Leomar Jose Heredia Gomez, Markus Valkner

Candidates number: 9101, 9049

Supervisor: Peter Molnar

What variables affect Bitcoin energy consumption and Bitcoin mining?

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Abstract

This comprehensive study provides an in-depth exploration of Bitcoin's history, its fundamental nature, and the intricate workings that underpin its functionality. Further analyzing Bitcoin mining and its sustainability, focusing on factors like network difficulty, hashrate, Bitcoin price, mining technology, cost per transaction, natural gas prices and electricity prices.

The study discusses how the Bitcoin mining sector uses energy resources, what politics different authorities have implemented for cryptocurrency and what the future of Bitcoin could look like. Furthermore, discussing what use there is for Bitcoin today and where Bitcoin could be used in the future.

Moreover, the study sheds light on the challenge Bitcoin brings to the current fiat currency system. The darker side of Bitcoin use is also discussed shedding a light on how Bitcoin is used to fund criminal activity. There is competition within cryptocurrencies, and there are alternatives which have tried to mitigate some of the issues with Bitcoin.

Acknowledgement

We would like to express our gratitude to our Master thesis supervisor Peter Molnar for guiding and advising us throughout our project and all the significant support needed to write it. This work would have been considerably more challenging to accomplish without his invaluable contribution.

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Stavanger, Norway June 15th, 2023

Leomar Heredia Markus Valkner

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1. Introduction

It is a known subject that the mining of cryptocurrencies has caused a lot of headlines in various media outlets, as it has been accused of not being sustainable and going against the United Nations goal of net zero emissions by 2050 (United Nations, 2023).

In this study we will analyze the effect of Bitcoin mining and its sustainability. Analyzing what factors influence the energy consumption of Bitcoin mining, focusing especially on the price of Bitcoin, cost per transaction and average hashrate per unique miner. Other topics will be discussed as well, such as Bitcoin's sustainability, electricity prices effect on Bitcoin mining, development of mining technology and what Bitcoin's future may look like. Having as a research topic:

What factors influence Bitcoin's mining industry, and are cryptocurrencies viable and sustainable in the face of an ongoing energy crisis?

2. Background

To provide a brief overview of our research, we would like to first define some of the key factors surrounding Bitcoin, Bitcoin mining activity, and the history of cryptocurrencies. The technical aspects of cryptocurrency mining will be discussed as well. In addition, our research will cover cryptocurrency policies, current utilization of Bitcoin, factors contributing to Bitcoin's price dynamics, and provide background information on Bitcoin's sustainability.

Cryptocurrency – A digital currency that has no central bank overseeing its flow of funds. These types of currencies can only be used to buy products and services online, as it is not a physical currency. For cryptocurrency to work, this technology is backed up by blockchain technology and cryptography (Zohuri et al., 2022, p. 3).

Blockchain technology – Set of blocks that store information and its source of transactions. This technology has its own encryption methods, which lowers the chance of faking cryptocurrency in contrast to traditional fiat currency which is vulnerable to counterfeiting.

Each block is linked by using the previous transaction's encrypted code, thus connecting the blocks together.

This technology offers the possibility of anonymity when using cryptocurrency. This is because the actual wallet the transaction is made from is hidden by a public encryption key. The wallet does not reveal where the money came from, and/or what wallet the cryptocurrency is being sent to (Rodeck & Curry, 2022).

Dark web - Part of the deep web. The deep web is 90% of the internet, but the dark web cannot be accessed through normal search engines on our pc's, but a special internet browser is needed to access it (Tor or Freenet). The dark web occupies 0,1% of the deep web, often related to sale of illicit substances, weapons, prohibited content, malware, stolen items etc. (Finklea, 2017).

Proof of work – Process of deciphering an encrypted code by the computers of the network users, to validate a block in the blockchain (Kiayias & Zindros, 2020, p. 22).

Hashrate - Measurement of calculations per second of computational power capability when trying to solve the proof of work process. In other words, how many attempts does a computer take to solve the proof of work process (Fantazzini & Kolodin, 2020, p. 1).

Bitcoin - Digital currency that was created to be decentralized and anonymous, created at the end of 2008 by an anonymous person named Satoshi Nakamoto (Nakamoto, 2008, p. 1).

Cryptocurrency mining - Process of solving and validating Proof of Work to add a block to an existing blockchain. In addition, to have more storage space for transactions in the blockchain (Hari, Sai & Venkata, 2015, p. 115).

Electricity and technology - These 2 variables affect the efficiency of Bitcoin mining, as computers need a source of energy to function and do calculations. The role of technology is a significant variable in the mining industry, as it directly impacts the capacity of computers involved in block mining. The continuous development of technology, alongside electricity availability and advancements, greatly influences the operations and progress of the mining industry (Li et al., 2019, p. 162).

2.1 History of cryptocurrency

David Chaum and his company Digicash were the first to create a digital cryptocurrency called "Digicash" in 1990. This introduced the idea of an untraceable digital currency to the world. It was a solution to Internet privacy, which was of concern for David. In the end his company went bankrupt, and in 1998 he had to leave the project behind (Abrar, 2014, p. 3). The previous year, Nick Szabo proposed to make cryptocurrency trading more secure. This was accomplished through the use of smart contracts embedded in hardware and software. The trading process was facilitated by these contracts, eliminating the need for any government entity to be involved in the transaction processing (Szabo, 1997, p. 1).

Until the end of October 2008, the concept of implementing a cryptocurrency remained just an idea. However, it was during this time, in the midst of the financial crisis, that the cryptocurrency Bitcoin was created. The profound negative impact of the financial crisis on the public served as a catalyst for the development of Bitcoin. It was made to be a more trustworthy currency, as it could not be interfered with or influenced by, for example, government spending. This ultimately led to the first Bitcoin block being mined in January of 2008 (Nakamoto, 2008, p. 8). The first actual transaction using Bitcoin was made in 2010, two years after its release. The transaction was 10,000 BTC for 2 pepperoni pizzas in the US (equivalent to 60 USD), showing to the world that cryptocurrency could be used to trade products in the real world (Rose, 2015, p. 619). Thereafter, in February 2011, the famous dark webpage “Silk Road” was established, having Bitcoin as its currency payment method. Bitcoin emerged as the preferred payment method for various illicit activities on the dark web, including the trade of illicit drugs, hacking services, malware, pirated software, and counterfeit documents. Its decentralized nature and relative anonymity made it attractive for conducting illicit transactions. All of this combined gave a popular opening to the use of cryptocurrency, which became more popular afterwards (Trautman, 2014, p. 92). The popularity of Bitcoin can be seen in figure 1.

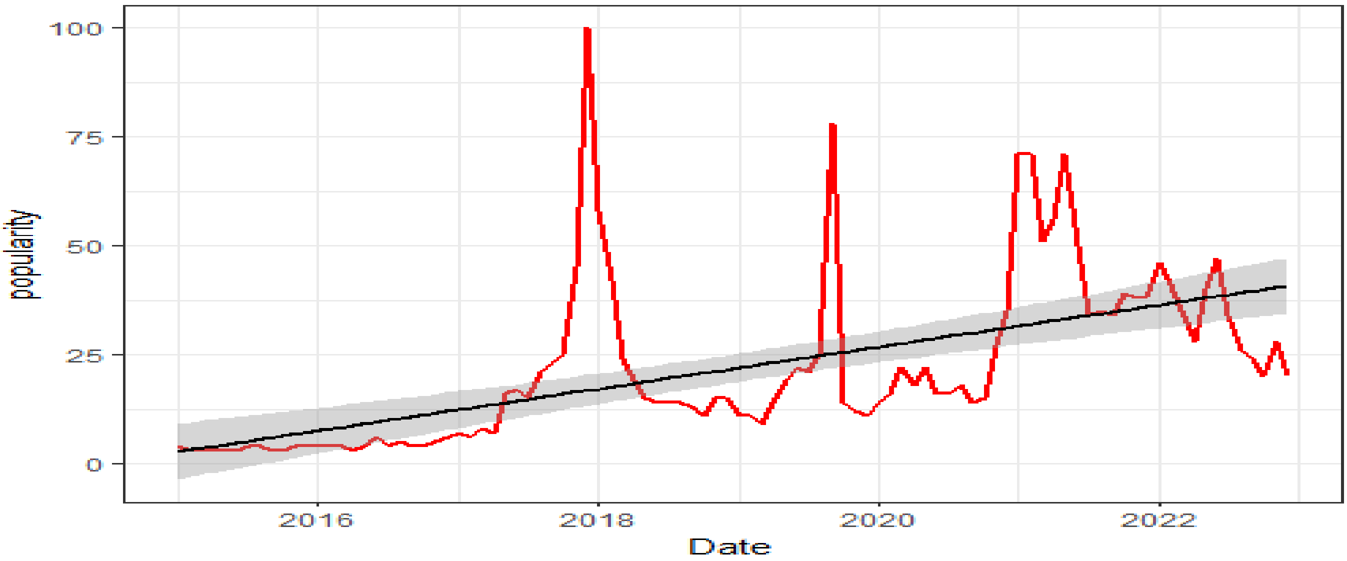

Figure 1. *Word "Bitcoin" searches in Google, translated into Bitcoin's popularity on Google.*

The high market price of Bitcoin drew the attention of financial technology savvy entrepreneurs with a keen understanding of technology and its applications in the financial sector. They began to consider how they could profit from Bitcoin. The high trading activity and volatile prices made an intriguing investment opportunity. At the start of 2011, other cryptocurrencies appeared in the market with the goal of being Bitcoin's competitor. These cryptocurrencies were marketed with better transaction time and/or anonymity but have never surpassed Bitcoin's popularity level (ElBahrawy et al., 2017, p. 2), where Bitcoin has the biggest cryptocurrency market (Coinmarketcap, 2023).

Furthermore, in 2012 the website creator company WordPress started accepting payments in Bitcoin, which increased its popularity and its use. With increased popularity and lack of cybersecurity it was often heard that Bitcoin wallets were hacked and left with nothing, leading Bitcoin to improve its cybersecurity issues (Skelton, 2012).

Subsequently, in 2013, with the scandal of Snowden, Wikileaks and the C.I.A U. S government secrets, Bitcoin was used as a donation payment method to Snowden. The U.S government had closed all transactions for Snowden with Visa and Mastercard (Simser, 2015, p. 157). In 2014, even online casinos started accepting cryptocurrencies as a valid payment method (Chohan, 2017, p.11).

