closing prices, whereas XRP has not. XRP's all-time high closing price occurred in early January 2018, following an upward trend that began on December 11, 2017. Prices soared to $3.37 USD on January 7, 2018, but plummeted to $2.45 USD the next day, representing a 27.29% decrease from the previous day. Even if the value of didn’t record an all-time high in 2021, The price trend was also in the upward direction just like Bitcoin and Ethereum.

Figure 12: XRP Closing Prices between 01/12/2017-01/02/2018.

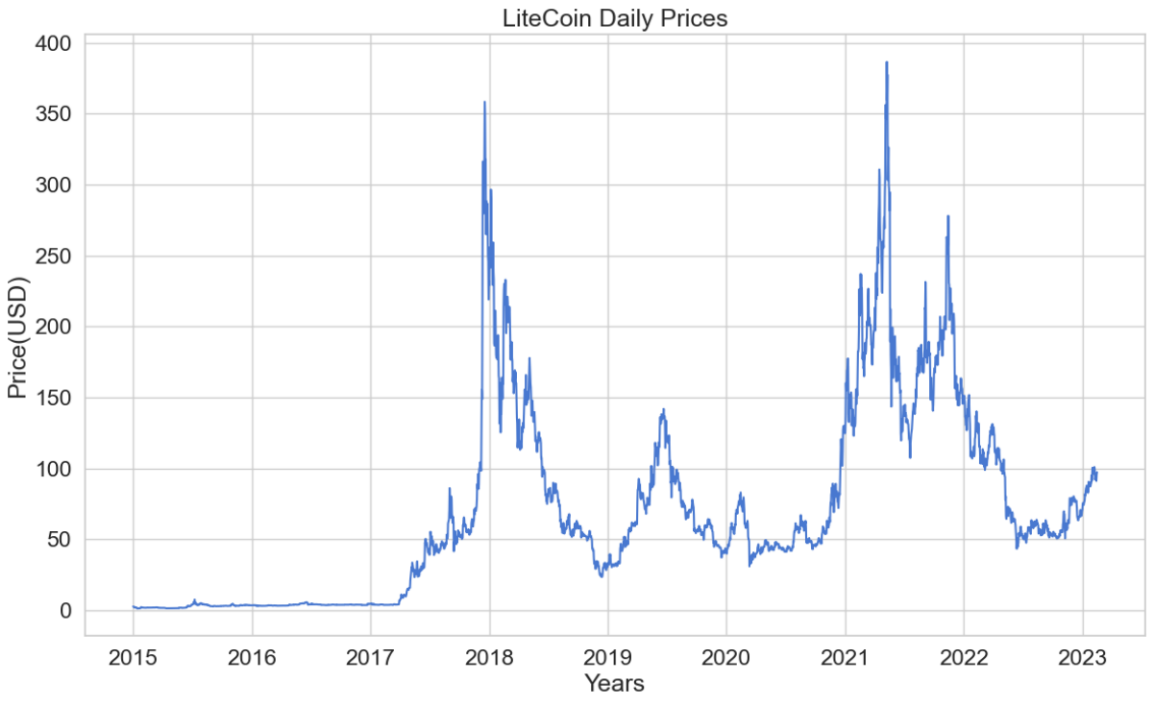
Source: Yahoo Finance, own work

4.1.4 LiteCoin Dataset

Daily LiteCoin prices ranges between the dates 01/01/2015 and 15/02/2023 which makes it a length of 2968 rows without any missing data. The closing price in the first point of the dataset is 2.699 USD while the closing price of the last point dataset was 97.2828 USD.

All-time-high price of LiteCoin so far is 386.450 USD and all time all time low is 1.15 USD in the dataset. The current growth percentage of the LiteCoin closing price in the dataset is 3504.40% % as it was calculated using the first closing price of the dataset and the last. This shows that the value of the LiteCoin increased by more than 35 times over the period covered in the dataset.

Figure 13: LiteCoin Daily Prices



Source: Yahoo Finance, own work

Just like Bitcoin, Ethereum and XRP, Litecoin prices also soared by the end of 2017 and beginning of 2018 and also end of 2020 and beginning of 2021 in a similar manner.

4.2 Forecasting using ARIMA Model

4.2.1 Augmented Dickey Fuller Test

Adfuller called function of statsmodels is used to check the 'p' value of the test is checked:

H0: Data has a unit root and is non-stationery

H1: Data has no unit root and is stationery

3 datasets in the Augmented Dickey Fuller Test failed to reject the null hypothesis. It indicates that all our datasets in its raw values are non-stationery meaning the prices of Bitcoin, Ethereum and LiteCoin exhibits a trend meaning the prices exhibits a consistent upward or downward trend over the time and seasonality means the prices exhibits regular, predictable fluctuations over the time and because of this, it may produce unreliable and inaccurate results. The closing prices of XRP on the other hand gives a p-value of 0.003251 which means that the data is already stationery and the value of d in the model of XRP can

be 0 in this case as it doesn't require and differencing and the other three cryptocurrencies d value will be 1 to apply differencing to make them stationery. The results of the p values of the Datasets of Augmented Dickey Fuller Test are as follows:

Table 1: P - values of the various cryptocurrencies

p-value	**Value**
Bitcoin	0.474838
Ethereum	0.575880
XRP	0.003251
LiteCoin	0.080814

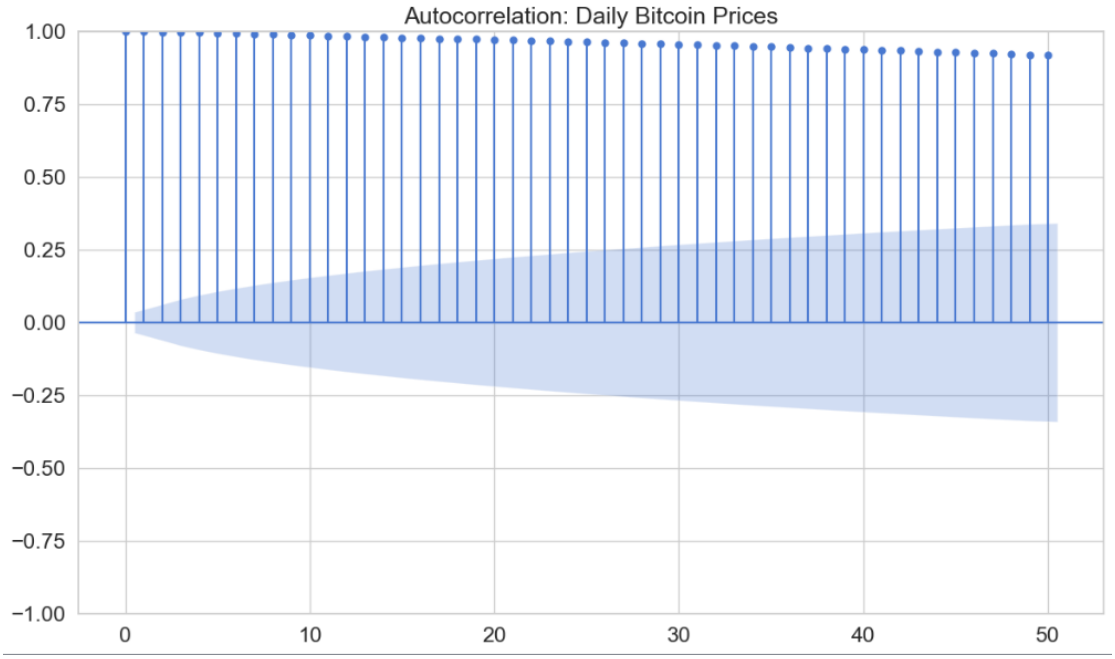
Source:own calculation, Jupyter notebook

In conclusion of this is test is that, ARIMA model of Bitcoin, Ethereum and LiteCoin will be ARIMA(p,1,q) and XRP will be ARIMA(p,0,q).