It wasn't until 2017 that Bitcoin's popularity hit its peak. The significant surge was primarily driven by the fear of missing out among investors, who were eager to capitalize on what they perceived as a highly lucrative opportunity. (Lee et al., 2017, p. 3). All of this combined, caused governments to start regulating the crypto market. This first happened mostly in Asian countries. The emergence of crypto had caused “projects” also called ICO’s, to appear. These were intentionally created for fraudulent purposes (Kethineni & Cao, 2020, p. 329). The emergence of various projects and their subsequent hype contributed to Bitcoin being viewed as a speculative bubble. This bubble eventually burst in 2018, leading to a substantial decline in Bitcoin's price from a high of nineteen thousand dollars to a low of seven thousand dollars (Kreuser & Sornette, 2018, p. 15).

In 2021 the country of El Salvador passed the legislation of making Bitcoin an official currency of the country at the same level as the USD. In April of 2022 the country of Central African Republic followed El Salvador’s steps and made Bitcoin an official currency (Katterbauer et al., 2022, p. 1). That same year, Russia invaded Ukraine causing the Ukrainian war. As a result of the war, Russia was sanctioned by the U.S and the rest of the West. This was done as an attempt to stop the war. The sanctions meant that Russia had to look for other payment method options to keep its trade going with other countries. They then proceeded to change their focus to cryptocurrency. Here, Russia is free from the financial sanctions that were given by the West and other countries for invading Ukraine (Theiri et al., 2023, p. 59).

2.2 Process: How does Bitcoin and Bitcoin mining work?

Firstly, we must explain how Bitcoin blockchain technology works. Normally, when storing data and or transactions, there are storage devices that serve as physical storage to be able to save data (IBM, 2023). In blockchain technology, there are not only storage devices to store transactions, but there is also a whole system that works together to be able to save these transactions. Distributing transaction data using the whole network allows the miners to validate new transactions more effectively. The same transactions are given to everyone who is validating them (also called nodes). This means that there is less chance for fraud in the system, as all the transactions are public, making the trustworthiness higher. Every node or miner has a copy of the blockchain and its information such as: transactions, previous blocks and addresses (Tijan et al., 2019, p. 2). However, inside the blockchains, there are blocks which are responsible for storing the data. To be able to acquire a new block the miners must go through a process called mining. Where there are machines that calculate/guess what the next hash number (nonce) will be. It is important to mention that the nonce number is a part of the total hash number, the total hash number consists of 256 encrypted characters, requiring a lot of data processing and machines that can handle such big data calculations (Bhaskar & Lee, 2015, p. 48). This process is called proof of work. However, a new nonce cannot be generated until 10 minutes after the last block, as this is one of the conditions of the Bitcoin blockchain coding generated by Nakamoto when he designed the currency (O'Dwayre & Malone, 2014, p. 281).

The blocks have a "natural" storage capacity of 36 MB pr. block, but in 2010 Nakamoto set the storage capacity limit to 1 MB per block (Vujičić et al., 2018, p. 3). He has never given a public explanation behind this reasoning, but it has led to some speculation. It is speculated that it was done to protect the blockchain from being manipulated as that would be non-beneficial for miners. If this was not the case, miners would be able to outcompete each other by creating bigger blocks than the other previous miner. A second argument is that if the block size were too big, the machines/system could collapse. This could happen because the information uploaded could get too large and be too much for a normal machine to handle. In addition, the time of validation of the transactions would be too long, risking that the users would use other cryptocurrencies (Bitcoin Magazine, 2022).

The size limit means that there is less space for transactions to be stored, which consequently means that more blocks must be mined to store more information. The limitation in block size caused the creation of another cryptocurrency, called Bitcoin Cash. It is the same as Bitcoin, but with a larger capacity of transactions per second. This cryptocurrency is not as popular as the original Bitcoin and is therefore less valuable in the market (Vujičić et al., 2018, p. 3).

In 2017, with the new technology of segregated witness (SegWit), it has been possible to increase the amount of MB that can be stored inside a block. The amount of data is in theory increased to 4 MB, but in practice it is closer to 2 MB per block. Segregated Witness (SegWit) can be described as a mechanism wherein a mined block is accompanied by an extension block that has a larger storage capacity compared to the original block. It can still be accepted by the system within its limitations of 1MB. This is done by, instead of measuring the block in MB, it is measured in transactions and its contained value. By increasing the MB in a block, it opens the possibility for Bitcoin to be more efficient, and to increase its capacity to process more transactions in less time, thus, making transaction fees lower and more affordable for its users (Pérez et al., 2019, p. 231-232).

In addition, the mining market is very competitive, and its mining technology is always in development. This is one of the main reasons for the creation of mining farms. Mining farms increase the possibility of guessing the right nonce, meaning that there are higher chances of getting a reward when mining (Bondarev, 2020, p. 527).

The motivation for miners to mine is that for every right nonce the miner(s) gets rewarded with a fixed number of Bitcoins. Miners can then convert their Bitcoins to other fiat currencies, save them, or invest them in new mining projects. The reward is on average halved every 4 years. It started with 50 Bitcoins in 2009 and is currently at 6,25 BTC. Consequently, adding these BTC to the blockchain increases the amount of BTC in circulation. It is estimated that the last Bitcoin will be mined around the year 2140 (O'Dwayre & Malone, 2014, p. 282). Another important motivation factor for miners is the transaction fee income. This is a fee that the miners charge the public when they validate and include a transaction in the blockchain. The transactions' process is classified as part of the mining activity. In figure 2 it can be seen that the number of Bitcoins in circulation has been increasing logarithmically since its creation. This is due to a variety of factors, including its increased popularity, particularly since 2017, when it was at its peak and the public became more familiar with blockchain technology. This garnered interest, increasing investors interest in cryptocurrencies and blockchain technology.

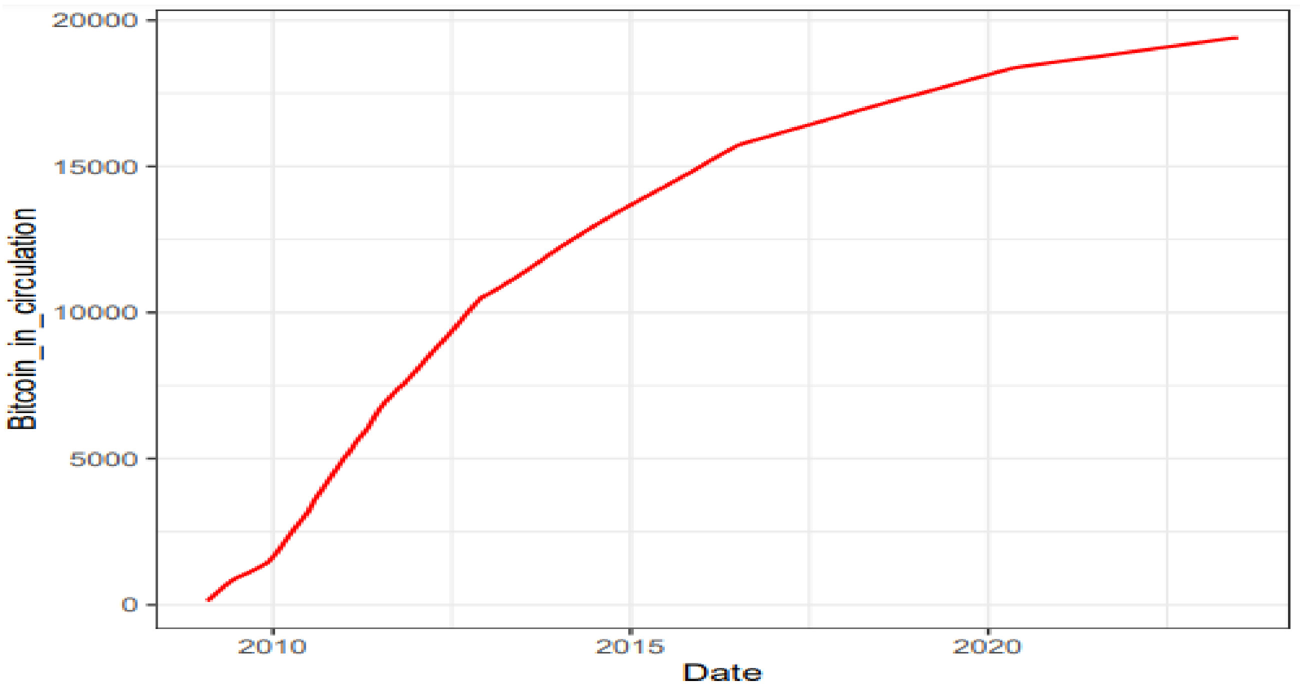

Figure 2. *Bitcoins in circulation (in thousand), from 2009 – 2022.*

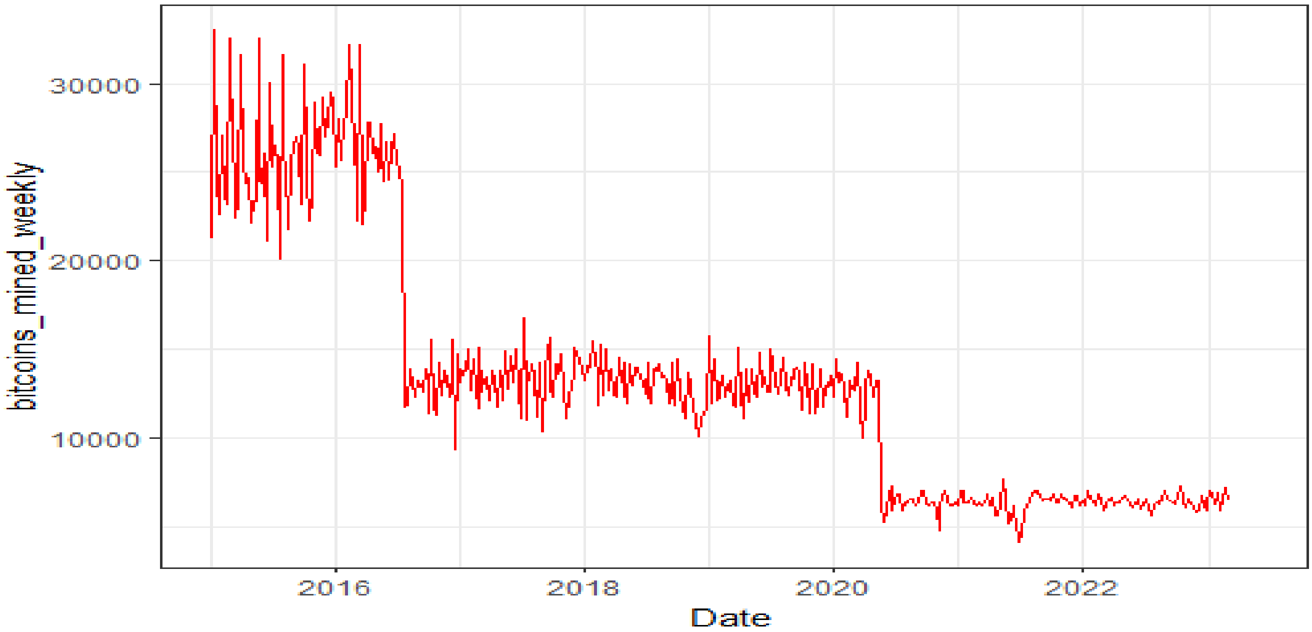

***Figure 3.** Bitcoins mined pr. week by miners, from 2015 – 2022.*

Furthermore, in order to use BTC, they must be stored somewhere. This is known now as a wallet. Its purpose is to store Bitcoins and send and receive transactions to other wallets. The wallet has its own address, which is known as a public address. A public address is known to the public and stored in the block's transaction information (Suratkar et al., 2020, p. 2). To log in to your wallet the user must log in using a password and a username, also called private key and Bitcoin address. Although the public key is generated by the Bitcoin address there is no relationship between them, and therefore the private key cannot be traced (Suratkar et al., 2020, p. 3). However, there are two types of wallets: hot and cold wallets. Hot wallets are applications which store your private key and are constantly connected to the internet network. While on the other hand, cold wallets are wallets stored in a hardware like a flash drive. Here the digital currency gets downloaded into external physical hardware, and it can only be accessed by having the physical control of the external hardware (Suratkar et al., 2020, p. 1). Furthermore, to be able to make a BTC transaction, the transaction must be validated and confirmed by miners. Here the miners charge a mining fee for their work to confirm the transaction. Figure 4 shows the average mining fee over time.

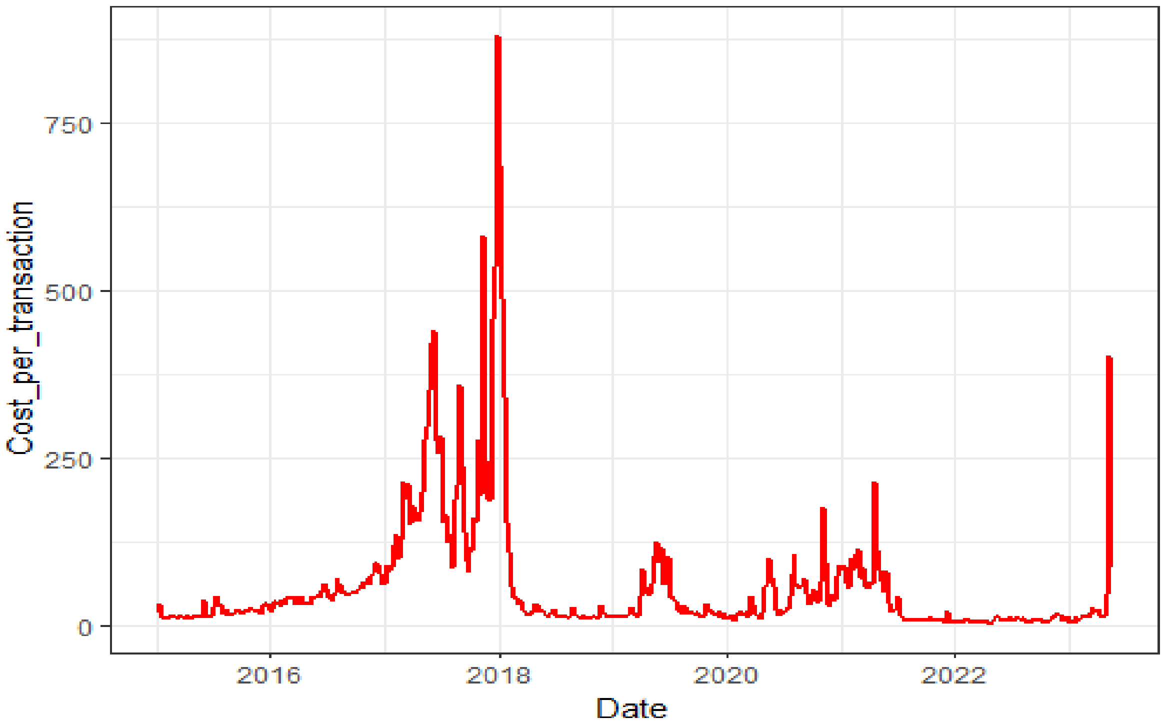

Figure 4. *Transaction fees paid to miners (in USD), from 2015 – 2022.*

2.3 Bitcoin and cryptocurrencies economic policies by country

The founder of Bitcoin was driven by the desire to establish a legitimate payment method capable of competing with traditional fiat currencies worldwide. Consequently, it is crucial to examine the economic policies implemented by different countries, as not all have embraced the concept of digital currencies. The viability of Bitcoin as a genuine payment alternative and a formidable contender to the existing system could be challenged if governments actively attempt to shut it down or impose bans.

According to a report by Goldman Sachs, 80% of Bitcoin trading exchange is held in RMB - China's currency, while only 19% of Bitcoin trading was held in USD - USA's currency (Chandran, 2015). This shows the importance of China's role in Bitcoin mining, hence why China is also called the world center of cryptocurrency mining.

In 2013 PBC (The People's Bank of China) banned financial institutions of holding and/or transacting cryptocurrencies. Arguing that cryptocurrencies can facilitate financial crime, create economic instability by leading to capital flight from the country, and increase environmental issues. This was since cryptocurrencies deviate from normal restrictions set by the Chinese government (Ju et al., 2016, p. 455). Other countries have also discussed and used the same arguments, weighing more for the banning of Bitcoin especially considering how much pollution Bitcoin mining creates.

Furthermore in 2017, the Chinese government had to step in and increase regulations in the crypto market as people were investing in ICO’s, this was later found to be frauds and scams. These projects took investor money and left them with worthless cryptocurrencies. This forced companies like Bitcoin China and other investors to cease their operations in the country and relocate them to other countries (Xie, 2019, p. 477).

In 2021 Bitcoin’s price was around 55,000 $ USD, attracting a lot of attention from investors due to its high price. The Chinese government knew there was a black market for cryptocurrency in China, and therefore, the government decided to totally ban cryptocurrencies from the country. This has resulted in the hashrate dropping by 50% (Figure 5), that year, in addition the price dropped to around 30,000 $ USD after the ban took place (Figure 6). The punishment for trading cryptocurrencies was up to 15 years in prison both for citizens and businesses. The ban included Bitcoin mining, employment in the mining sector and crypto trading transactions (Alekseenko, 2022, p. 371).

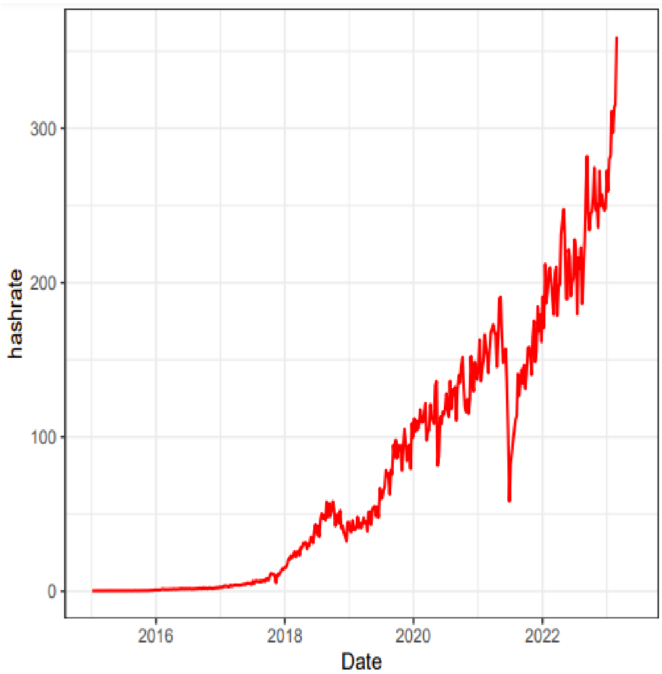

Figure 5. *Bitcoin’s hashrate (in million), from 2015 – 2022.*

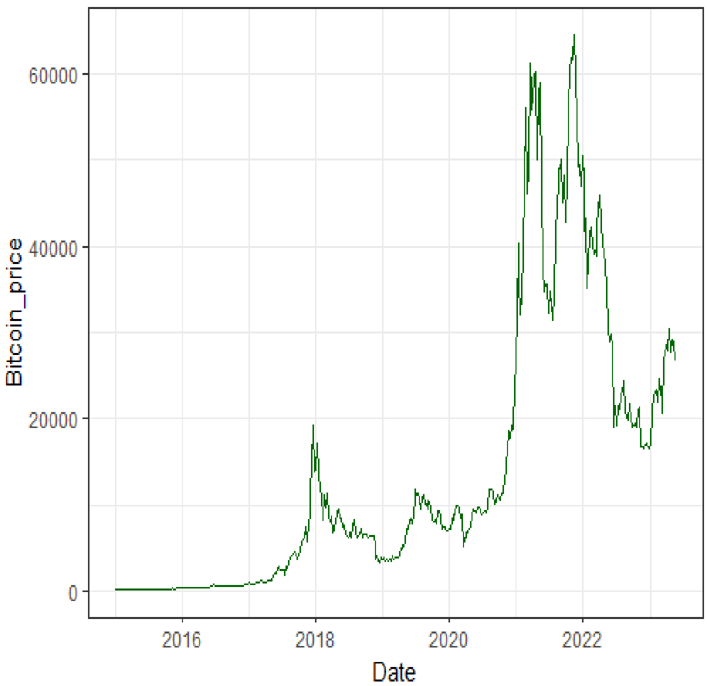

Figure 6. *Bitcoin Price (in USD), from 2015 – 2022.*

To address security concerns related to money laundering, several countries, including the USA, have contemplated the potential banning of cryptocurrencies, thus highlighting the opportunity for developing a state-backed digital currency that offers increased security and regulation under governmental oversight. (Campbell-Verduyn, 2017, p. 97).