4.2.2 ACF and PACF charts

ACF and PACF plots are used to calculate the p and q value of the ARIMA models. Creation of the charts, statsmodels library is imported. If the ACF plot has a statistically significant correlation coefficient and no significant spike after the spikes, ARIMA q value will the number of spikes before the non-significant spikes and p value of the ARIMA model will be 0. If the plot has a statistically significant patrial correlation coefficient and no significant spike after the spikes, ARIMA p value will be the number of spikes before the non-significant spikes and value of q will be 0.

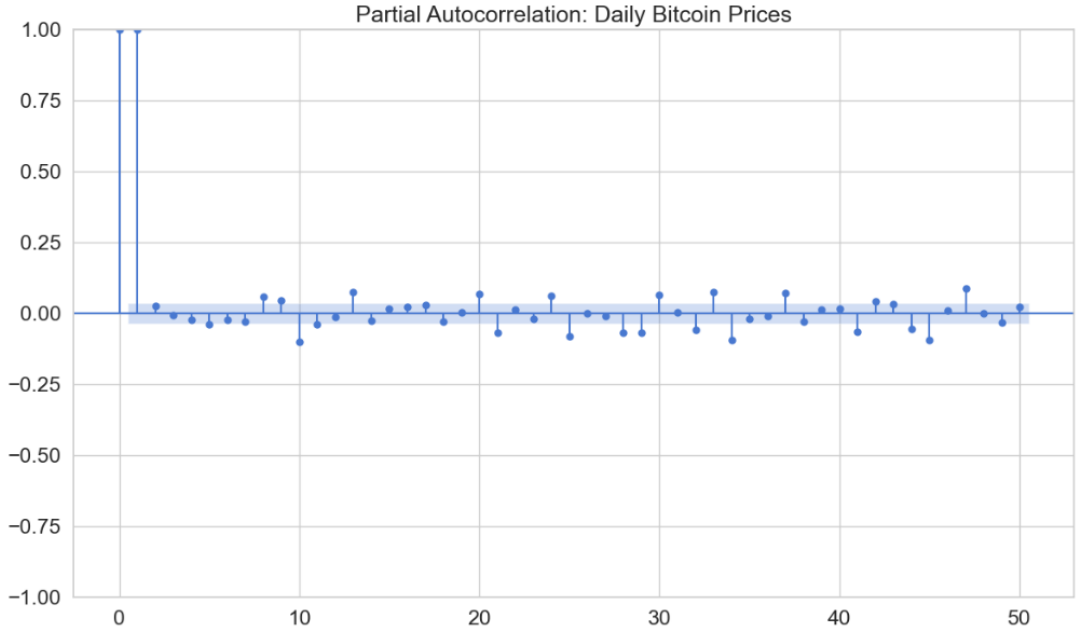
Figure 14: Autocorrelation Plot of Bitcoin



Source: own calculation, Jupyter notebook

ACF plot suggests that the q value of the ARIMA model will be 0. Ethereum, LiteCoin and XRP suggests the same as the ACF plots are very similar to the plot above and the q value of the ARIMA model will be 0 for all of them.

Figure 15: Partial-Autocorrelation Plot of Bitcoin



Source: own calculation, Jupyter Notebook

2 spikes can be observed in the PACF plot of Bitcoin suggesting that the value of the p will be 2. Ethereum, LiteCoin and XRP plots suggest the same as they all plot 2 spikes and a no significant spikes after the 2 spikes as can be observed from the plot above.

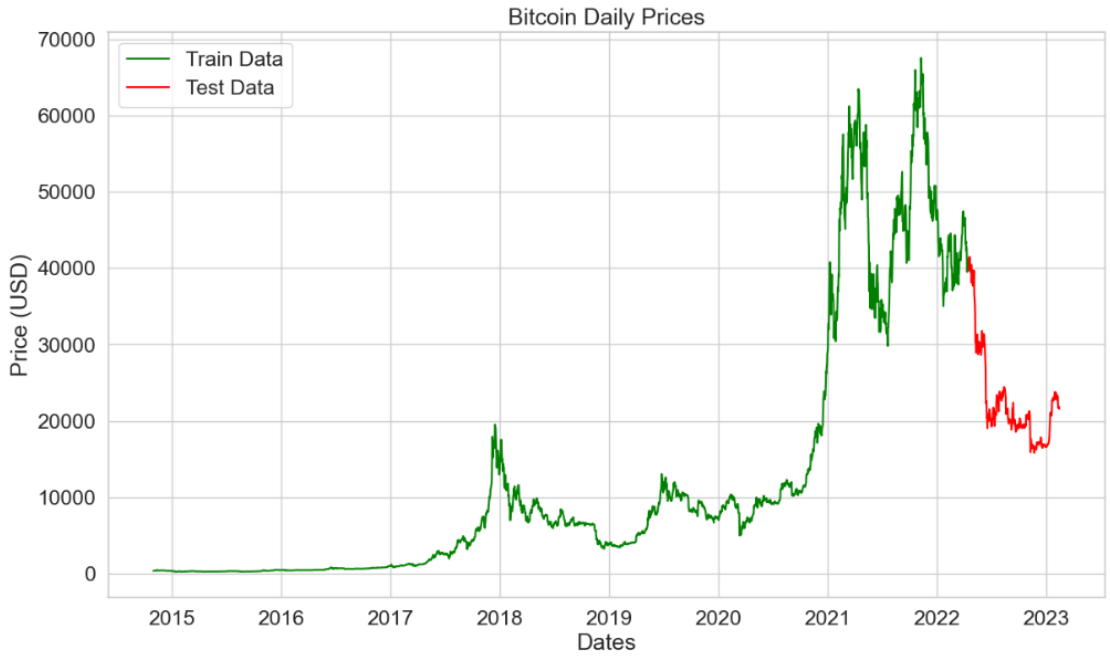
After the tests above, it is suggested that the ARIMA model of Bitcoin is ARIMA(2,1,0), ARIMA model of Ethereum is ARIMA(2,1,0), ARIMA model of LiteCoin is ARIMA(2,1,0) and ARIMA Model of XRP is ARIMA(2,0,0).

4.2.3 Train and Test Data

The train and test split data method are a way to divide the original dataset into two sets which are the training set and the testing set. 90% of the data is allocated for training the ARIMA model, and the remaining 10% for testing the model's accuracy in cryptocurrencies prices. By splitting the data into two sets, evaluating the model's generalization capability to predict new and unseen data is possible.

In this regard, 90% of the data will be allocated for train purposes and 10% for test purposes. Train data for Bitcoin will consist of dates ranging between 01/11/2014 - 16/04/2022. Test data will consist of dates ranging between 17/04/2022 – 13/02/2023.