In other countries like Norway, Canada, Japan, Australia and the UK, cryptocurrency is classified as a commodity and therefore subject of taxation. These countries are arguably approaching cryptocurrencies from an open perspective, as they seem to treat cryptocurrencies like stocks and other commodities/investments (Moorthy, 2018, p. 36-38).

Following Russia's invasion of Ukraine, the Russian government has been more open to develop cryptocurrency mining in the country, as cryptocurrencies are an alternative payment method, that could bypass international sanctions linked to the Ukrainian war. This raises general concerns about the purposes for which cryptocurrency trading can be used to fund. Some are suspecting that crypto currency trading may be linked to war funding or corruption purposes (Theiri et al., 2023, p. 68).

2.4 Where is Bitcoin used today?

Although many countries have implemented and tried to govern cryptocurrencies, they do have their usage in today's economy. To provide comprehensive insights into this particular activity, we have dedicated a chapter that delves into this subject.

Currently some companies are trying to adapt and innovate, accepting cryptocurrencies as a viable payment method. Companies like Microsoft have publicly announced their acceptance for Bitcoin payment from customers. It is via BitPay that Microsoft made it possible for other companies like Twitch to start accepting Bitcoin as a payment method. In Twitch streams, it is normal to tip the live streamers. With BitPay, it's possible for the public to start donating to the streamers via Bitcoin (Bitpay, 2023).

Other companies that also have taken advantage of Bitcoin are online casinos, some of them have started to accept Bitcoin and other cryptocurrencies as valid payment methods (Brown, 2021).

Long-term investments made by some banks and companies have garnered a lot of attention. Particularly noteworthy are the investments made by Bank of America (Tellez, 2021), Goldman Sachs (Kaplan, 2023) and the car manufacturer Tesla (Gerken, 2023). In addition, cryptocurrency has been ever growing in popularity amongst individual investors. Individual investors have also been taking advantage of Bitcoins' natural characteristics to avoid taxes. Therefore, the authorities made regulations according to how Bitcoin and other cryptocurrencies must be included as property in a tax statement. Implementing this has been difficult and tax fraud is not uncommon amongst investors (Guadamuz & Marsden, 2015, p. 22). Bitcoin and other cryptocurrencies are therefore popular among investors for tax fraud (Ülger, 2018, p. 36).

However, companies like Coinbase and Binance which are cryptocurrency exchange companies have developed debit cards for customers' use (Binance, 2023; Coinbase, 2023). Customers who use the cards get rewarded in cryptocurrencies. This is done to incentivize consumers to use their debit card.

In the service industry companies like Starbucks and fast-food restaurants like McDonald's and Burger King newly announced that they would make it possible to pay for their products using Bitcoin. This is being done in an attempt to reach out to more customers (Amick, 2022). Same happened with a known retail store in South Africa called Pick-n-save. The company also announced that Bitcoin could be used as a valid payment method (Manning, 2022).

On the other hand, when El Salvador made Bitcoin a formal currency in the country in 2021, there was a law called "Ley de Bitcoin" where pensions and government bonuses were going to be paid to the persons in Bitcoin (Ley Bitcoin, 2021, §13).

Another area in which Bitcoin is commonly used is in the dark web. One of the most peculiar characteristics for Bitcoin and cryptocurrencies in general is that they are non-traceable to the user's wallet account. This is caused by the anonymity quality of the blockchain network. It is only when Bitcoin is being exchanged into fiat currency that authorities or other entities can trace back the Bitcoins to the wallet's account. Bitcoins anonymity characteristics makes it a natural payment method for money laundering across the dark web. It is very convenient, both for sellers and buyers of the dark web to be anonymous, as in this web there is easy access to buy illicit substances, weapons, prohibited content, malware, stolen items etc. By being anonymous they bypass the conventional regulations sat by the different authorities around the world (Lee et al., 2019, p. 1). It is also a known issue, that countries like for example North Korea steal cryptocurrency funds. They then money launder the profits made from selling the cryptocurrency. This causes North Korea to have more capital to spend in the national budget (Chainanalysis, 2023, p. 46).

2.5 What can help explain the price of Bitcoin

Bitcoins price through the years has been a common headline in different financial newspapers. It would not be unreasonable to assume that many Bitcoin miners have been motivated by this. We therefore would like to provide a chapter on Bitcoin price and some of the factors that are believed to influence it.

Bitcoin's price is determined by supply and demand, as BTC has a limit of 21 million BTC and its users has increased significantly through the years. Consequently, BTC price rise as it cannot hold so many users at the same price (Kristoufek, 2015, p. 6). Bitcoin's increasing demand also has a lot to do with investors and the price of BTC. Some investors seem to invest in Bitcoin in the short term to get a "quick" profit out of it. This could be compared to short-term trading activity. The investors then tend to quickly sell off their investment once they turn a profit. It can therefore be argued that BTC price is up to a certain point manipulated short term by its users. This makes the BTC price very unstable and difficult to predict, leading to a lot of speculations around BTC (Nguyen et al., 2018).

In addition, media news can significantly affect the price of BTC, as for example: Elon Musk's mentions of Dodgecoin or Bitcoin in the news. These actions lead to positive or negative reactions in the cryptocurrency market (Browne, 2021). Other factors which may affect the BTC price are mining equipment development (Kubal & Kristoufek, 2022, p. 6), The Dow Jones index, and EUR and/or USD exchange rate (Antoniadis et al., 2018, p. 514-515).

2.6 Bitcoin sustainability background

One of Bitcoin's primary issues has been its energy footprint. Many argue that Bitcoin has no place in a world in which we wish to reduce our carbon footprint. Many argue that in a world striving to transition away from fossil fuels and minimize environmental impact, Bitcoin may not align with these sustainability goals. (Gschossmann et al., 2022).

It is difficult to give an exact estimation of the carbon footprint of Bitcoin, as Bitcoin mining companies do not report their carbon emissions. Despite this, researchers have found different methods for estimating Bitcoin's carbon footprint. Most use a measurement of how much electricity/power the mining industry consumes (Küfeoğlu & Özkuran, 2019, p. 2-3). Estimates show that Bitcoin mining produces less emissions than fashion, gold, deforestation, livestock and tourism industries (CCAF, 2019). It can be argued that this just shows how large the estimated emissions are. Leading Bitcoin to be ranked #27 on a global scale for its electricity consumption. It is ranked as #67 on a global scale for its greenhouse gas emissions, if it were to be classified as a country (CCAF, 2019). Simultaneously, if we were to compare a Bitcoin transaction with a Visa transaction and their greenhouse gas emissions. One transaction with Bitcoin would be equal to 1,195,657 Visa transactions. (Kohli et al., 2023, p. 82).

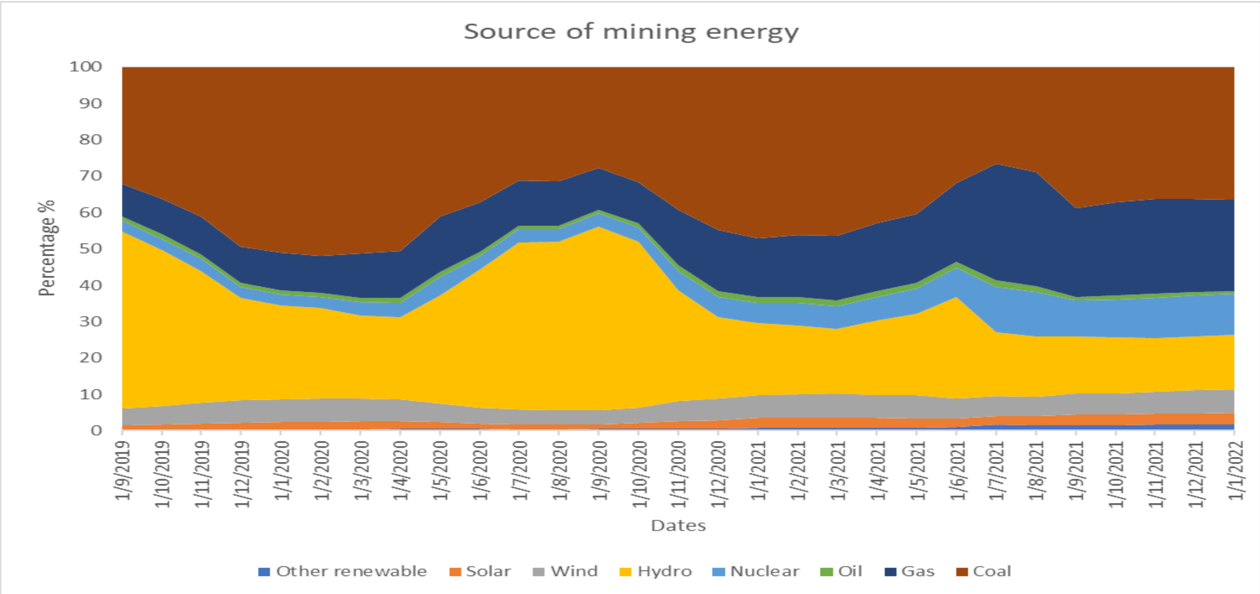

Figure 7. *Energy source of Bitcoin mining, from 2019 – 2022.*

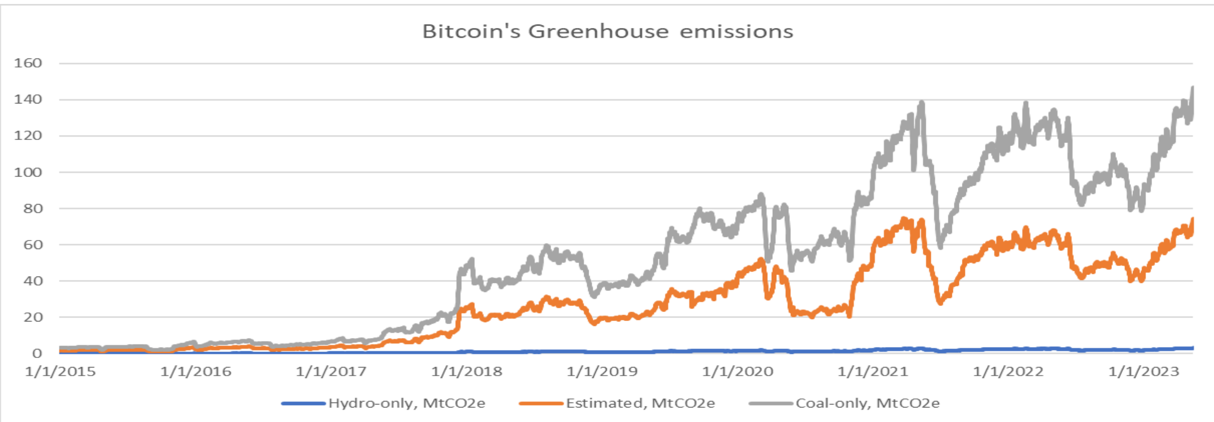

Figure 8. *Bitcoin's Greenhouse emissions measured in Metric tons of carbon dioxide equivalent, from 2015 - 2022.*