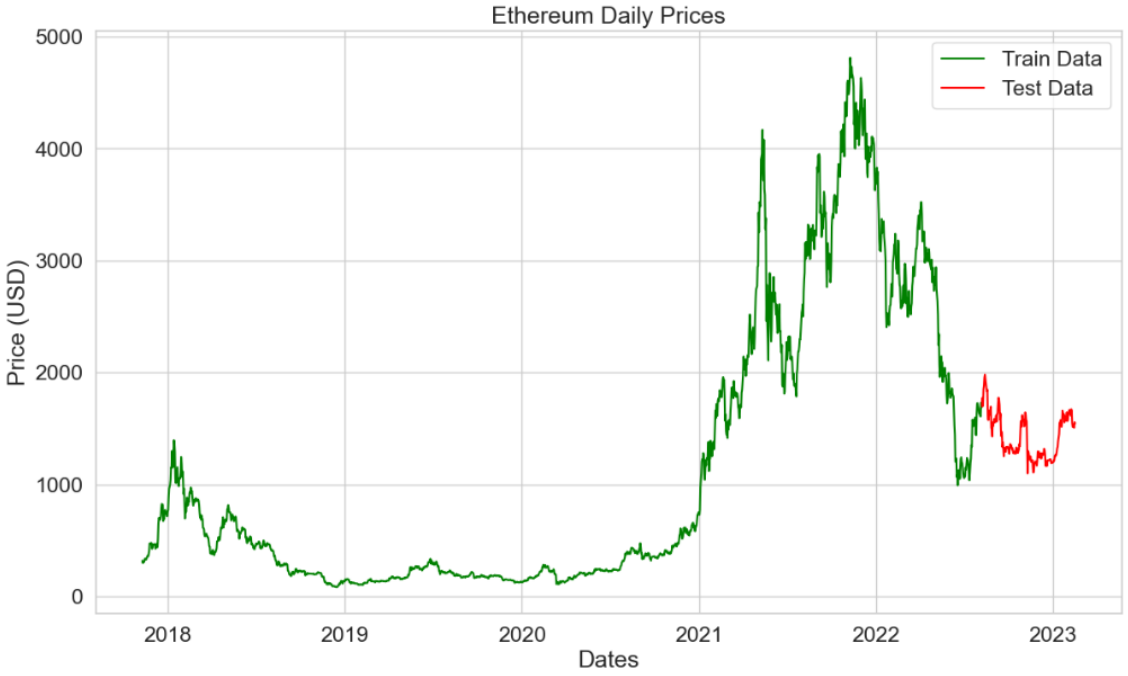
Figure 16: Train/Test Split Data of Bitcoin



Source: Yahoo Finance, own work

Train data for Ethereum will consist of dates ranging between 09/11/2017 - 06/08/2022. Test data will consist of dates ranging between 07/08/2022 – 15/02/2023.

Figure 17: Train/Test Split Data of Ethereum



Source: Yahoo Finance, own work

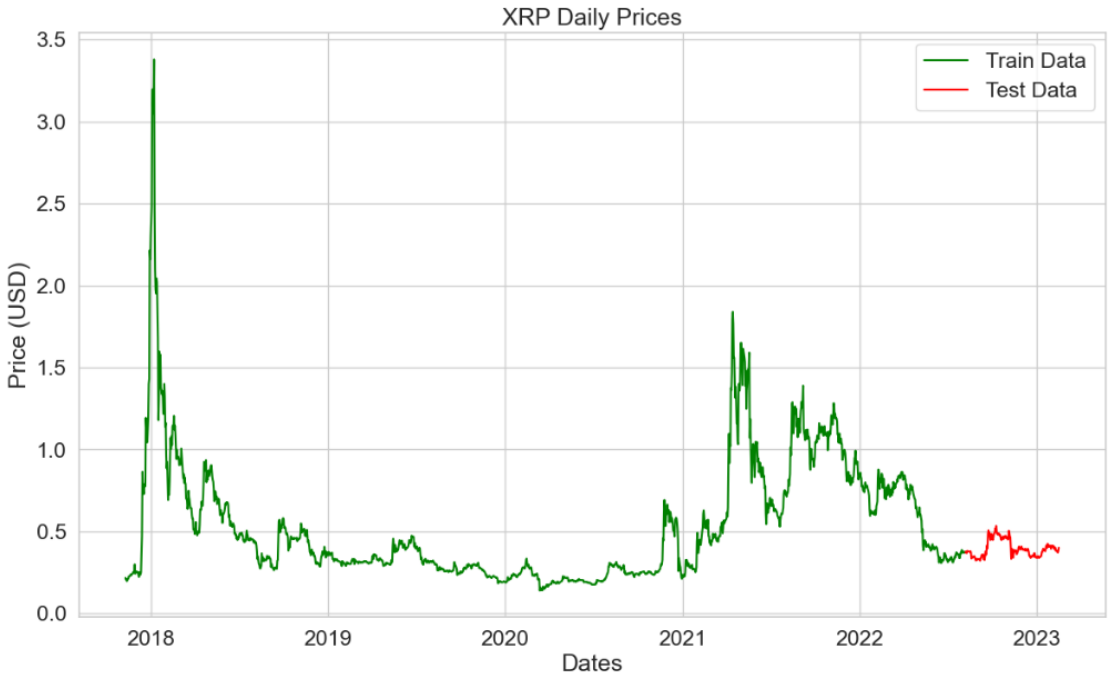
Train data for LiteCoin will consist of dates ranging between 01/01/2015 - 24/04/2022. Test data will consist of dates ranging between 25/04/2022 – 15/02/2023.

Figure 18: Train/Test Split Data of LiteCoin

Source: Yahoo Finance, own work

Train data for XRP will consist of dates ranging between 09/11/2017 - 06/08/2022. Test data will consist of dates ranging between 07/08/2022 – 15/02/2023.

Figure 19: Train/Test Split Data of XRP



Source: Yahoo Finance, own work

Using the model, predictions of the test data will be made, and the test data will be used to compare against the predicted the values as explained above.

4.2.4 ARIMA Model Summary

Summary of the ARIMA Model provides many information about the specific ARIMA Model like several statistics such as coefficient estimates, standard errors, t-values and p-values. Other information such as the ARIMA Model order like the p,d and q value are given as well as the sample size, date when the model was run.

Table 2 : ARIMA Model Summary of Bitcoin

SARIMAX Results

Dep. Variable:	y	No. Observations:	3026
Model:	ARIMA(2, 1, 0)	Log Likelihood	-24502.936
Date:	Sat, 25 Feb 2023	AIC	49011.871
Time:	18:14:15	BIC	49029.915
Sample:	0	HQIC	49018.359
	- 3026		
Covariance Type:	opg		

	coef	std err	z	P>|z|	[0.025	0.975]
ar.L1	-0.0241	0.009	-2.548	0.011	-0.043	-0.006
ar.L2	0.0039	0.009	0.430	0.667	-0.014	0.021
sigma2	6.361e+05	5417.892	117.403	0.000	6.25e+05	6.47e+05

Ljung-Box (L1) (Q):	0.00	Jarque-Bera (JB):	35356.64
Prob(Q):	0.99	Prob(JB):	0.00
Heteroskedasticity (H):	996.47	Skew:	-0.25
Prob(H) (two-sided):	0.00	Kurtosis:	19.74