3. Relevant Literature

In Vranken's article entitled "Sustainability of Bitcoin and blockchains" published in 2017, he debates that miners have had to improve their hardware. The mining sector has been getting more competitive, forcing miners to get the newest hardware. This implies a more efficient hashrate, which is viewed as a threat to other miners and the reward they can obtain. Mining hardware has developed a lot since its beginning in late 2016. Vranken, for example, looked at the different mining chip hardware and compared their electricity usage. He then looked at how much the miners would have to pay with every different computer hardware. He argued that ASIC was the best option as it has a low electricity footprint and a high mining efficiency rate. (Vranken, 2017, p. 8).

Vraken compared the energy usage from the traditional banking systems and the Bitcoin mining sectors. He has criticized the way Bitcon operates and the amount of energy it takes to mine, insinuating that the energy rate it takes to mine BTC is less scalable and practical. Considering the concerns and limitations associated with the proof-of-work process, alternative approaches such as proof-of-stake or proof-of-space have been proposed as potential replacements. However, Vranken suggests that these alternative processes may not offer the same level of security as the current proof-of-work mechanism, presenting a challenge that necessitates further research and exploration (Vranken, 2017, p. 7).

In another article, called "Green FinTech: sustainability of Bitcoin " published by Kabaklarli in 2022, Kabaklarli debates if Bitcoin can be classified as green fintech and goes on to define what green fintech is. Furthermore, he mentions that it is difficult to know what energy sources are used in Bitcoin mining. He therefore finds it hard to estimate how big the carbon footprint of Bitcoin really is. Hereafter, he explains what source of energy Bitcoin mining comes from as it is very unclear, making it difficult to have specific factors that may influence its price, such as: miner's revenue, electricity prices, market news and falling markets. He links these factors to the users' use of Bitcoin, which can be translated to Bitcoins carbon footprint. This concludes that Bitcoin can in fact be classified as a sustainable fintech as it can help reduce poverty and create more equality in our society. However, an interesting discovery from this article is that miners seem to increase mining operations when prices increase or when prices are expected to increase, which as a result gives a positive correlation between electricity use and mining operations. He explains that a lot of the mining energy comes from coal, which is a nonrenewable energy resource. Therefore, encouraging miners to switch to more renewable sources of energy such as wind, geothermal or solar (Kabaklarli, 2022).

An article published by O'Dwyer and Malone in 2014 named "Bitcoin Mining and its Energy Footprint" researched the energy consumption in the proof of work process when Bitcoin is mined. This was done by using different mining hardware and estimating its carbon footprint from the electricity consumption. The conclusion was that the energy consumption was on par with Ireland's energy consumption. Furthermore, they explain which factors affect Bitcoin mining's energy consumption. They mainly look at the variable hashrate. Factors that they found to affect Bitcoin's hashrate were mining revenue, number of miners, hardware efficiency and electricity price, among others (O'Dwyre & Malone, 2014, p. 280).

They then went on to describe how the technological development in mining hardware used is a significant factor for the mining development and its energy consumption. Another variable which is of importance according to O'Dwyer and Malone is the Bitcoin price in USD, as this is the main reward miners are looking for. Concluding that Bitcoin's price and electricity prices are the primary factors influencing Bitcoin's development. Further explaining that for Bitcoin to further develop, the energy consumption of the mining sector must increase. As there is a lot of competition in the mining industry. This requires the miners to keep up with the market's best hardware, to obtain any significant reward when mining (O'Dwyre & Malone, 2014, p. 281).

4. Method

4.1 Understanding of methods used.

To be able to find out what variables influence the mining difficulty of Bitcoin multiple time series regressions are conducted. The analysis is conducted in R, a programming language for statistical computing, as we find this tool to have many helpful features. Time series regression is a statistical method used to predict a future response based on a response history. It can help one understand and predict dynamic systems from experimental or observational data. The mathematical formula for regression analysis is $Yt = Xt\beta + et$ (Baffes, 1996, p. 70).

There are several steps to conduct a time series regression. When one is conducting a time series regression the time series used must be stationary. A stationary time series is a time series in which the mean and the standard deviation is constant. We also do not witness any seasonality within the time series. If one of these points is validated the time series will not be considered stationary, meaning that the results yield from the data analysis won't be valid. (Baffes, 1996, p. 69). We have therefore checked our variables for stationarity and transformed them adequately. The variables were checked by using a R package called t-series. To transform our variables so that they are stationary the percentage change is used. This can be easily done using the R function delt. Many of the variables used have also been separated into positive and negative percentage changes. This is done to see how different changes affect the network difficulty. This can give one insight into how miners think about different changes. It is important to note that a negative explanatory variable often shows up positive in the regression as the x variable will be negative in the formula. For our analysis we also used multiple different lags for each variable. This is done to see how different time variables affect change depending on the time frame. The results shown in our analysis are the ones found to be of most relevance for the research question.

4.2 Data description

The data used in our analysis is downloaded from the Nasdaq data link and Fred database. When it comes to data regarding Bitcoin one can download data that stems from 2009 when it was first introduced. In our analysis, however, data from 2015 and onward is used. This was decided as data from 2009, some of it seemed inconsistent. Bitcoin was relatively new in 2009, which could explain the discrepancy. The media attention and in turn popularity of Bitcoin was nowhere near as present as it is today. For our analysis weekly data is used as this seemed most appropriate for our research question.

4.3 Data description of dependent variable

There were two relevant options to determine an appropriate dependent variable. The two options were hashrate and network difficulty. Hashrate is the estimated number of tera hashes per second the Bitcoin network has been performing in the last 24 hours. This is a direct measure of the energy consumption of Bitcoin mining the machines involved require. Network difficulty is a relative measurement of how difficult it is to mine a new block for the blockchain. For our analyses we decided to use network difficulty. The reasoning for this was because of statistical properties inhibited in the variable. A time series line graph and a percentage change point graph are shown to explain the reasoning.

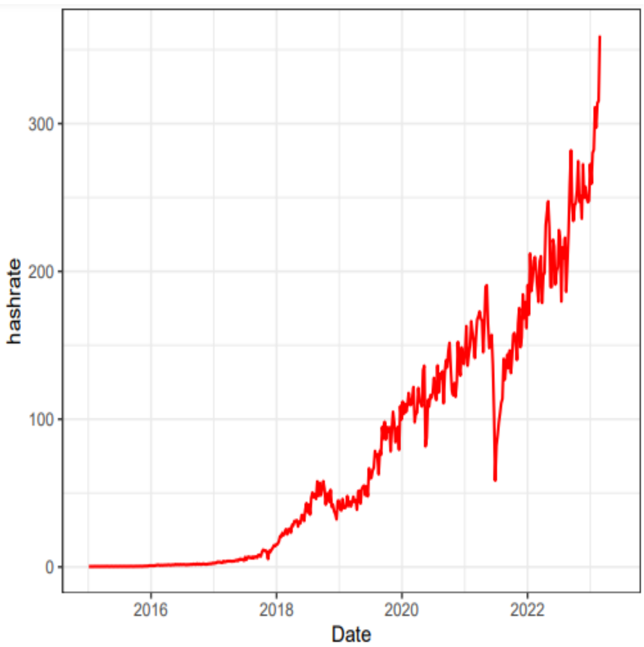

Figure 5. Bitcoin's hashrate (in million) from 2015 – 2022.

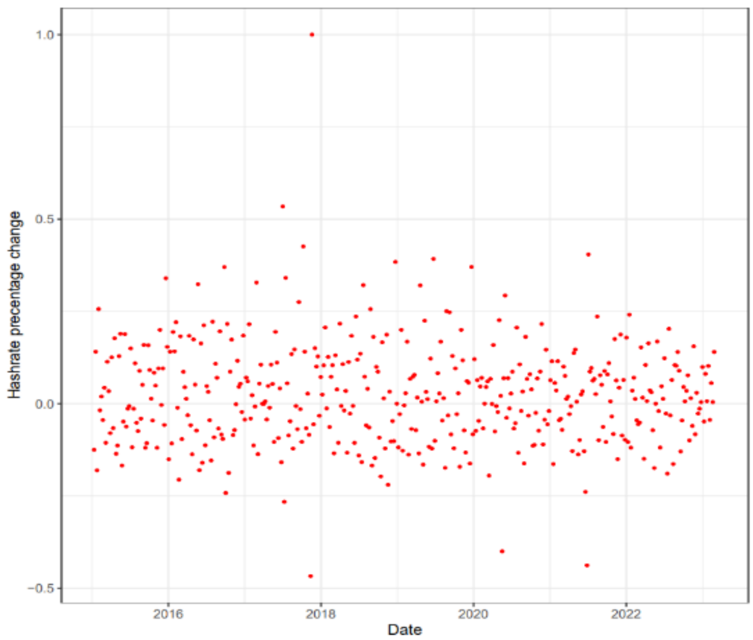

Figure 9. *Hashrate percentage change from 2015 - 2022*

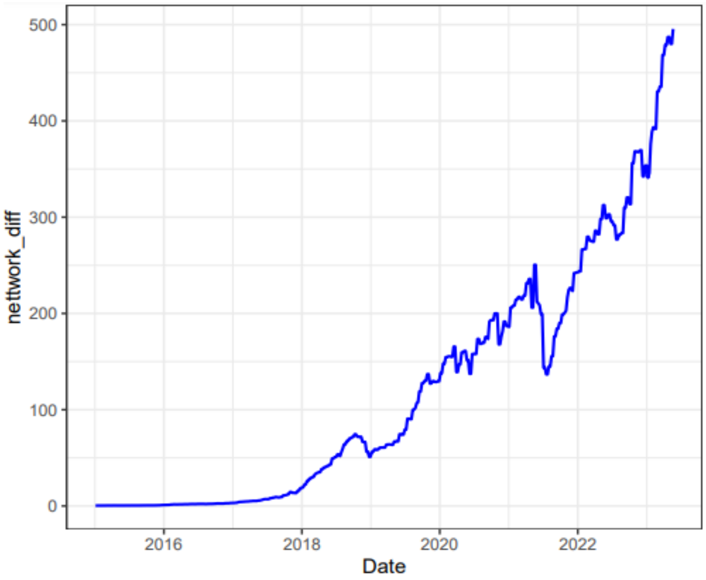

Figure 10. *Bitcoin's network difficulty (in 100 billion), from 2015 – 2022.*

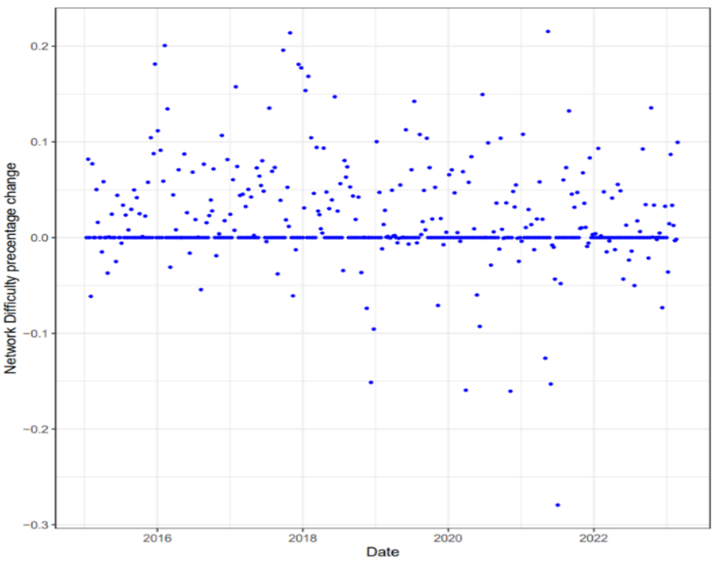

Figure 11. *Network difficulty percentage change, from 2015 – 2022.*

It can be observed in figure 5 and figure 10 that the two variables vary in a similar way, they both exhibit the same characteristic and trend. When looking at figure 9 and figure 11, the two begin to differ. There seems to be much more noise associated with hashrate compared to network difficulty. Hashrate percentage change per week has a much wider range than its counterpart network difficulty. Network difficulty also has multiple weeks where the percentage changes are zero. These factors contribute to why network difficulty was chosen as a dependent variable.

4.4 Data description of explanatory variables

Many different variables are used in the analysis to see how they affect the network difficulty. We have chosen to focus on exogenous variables as we find these variables to be most relevant. An exogenous variable is a variable in a model whose value is determined externally, outside the scope of the model itself. This variable is subsequently incorporated into the model and its impact is observed (Varian, 1992, p. 202).

4.4.1 Bitcoin price

The Bitcoin price represents the value of one Bitcoin and is reported on a daily basis. In our study, we have obtained weekly data and divided the variable into positive and negative changes. This approach allows us to examine how different price movements impact energy consumption. To ensure stationarity, we have employed percentage change as a measure.

4.4.2 Natural gas price

To see how energy prices affect Bitcoin mining the variable natural gas is used. The variable has been divided into positive and negative changes to see how miners react to differing energy prices.

4.4.3 Cost per transaction

As transaction fees are also a part of the mining revenue, one finds it relevant to see its impact on network difficulty. The variable has been divided into positive and negative changes. The percentage change is again used to make the variable stationery.

4.4.4 Hashrate per unique miner

This variable has been created by taking total hashrate divided by unique users. This was done to gauge the average computing power of each individual miner. The variable has also been divided into positive and negative changes. The percentage change is used to make the variable stationary.

4.4.5 Summary statistics

To provide information about the different variables used in the analysis a descriptive table for the variables is provided.

Descriptive

Statistic	N	Mean	St. Dev.	Min	Pctl(25)	Pctl(75)	Max
nettwork_diff_pct	435	0.018	0.050	-0	0	0.03	0
Bitcoin_price_pct	435	0.016	0.107	-0.419	-0.036	0.066	0.463
Natural_gas_price_pct	435	0.007	0.130	-0.765	-0.041	0.042	1.632
Cost_per_transaction_pct	435	0.079	0.539	-0.701	-0.178	0.194	7.477
Hashrate_per_unique_miner_pct	435	0.026	0.158	-0.361	-0.080	0.114	0.697

Table 1. *Variables descriptive statistics*

4.5 Data analysis and results

Our objective is to investigate which factors influence Bitcoin mining and its energy footprint. To do this, our focus has been on identifying what factors influence the variable network difficulty. A natural starting point for our analysis was to see how the variable Bitcoin price affects the energy consumption of mining. It is reasonable to assume that the price of a Bitcoin would have a significant impact on the desire for Bitcoin mining. For many individuals, profits are the main motivation for Bitcoin mining. We have therefore started with this variable in our analysis. Thereafter, we analyzed how the variables cost per transaction, natural gas prices and hashrate per unique miner affect the network difficulty of Bitcoin mining.

4.5.1 Model 1

The first variable we would like to focus on is Bitcoin price. Bitcoin price is a key determinant of how much revenue a Bitcoin miner will generate. As mentioned previously in our paper, miners are rewarded with a fixed number of Bitcoins for cracking the code. This naturally makes the current price of Bitcoin a large motivation for miners to conduct mining activities.

The formula for our first model is:

$$Nettwork\ Difficulty \ = \ bitcoin\ price\ pos_{t-x} \cdot \beta + bitcoin\ price\ neg_{t-x} \cdot \beta$$

Network Difficulty model (weekly)

	Dependent variable:	
	nettwork_diff_pct	
	(1)	(2)
price_pos_2	0.047**	
	(0.023)	
price_neg_2	-0.032	
	(0.035)	
price_pos_4		0.041***
		(0.013)
price_neg_4		-0.010
		(0.027)
Constant	0.013***	0.012***
	(0.004)	(0.004)
Observations	436	434
R^2	0.010	0.023
Adjusted R^2	0.005	0.019
Residual Std. Error	0.050 (df = 433)	0.049 (df = 431)
F Statistic	2.141 (df = 2; 433)	5.131*** (df = 2; 431)
Note:		*p<0.1; **p<0.05; ***p<0.01

Table 2. *Network difficulty weekly model with Bitcoin price positive and negative percentage change as explanatory variables. Using 2 weeks and 4 weeks delay effect.*

The first table shows the regression results with a two- and four-week delay for the Bitcoin price. The results yielded are intriguing. It shows how positive movements in the Bitcoin price affect the Network difficulty. The positive movement for the Network difficulty is stronger for two weeks compared with a four-week delay. However, the two-week delay is only significant at the five percent level while the four-week delay is significant at the one percent level. Negative price movements do not seem to have any noteworthy effect on the network difficulty. Neither one shows any significance. The results yielded indicate that Bitcoin miners are motivated to mine more if the Bitcoin price has been going up in recent weeks. They do not seem to be discouraged from mining when the Bitcoin price goes down during recent weeks.

Network Difficulty model (weekly)

	Dependent variable:	
	nettwork_diff_pct	
	(1)	(2)
price_pos_8	0.011	
	(0.008)	
price_neg_8	0.053^{**}	
	(0.022)	
price_pos_11		0.014^{**}
		(0.006)
price_neg_11		0.056^{***}
		(0.019)
Constant	0.019^{***}	0.018^{***}
	(0.004)	(0.004)
Observations	430	427
R^2	0.029	0.052
Adjusted R^2	0.024	0.048
Residual Std. Error	0.049 (df = 427)	0.049 (df = 424)
F Statistic	6.297^{***} (df = 2; 427)	11.704^{***} (df = 2; 424)
Note:		*p<0.1; **p<0.05; ***p<0.01

Table 3. *Network difficulty weekly model with Bitcoin price positive and negative percentage change as explanatory variables. Using 8 weeks and 11 weeks delay effect.*

Our second table shows the regression results with an eight- and eleven-week delay. The results yielded here are very different from the previous regression. For the eight-week delay positive movements in the Bitcoin price do not exhibit a significant impact on the network difficulty. The negative price movements on the other hand have a significant impact at the five percent level. The impact here is higher than for positive movements in the previous model. For the eleven-week delay both positive and negative price movements are significant. The negative price movements are significant at the one percent level, while positive price movements are only significant at the five percent level. Negative price movements also seem to affect the network difficulty much more than positive movements. As the "impact factor" is three times as high as for positive changes. Bitcoin miners' willingness to mine seems to be much more affected in the long term by negative price movements than by positive ones.

Network Difficulty model (weekly)		
	Dependent variable:	
	nettwork_diff_pct	
	(1)	(2)
price_pos_26	0.007^{***}	
	(0.002)	
price_neg_26	0.014	
	(0.015)	
price_pos_52		0.003^{***}
		(0.001)
price_neg_52		0.014
		(0.013)
Constant	0.014^{***}	0.014^{***}
	(0.004)	(0.004)
Observations	412	386
R^2	0.031	0.032
Adjusted R^2	0.026	0.027
Residual Std. Error	0.050 (df = 409)	0.050 (df = 383)
F Statistic	6.529^{***} (df = 2; 409)	6.384^{***} (df = 2; 383)
Note:		*p<0.1; **p<0.05; ***p<0.01

Table 4. *Network difficulty weekly model with Bitcoin price positive and negative percentage change as explanatory variables. Using 26 weeks and 52 weeks delay effect.*

Our third table shows the impact of the Bitcoin price with a twenty-six-week delay and a fifty-two-week delay. The results here are in line with what we found in the first table. The only significant variables are positive movements in the Bitcoin price. For both models the variable is significant at the one percent level. Their impact on the network difficulty however is very low compared to our previous models. It seems like Bitcoin miners are influenced by price movements over larger periods of time, however the impact is much less than over shorter periods. The reasoning could be because miners care less about longer time frames. At the same time for Bitcoin mining to be profitable in the long term, the price of Bitcoin must increase.