Source: own calculation, Jupyter Notebook

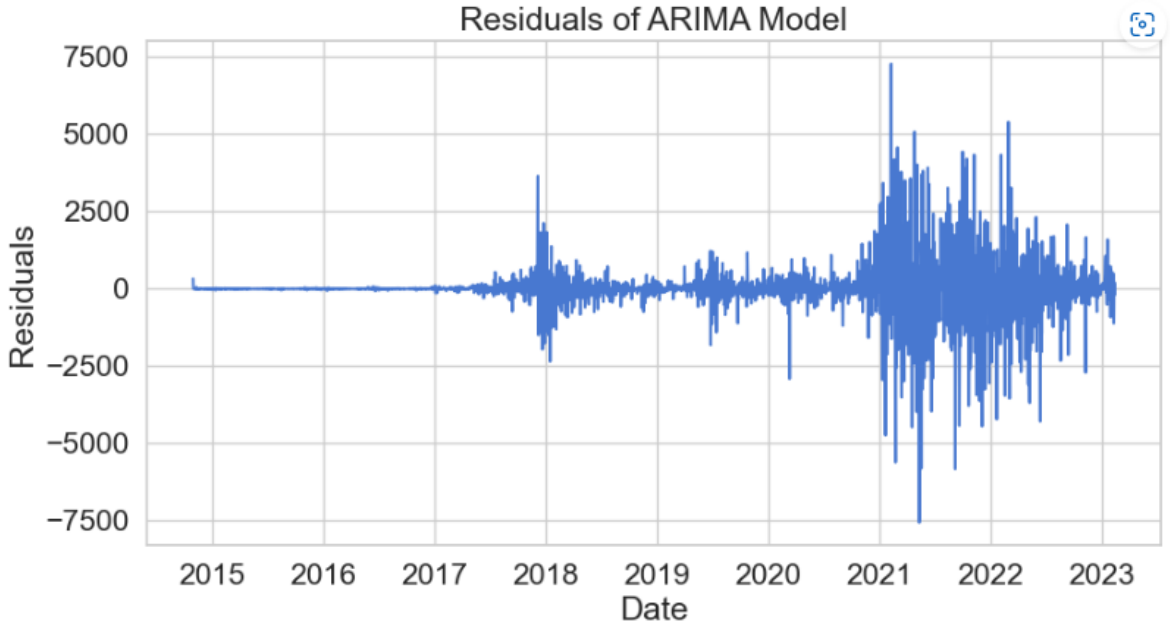
ARIMA Model Summary provides important information about the performance of an ARIMA Model. Dependent Variable is the target variable value. This is the variable that the ARIMA Model is trying to predict. Sample is the total number of observations in the dataset. In this case it is 3027 row but the first observation is lost to differencing as the ‘d’ value was 1. Log likelihood shows how well the ARIMA Model fits to the data. The higher the likelihood, the better. AIC measures the relative quality of the ARIMA Model. It balances the goodness of fit of the model with the complexity of the model. BIC is very similar to AIC except BIC also penalizes models more heavily for having more parameters. The lower the BIC and AIC, the better. Ljung-Box is a test for autocorrelation in the residuals of the ARIMA Model. P-value of the Ljung-Box test is Prob(Q). Prob(Q) value of the current model is 0.99 which suggests that there is not enough evidence to reject the null hypothesis which means there is no-significant autocorrelation in the residuals of the model which can be considered a good thing as it means that the model is doing a good job of explaining the variation in the data and there are no major patterns oftrend that have been missed by the model but it is also possible that there is some low-level autocorrelation in the residuals that hasn’t been fully captured by the model.

It is possible to see from the heteroskedascity result that the data contains heteroskedascity as the Prob(H) (two-sided) is not greater than 0.05. It is important to know

the heteroscedasticity in the data as it can lead to biased parameter estimates because the standard errors of the estimators may not accurately reflect the true variability of the data.

Heterokedesticity can also be pointed out in the residual plot of the model. This plot shows the difference between the real data and the predicted data and at which points the differences are. It can also be seen that the heterokedesticity in the data increase during the soaring of Bitcoin Prices as in 2018, 2021 and 2022 which show the peak prices of Bitcoin Prices. This can be seen in **Figure 15.**

Figure 20: Residuals of Bitcoin ARIMA Model

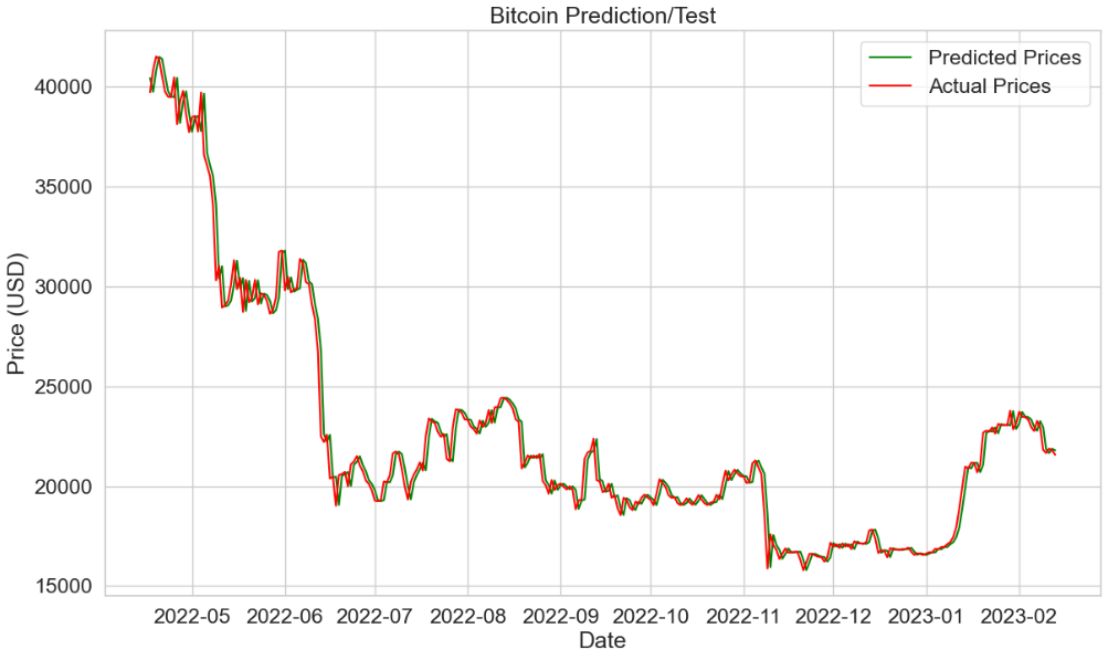


Source: Yahoo Finance, own work

4.2.5 Predictions plotting

Predictions have been made along the test data and the test data values have been added to the train values when the forecasting plotting were made to plot the values of the real values and predicted values. The purpose of the plotting the real value against the predicted values is to see how well model's predictions match up with the actual data and can help identify where the model is overfitting or underfitting.

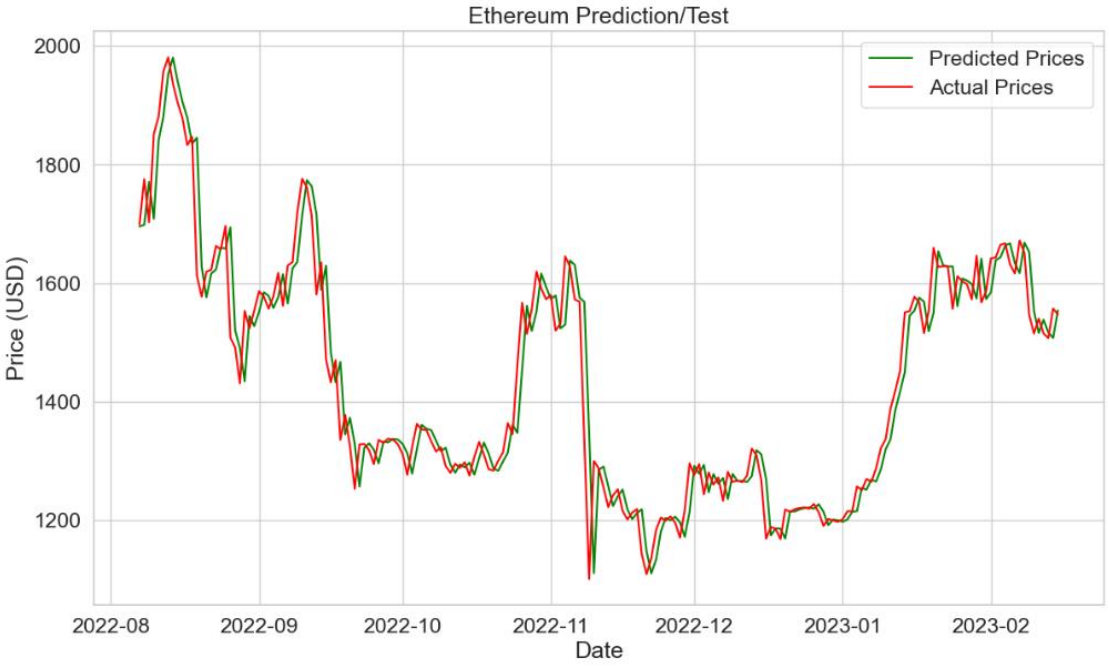
Figure 21: Bitcoin Prediction/Test



Source: own calculation/Yahoo Finance, Jupyter Notebook

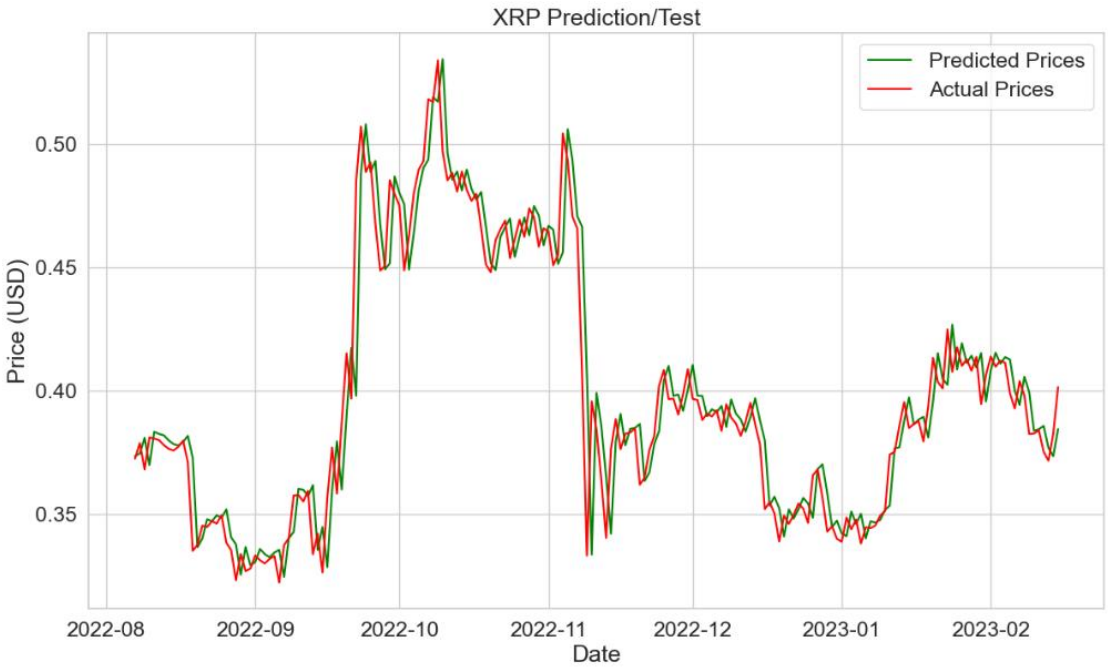
It can be seen from **Figure 15** that the values are fitted very well the for Bitcoin Predictions with ARIMA Model(2,1,0). It can also be seen that the predicted prices are lagging compared to the real prices. This still is a very good plotting. The plots of Ethereum, LiteCoin and XRP are as follows:

Figure 22: Ethereum Prediction/Test



Source: own calculation/Yahoo Finance, Jupyter Notebook

Figure 23: XRP Prediction/Test



Source: own calculation/Yahoo Finance, Jupyter Notebook

Figure 24: LiteCoin Prediction/Test

Source: own calculation/Yahoo Finance, Jupyter Notebook

The ARIMA Model order have been really good including the model where XRP was given an order without the d value indicating the order of the Model that were chosen was a good fit. What can be mentioned about the predictions are that they seem to be slightly

lagging. Even though this may not be an issue on the long run, in the short run, it can be very dangerous for the person trading and getting advices and references from the models.

It can not be clearly seen and known how well the model did just by looking at it but it can only give an idea of how good it performed. RMSE is used to compare different models. Real prices and predicted values are evaluated to measure the performance of the ARIMA Model. Using RMSE helps to view the results in the respective units. The RMSE metric results are as follows:

Table 3: RMSE of various Cryptocurrencies

Cryptocurreny	**RMSE (in USD)**
Bitcoin	782.533
Ethereum	56.891
XRP	0.016
LiteCoin	3.0203

Source: own calculation, Jupyter Notebook

It is seen that when the RMSE of Bitcoin is in 3 tables, the RMSE of Ethereum is in 2 figures. One of the reasons for this is that Bitcoins' test datas' mean is 22479.103 USD while Ethereums' test data mean is 1431.910 USD. So comparing the accuracy of the model is a better fit for this scenario. When the mean and the RMSE value is divided, that's when it is possible to see the clearer picture. Minusing 100 with the error in percent

Table 4: Error in percentage and Accuracy in Percentage

Cryptocurreny	**Error(in%)= (RMSE/Mean)*100**	**Accuracy:100-error%**
Bitcoin	3.48%	96.52%
Ethereum	3.97%	96.03%
XRP	4.10%	95.90%
LiteCoin	4.54%	95.46%

Source: own calculation, Jupyter Notebook

5 Results and Discussion

It has been found that the models were pretty good at making accurate predictions for Bitcoin, Ethereum, XRP, and Litecoin. This means that we were able to capture the patterns and trends in the data well. The respective models had error rates ranging from 3.48% to 4.54%. This might sound like a lot, but it's actually pretty good for predicting the highly volatile market which is the market of cryptocurrency. The accuracy of the ARIMA models were also high, ranging from 95.46% to 96.52%. This means that the models can be used to make short-term investment decisions with a high degree of confidence.

Another thing to note in the Model was the presence of heteroskedasticity. This can lead to less efficient estimates, incorrect statistical inference and invalid confidence intervals but predictive performance is pretty good. Additionally, data has been shortened in order to tackle this same very issue but heteroskedasticity was still present in the data. But it is important to know the limitations and how it can affect the data at hand. One of the reason for the data to contain heteroskedesticity is the nonlinear relationship between dependent and independent variables. The dependent variable in this case is the Closing Prices while the independent variable is Date. The other reason can be that we are omitting an important variable in the model as the omitted variable can have a significant impact on the model since model used closing prices as the only variable to train the model, this needs to be investigated upon. As we concentrate on the success of the model, other researches can be made in order to study on the heteroskedesticity of Bitcoin Data as well as how it can be improved as this will definetely improve the reliability of the predicting model.