4.5.2 Model 2

The second variable we wanted to study was cost per transaction. Transaction fees, as previously mentioned in our paper, are another source of income for miners. We therefore wanted to study how this variable would affect the network difficulty of Bitcoin mining. Miners would most likely be motivated by the revenue generated by transaction fees.

The formula for this model is:

$$Network\ difficulty\ =\ \cos t\ per\ transaction\ pos_{t-x} \cdot \beta + \cos t\ per\ transaction\ neg_{t-x} \cdot \beta$$

Network Difficulty model (weekly)		
	Dependent variable:	
	nettwork_diff_pct	
	(1)	(2)
Cost_per_transaction_neg	0.052^{***}	
	(0.017)	
Cost_per_transaction_pos	-0.002	
	(0.005)	
Cost_per_transaction_neg_2		0.019
		(0.014)
Cost_per_transaction_pos_2		-0.002
		(0.002)
Constant	0.023^{***}	0.020^{***}
	(0.003)	(0.003)
Observations	436	435
R^2	0.022	0.006
Adjusted R^2	0.018	0.001
Residual Std. Error	0.049 (df = 433)	0.050 (df = 432)
F Statistic	4.912^{***} (df = 2; 433)	1.317 (df = 2; 432)
Note:		*p<0.1; **p<0.05; ***p<0.01

Table 5. *Network difficulty weekly model with cost pr. transaction positive and negative percentage change as explanatory variables. Using 0 weeks and 1 week delay effect.*

Many different lags for the variable cost per transaction were checked, however the only lag to show a significant impact was lag 1. Our fourth table shows the impact of the variable cost per transaction for a one- and two-week delay. The results show how negative movements in transaction fees paid out to miners' negatively impact network difficulty. The variable is significant at the one percent level. Positive movements on the other hand don’t seem to affect the network difficulty much. Our results indicate that transaction fees motivate miners' willingness to mine in the short term. The results yielded are very different from the price of Bitcoin which seems to affect mining activity over different time periods.

4.5.3 Model 3

The third variable we wished to study was natural gas. Energy prices as explained earlier are one of the major costs associated with Bitcoin mining. We therefore wanted to test how movements in the energy commodity market would affect Bitcoin mining. Many different energy commodities were tested, however the most prominent results yielded came from natural gas.

The formula for the model is:

$$Network\ difficulty = Natural\ gas\ pos_{\,t-x} \cdot \beta + Natural\ gas\ neg_{t-x} * \ \beta$$

Network Difficulty model (weekly)

	Dependent variable:	
	nettwork_diff_pct	
	(1)	(2)
price_pos_gas_2	-0.112^{***}	
	(0.039)	
price_neg_gas_2	0.045	
	(0.044)	
price_pos_gas_13		-0.050^{***}
		(0.014)
price_neg_gas_13		0.021
		(0.020)
Constant	0.024^{***}	0.025^{***}
	(0.004)	(0.004)
Observations	435	424
R^2	0.019	0.030
Adjusted R^2	0.014	0.025
Residual Std. Error	0.050 (df = 432)	0.050 (df = 421)
F Statistic	4.079^{**} (df = 2; 432)	6.399^{***} (df = 2; 421)
Note:		$^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$

Table 6. *Network difficulty weekly model with gas price positive and negative percentage change as explanatory variables. Using 1 week and 13 weeks delay effect.*

The table above shows us the result yield from a two week and thirteen-week lag. In both models the only variable to be significant is positive movements in the natural gas price. The variable is significant at the one percent level for both models. Positive movements in the natural gas cause the network difficulty to go down. This could be as natural gas is a prominent energy commodity across the world. The effect is twice as great with a two-week delay compared to a thirteen-week delay. This could indicate that miners are more influenced by natural gas price movements in the short term. The two-week effect has the strongest influence observed thus far in the short term for our analysis. Negative movements in the natural gas price also seem to negatively affect the network difficulty. The variable is not significant at any level, it therefore can be argued if these results are of relevance.

4.4.4 Model 4

The fourth variable we wanted to look at was hashrate per unique miner. As we were able to download data for hashrate and unique users, combining these two variables made sense. How many unique addresses and the amount of terahash each user produces on average, will naturally be believed to affect the network difficulty.

The formula for the model is:

$$Network\ difficult = unique\ hashrate\ neg_{t-1} \cdot \beta + unique\ hashrate\ pos_{t-1} \cdot \beta$$

Network Difficulty model (weekly)

	Dependent variable:	
	nettwork_diff_pct	
	(1)	(2)
Hashrate_per_unique_miner_pos_4	0.036^{***}	
	(0.012)	
Hashrate_per_unique_miner_neg_4	0.096^{***}	
	(0.032)	
Hashrate_per_unique_miner_pos_9		0.020^{***}
		(0.006)
Hashrate_per_unique_miner_neg_9		0.117^{***}
		(0.034)
Constant	0.017^{***}	0.018^{***}
	(0.003)	(0.003)
Observations	432	427
R^2	0.058	0.066
Adjusted R^2	0.054	0.062
Residual Std. Error	0.049 (df = 429)	0.048 (df = 424)
F Statistic	13.219^{***} (df = 2; 429)	15.053^{***} (df = 2; 424)
Note:		*p<0.1; **p<0.05; ***p<0.01

Table 7. *Network difficulty weekly model with hashrate pr. miner positive and negative percentage change as explanatory variables. Using 4 weeks and 9 weeks delay effect.*

The table above shows the results yielded from a four- and nine-week delay. Many different lags were checked. The results shown were the ones we found most interesting. The results yielded for both models are similar in nature. Negative movements in the hashrate produced by each individual miner have a much greater negative impact on the network difficulty, than a positive movement in the hashrate produced by each individual miner. Both variables are significant at the one percent level. The difference in the two variables' effect is greater after nine weeks compared to four. Especially, the positive movements effect is decreased significantly. This could be explained by the fact that positive movements are more common, making their individual effect lessened. The occurrence of a negative change is less, making the impact larger when it occurs.

4.5.5 Model 5

As multiple variables have been tested individually our fifth model encompasses multiple variables to see how they affect each other in unison. The two models shown run with a four-week lag and a twelve-week lag. This is done to show differences in the short term and long term. The variable cost per transaction is not shown as this variable only is significant with no lag.

Network Difficulty multivariable model (weekly)

	Dependent variable:
	nettwork_diff_pct
price_pos_4	0.049***
	(0.013)
price_neg_4	0.007
	(0.027)
Hashrate_per_unique_miner_pos_4	0.038***
	(0.012)
Hashrate_per_unique_miner_neg_4	0.112***
	(0.032)
price_pos_gas_4	-0.015
	(0.011)
price_neg_gas_4	0.001
	(0.024)
Constant	0.013***
	(0.004)
Observations	432
R^2	0.098
Adjusted R^2	0.085
Residual Std. Error	0.048 (df = 425)
F Statistic	7.696*** (df = 6; 425)
Note:	*p<0.1; **p<0.05; ***p<0.01

Table 8. *Network difficulty weekly model with Bitcoin price-, hashrate pr. miner- and gas price- positive and negative percentage change as explanatory variables. Using 4 weeks delay effect.*

Network Difficulty multivariable model (weekly)

	Dependent variable:
	nettwork_diff_pct
price_pos_12	0.016***
	(0.005)
price_neg_12	0.029
	(0.020)
Hashrate_per_unique_miner_pos_12	0.008*
	(0.005)
Hashrate_per_unique_miner_neg_12	0.112***
	(0.037)
price_pos_gas_12	-0.013
	(0.009)
price_neg_gas_12	-0.013
	(0.019)
Constant	0.017***
	(0.004)
Observations	424
R^2	0.088
Adjusted R^2	0.074
Residual Std. Error	0.048 (df = 417)
F Statistic	6.664*** (df = 6; 417)
Note:	*p<0.1; **p<0.05; ***p<0.01

Table 9. *Network difficulty weekly model with Bitcoin price-, hashrate pr. miner- and gas price- positive and negative percentage change as explanatory variables. Using 12 weeks delay effect.*

Only positive movements in the Bitcoin price appear to be significant for the short-term multivariable model. Negative price movements in Bitcoin appear to have no effect. Bitcoin miners appear to mine more if the Bitcoin price increases. The opposite effect is seen for the variable hashrate per unique miner. Both positive and negative movements are significant in this case. Negative movements have a much greater impact on network difficulty than positive movements. The effect is nearly three times stronger. Reduced output from each individual miner has a much greater impact on network difficulty. The variable for natural gas price movements appears to have no effect on network difficulty in this model.

The twelve-week multivariable model results are both similar and different from the previous model. The Bitcoin price movement variable has changed somewhat. Positive movements are significant at the one percent level while negative movements are non-significant. Negative movements do have a greater impact on the network difficulty. The impact of positive price movements is slim. For changes in the variable hashrate per unique miner both negative movements and positive movements are significant, however, to differing digress. Moreover, showing how large of an impact less output by miners has on network difficulty. For the final variable natural gas price no significant effect is observed.

5. Discussion

We will discuss our key findings from the regressions in this section of the paper. We will also discuss other Bitcoin-related topics that we find important. These are topics we discussed earlier in our paper and would like to expand on in order to provide a more detailed answer to our research question.

5.1 Results of analysis

The results yielded from the different models presented have provided us with information on what factors cause network difficulty to increase or decrease. We will discuss our key findings and what implications they might have. The results yielded have varied depending on the period's percentage change in which it is conducted from. It seems that Bitcoin miners are affected by percentage changes in the different variables to differing degrees.

One of our key findings is how negative percentage change variables commonly were of greater significance than positive percentage changes. A negative percentage change variable also often had a much stronger impact than a positive percentage change variable. This was of special significance when it came to the variable's Bitcoin price, hashrate per unique miner and cost per transaction. When it came to the variable natural gas positive changes had a much larger negative effect than negative changes. This was expected as falling natural gas prices would mean lower energy prices for much of the world.

Why do negative changes in Bitcoin price, cost per transaction and hashrate per unique miner affect network difficulty so strongly? One natural explanation when it comes to Bitcoin price and cost per transaction comes from the fact that miners quite easily can shut down mining activity. Negative movements in these two variables will have a profound effect on miners' profits. Some miners will therefore decide to shut off their machines. This in turn will cause network difficulty to go down.