There are multiple reasons why the prices of these mentioned cryptocurrencies prices soared by the end of 2017 and beginning of 2018. Many businesses started to show more interest, large institutional investors started showing interest in cryptocurrencies, communities of cryptocurrencies made upgrade to the technology which improved the networks scalability and of course cryptocurrencies received a lot attention from media coverages which led to investor interest. Even if these positive occurred to the cryptocurrency world, governments around the globe started to implement new regulations to them and the media coverages started to report negative news which was also a factor of price drop. Other reasons including lack of adoption started to be problem as a means of payment.

What does this all mean for people who invest in cryptocurrency? Well, it means that ARIMA models can help them make better investment decisions. People who are interested

in investing in cryptocurrencies can get an idea of how the prices will shape in the future can get an idea using the past historical data. It has also been found that the accuracy of the models varied for different cryptocurrencies. For example, Bitcoin was the most predictable, while Litecoin was the least predictable. This suggests that some cryptocurrencies might be influenced more by market forces and news events than by underlying patterns in the data.

According to Forbes's article in December 30, 2021 Total cryptocurrency market capitalization by 2021 was 3 trillion USD and they have suggested that there is clear momentum for cryptocurrency to grow in the future. They also suggest that in terms of inflation, the reliability of Crypto isn't as good as gold. It's been also reported that some cryptocurrencies have over time proven to be relatively stable while other have declined in value. Other thing to note that the prices will mostly be influenced by regulators but that have also been shown that regulators can have an impact in the short term but they become less effective in the long term and that is why for example China often makes announcements that it is again banning cryptocurrencies which also sends the prices of main cryptocurrencies such as Bitcoin and Ethereum for short-term. It has been also advised that once ignored because of volatility, this can be the good time to reconsider if it aligns with short-, mid- or long-term goals (Carr, 2021)

However, there are limitations to the respective models. They rely on historical data, which might not fully represent future price trends. Additionally, the cryptocurrency market is highly volatile, which makes it hard to make long-term predictions with a high degree of accuracy. Future research could focus on improving the accuracy of long-term predictions by considering of additional variables into the models. For example, considering news events or market sentiment to see how they impact cryptocurrency prices.

6 Conclusion

In conclusion, this study found that ARIMA models are pretty good at predicting the prices of major cryptocurrencies. ARIMA models can be used to make short-term investment decisions with a high degree of confidence. However, it is essential need to keep in mind that the models have limitations, and the cryptocurrency market is highly unpredictable. Improvements can be done to increase the accuracy of the models and that the crypto world is a changing world everyday and the investments should be made careful, and these results can get people excited but it is also essential to note that with great profits and returns come with great risks and capital to put in line which can be frustrating.

It is important to remember that none of the information that have been provided in this Bachelor Thesis is a financial advice and investors should be aware of the risks of cryptocurrencies.

7 References

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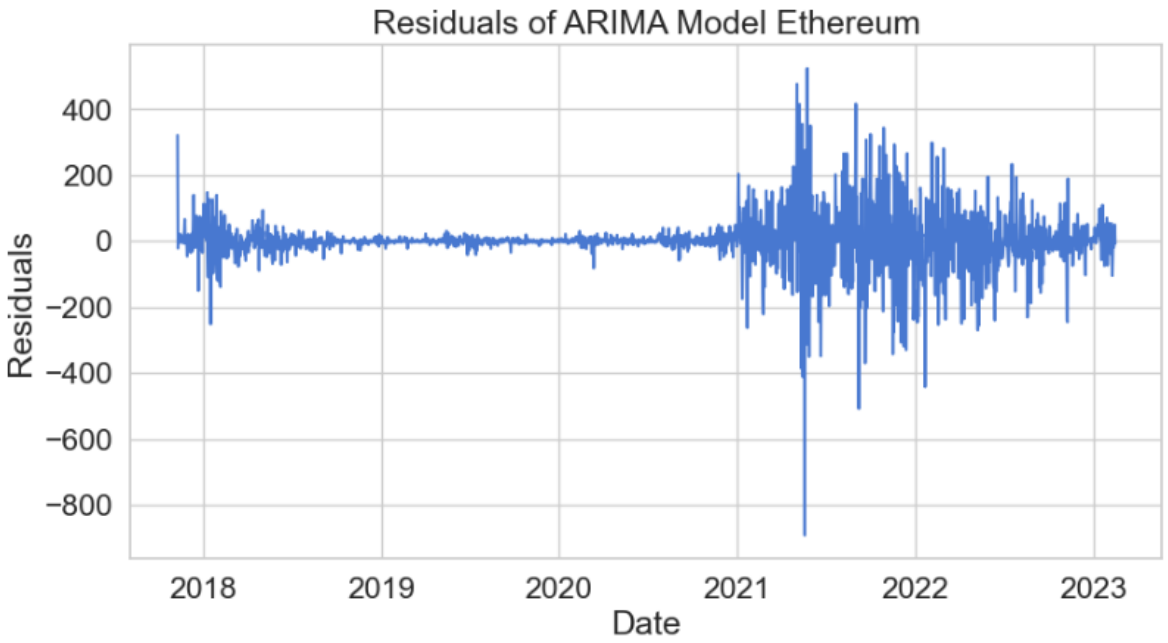
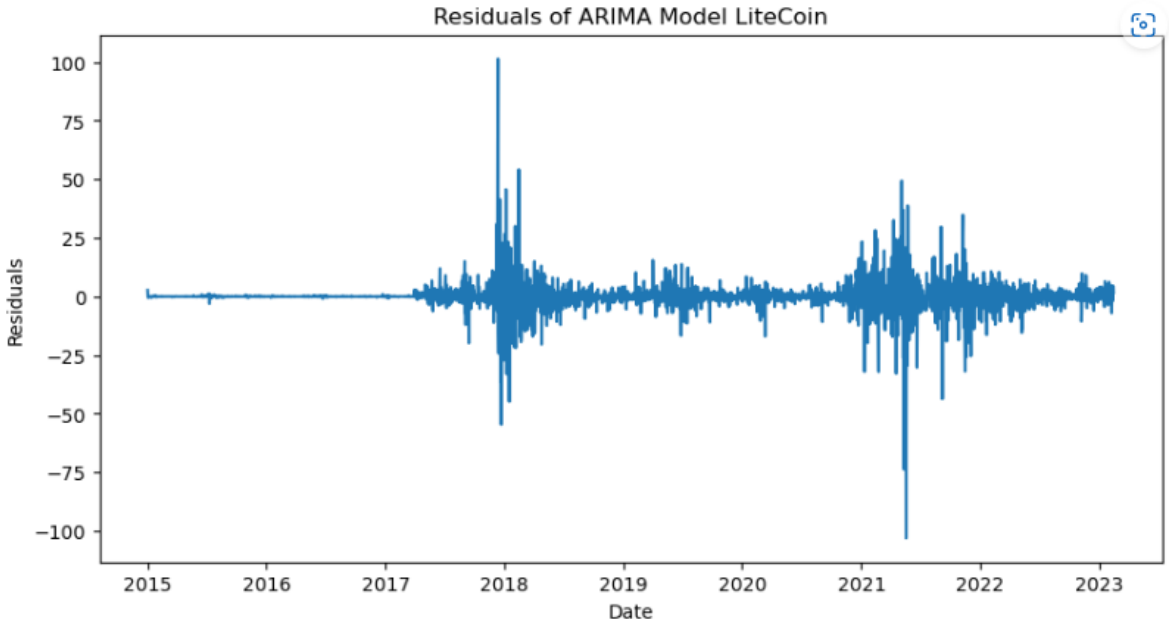
8 Appendix

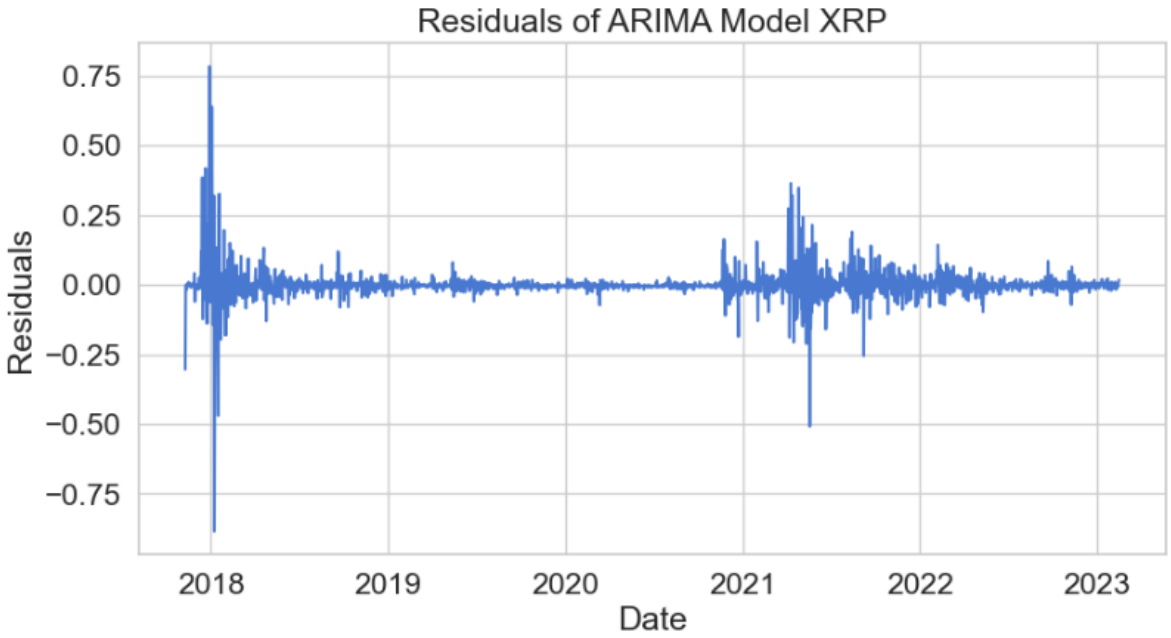
Appendix 1: Residuals of ARIMA Model Ethereum



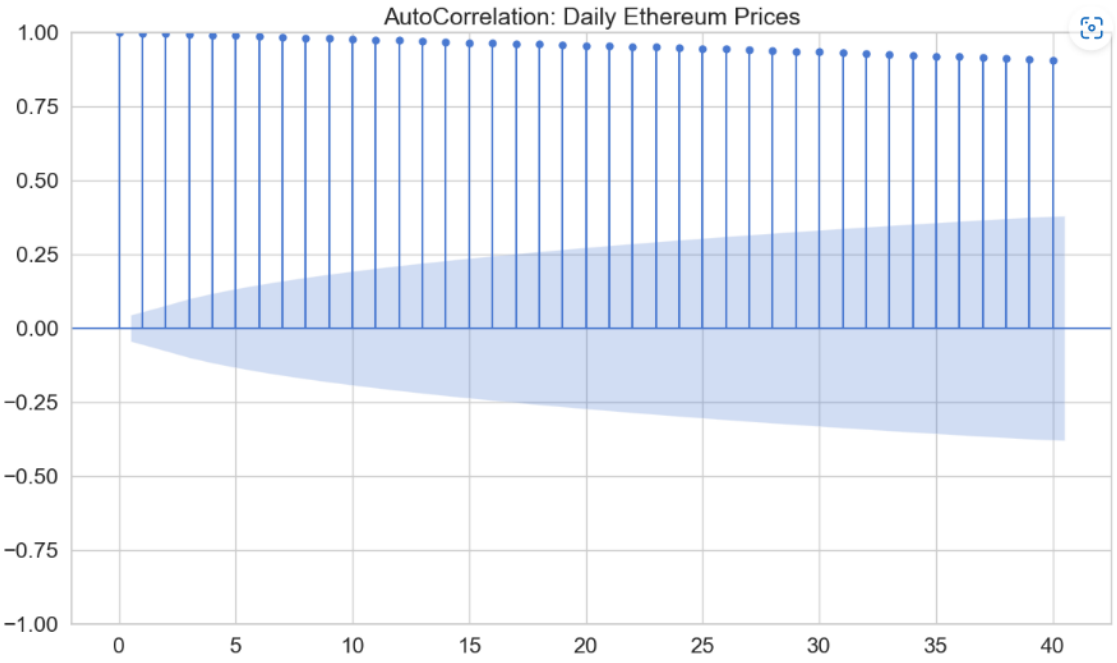
Appendix 2: Residuals of ARIMA Model LiteCoin



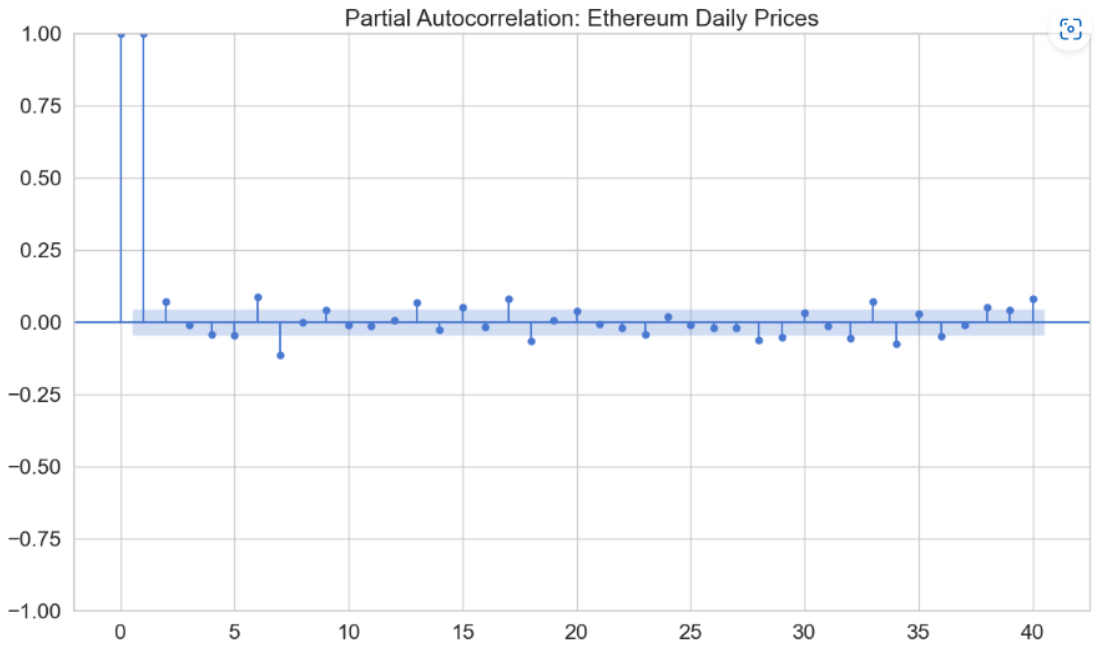
Appendix 3: Residuals of ARIMA Model XRP



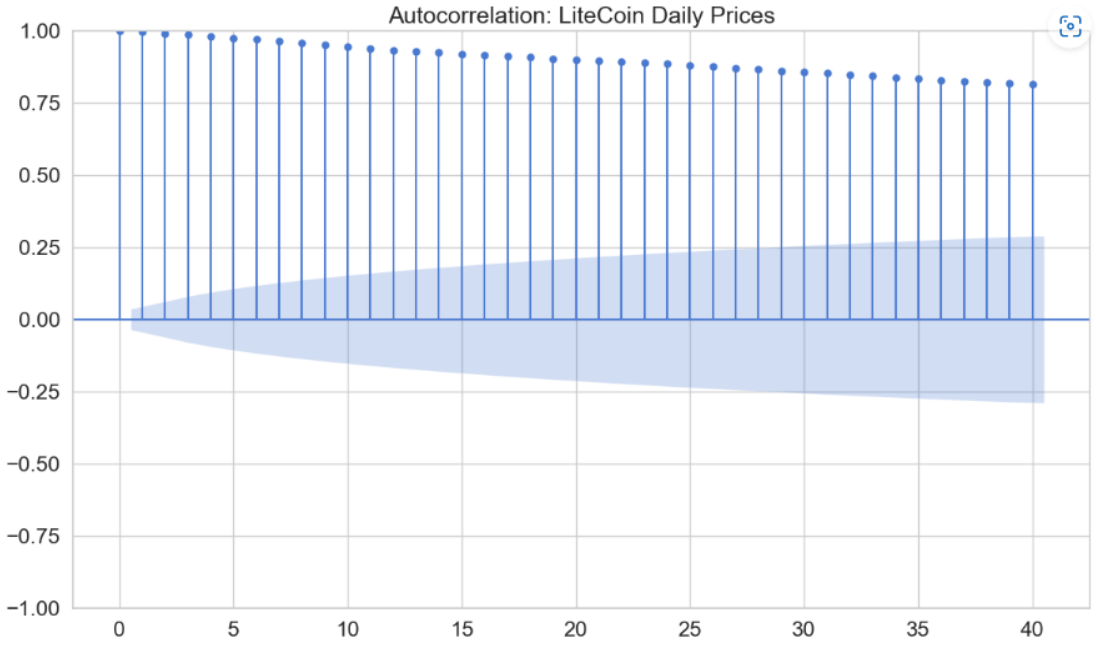
Appendix 4: Autocorrelation: Daily Ethereum Prices



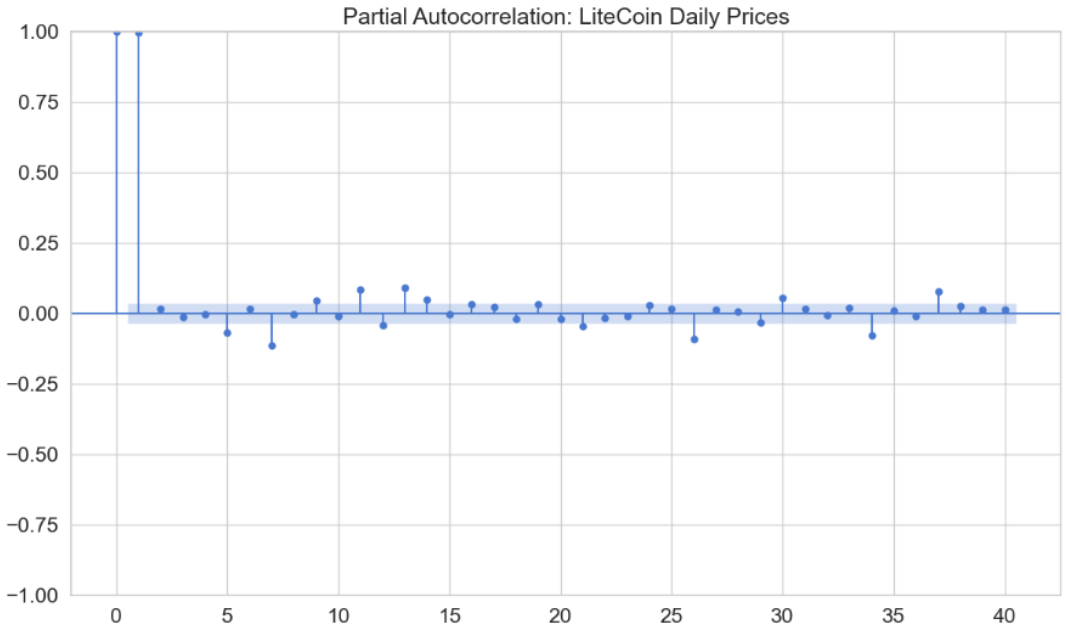
Appendix 5: Partial Autocorrelation: Daily Ethereum Prices



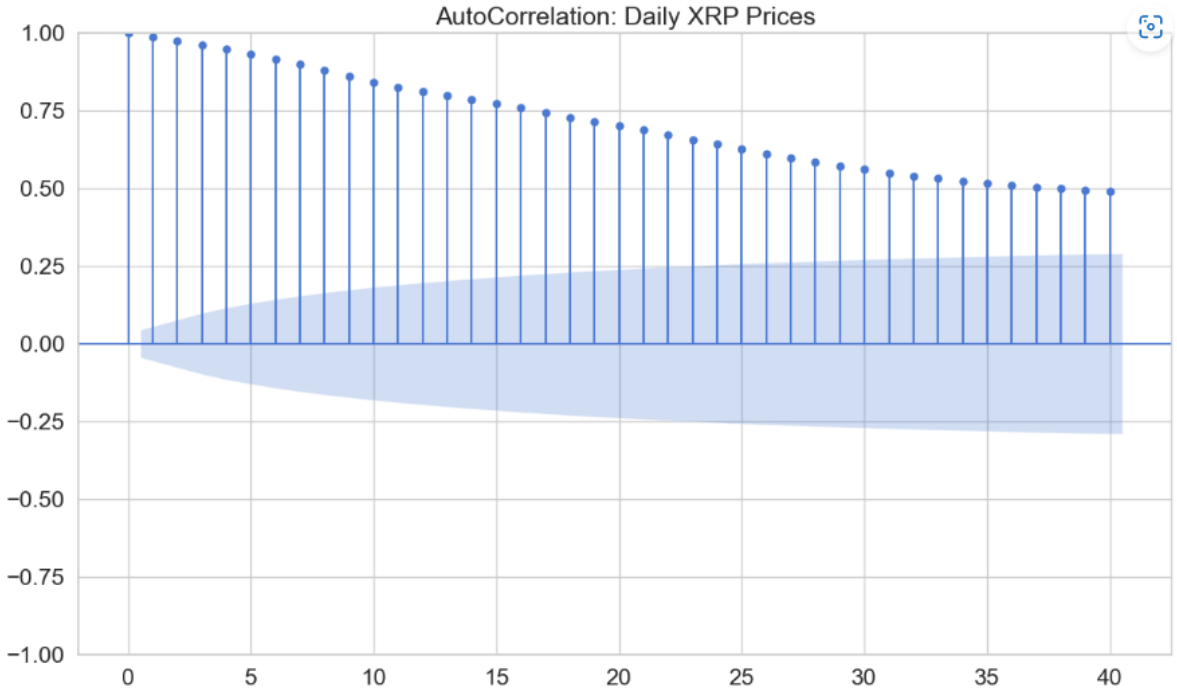
Appendix 6: Autocorrelation: Daily LiteCoin Prices



Appendix 7: Partial Autocorrelation: Daily LiteCoin Prices



Appendix 8: Autocorrelation: Daily XRP Prices



Appendix 9: Partial Autocorrelation: Daily XRP Prices