Natural psychological reactions could also be used to explain why this occurs. It is common for negative news to significantly impact the prices of various assets. It is frequently discussed how the market seems to overreact to news. According to studies, many people feel a loss twice as much as they do on an equivalent gain. As a result, negative movements may be selffulfilling. People do not want to suffer a loss, so they sell as a preventive measure, resulting in a runoff. This can also be seen with the rewards given to miners, who shut down their machines to avoid losses. When it comes to transaction costs, this effect is immediate, whereas the Bitcoin price takes some time to manifest (Schmidt & Zank, 2005, p. 157).

It should be discussed how this also is observed when it comes to hashrate per unique miner. The negative change has a profound effect compared to positive changes in output. It can be hard to pinpoint why exactly this is. An explanation could be that the network wants the network difficulty to fall when a negative change first occurs. This is done simply to encourage miners to mine again as network difficulty falls and the rewards are easier to come by. Another explanation is that the Bitcoin price first declines causing miners to shut off their machines and this in turn will cause the network difficulty to go down.

5.2 Power and Electricity

Although in our research we were not able to find adequate data for the electricity prices, this factor is still of importance for the development of the cryptocurrency mining industry. As the electricity price is of considerable importance for the profitability of the miners. This effect was shown through the use of variable natural gas in our model. We find it appropriate, however, to discuss this variable further.

The electricity price is a variable cost that varies depending on the country and what part of the country the miner is located. For example, if the miner is in Canada, the electricity price would depend more on natural weather factors such as: wind, sun, and rain (CER, 2019). Contrary to, if the miner is in Kazakhstan, where the electricity price will depend more on the price of fossil fuels like coal, gas, and oil. (IEA, 2020). It is important to mention that countries like the United States, China and Kazakhstan are the top 3 countries in which Bitcoin mining takes place (CCAF, 2019). These countries heavily rely on fossil fuel sources to generate electricity (IEA, 2020). The article from 2017 by Vranken and the article by Kabaklarli from 2022 both relate the significant effect of electricity's price influence on Bitcoin mining, therefore supporting our use of the electricity variable in this discussion.

In figure 12, we have listed the top 8 Bitcoin mining countries (CCAF, 2019) and their electricity prices. The countries shown are Canada, The United States, Malaysia, Kazakhstan, Russia, Ireland, Germany, and China. The average electricity price development can be seen in figure 13 for each country. In addition to a price index that we created, which is an average of all the 8 countries' electricity prices.

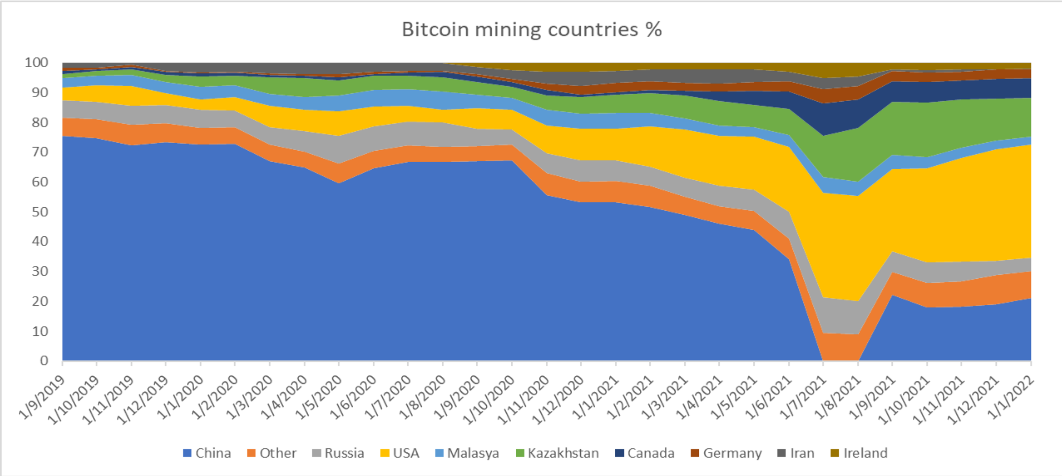

Figure 12. *Percentage of Bitcoin mining by top 10 leading countries, from 2019 – 2022.*

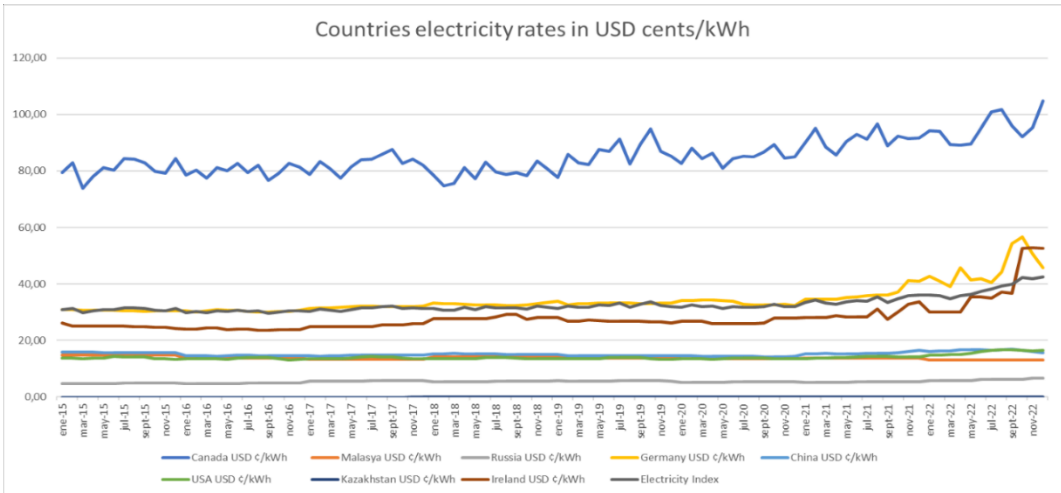

Figure 13. *Electricity prices in Canada, Malaysia, Russia, Germany, China, USA, Kazakhstan and Ireland, from 2015 – 2022.*

As mentioned earlier, countries' electricity prices differ depending on the miner's location. For example, in China miners were willing to move to Xinjiang, Sichuan, Inner Mongolia and Yunnan, as these regions have electricity rates among the cheapest in the country (MacKenzie, 2021). Cheap electricity prices can therefore be seen as a stimulus for the mining activity location.

5.3 Development of mining technology

One of the biggest factors for network difficulty is the hashrate capacity of the mining equipment. The equipment will determine how many attempts it may take to mine the next block. This can be seen in figure 5 and figure 10, where higher hashrate leads to higher network difficulty. In April 2017, the machine AvalonA741 was released, with a mining hashrate capacity of 7,3 Terabytes, using 1150 Watts/h (f2pool, 2023). The network difficulty was then around 521.000.000.000 (figure 10). On the other hand, in October 2022, the machine Antminer S19 XP Hyd with a hashrate capacity of 255 Terabytes was released, using 5304 Watts/h (f2pool, 2023). The network difficulty then was around 35.000.000.000.000 (figure 10). These graphs show the increase in network difficulty while the hashrate mining equipment capacity also increased.

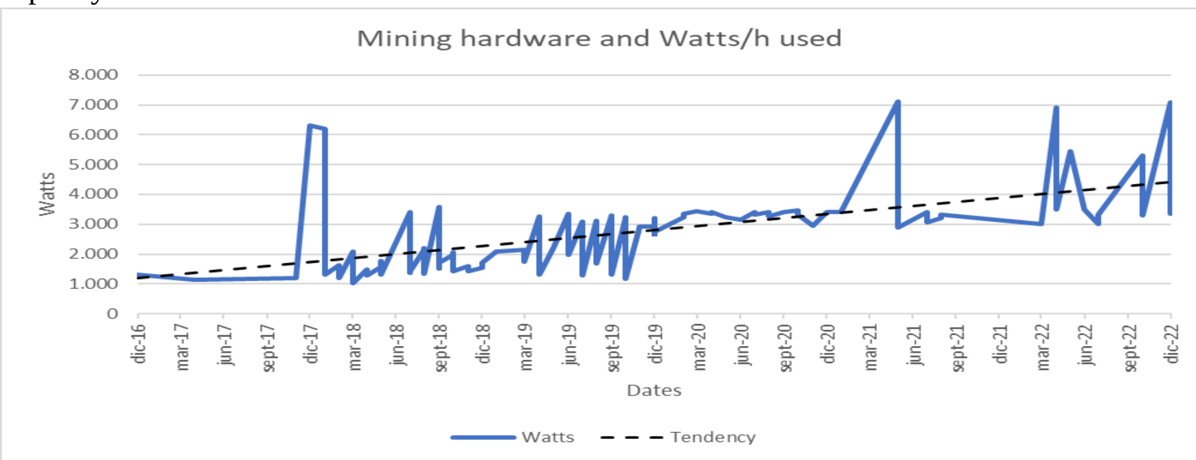

Figure 14. *Release date in the market of mining hardware used by miners, from 2016 - 2022. Measuring energy consumption of the mining hardware in Watts.*

The proof of work process takes the most energy consumption in Bitcoin mining (Gschossmann et al., 2022). Modern machines with more hashrate capacity need more energy consumption which is an important reason for why energy consumption and greenhouse emissions have increased in the mining industry. Miners often upgrade their hardware to keep up with the ever-growing network difficulty. This results in increased greenhouse emissions and a higher energy consumption (Houy,2019, p. 655).

5.4 Bitcoin's sustainability

Some argue that Bitcoin mining is an effective use of energy in areas in which there is an energy surplus. Energy storage is as of today very ineffective. Some also argue that these areas benefit from Bitcoin mining. The act of mining helps keep the energy prices low in areas where there is an energy surplus. The energy would have vanished instead of being consumed by the mining activity. (King et al., 2021). If energy storage improves in the future this will no longer be the case. Arguing against Bitcoin mining especially considering a world in which energy is a finite resource. The data we found points in the direction that miners seem to mine in areas in which there is an energy surplus. It could be argued that miners are ethical in where they decided to mine. However, one would assume that lower energy prices are the main driver for their location decision.

Nonetheless, Bitcoin's energy source is heavily dependent on where and how electricity is produced, emphasizing the importance of both the country's development in the green shift, and how much the country is investing in developing greener energy sources. It would be difficult for Bitcoin to adopt greener energy sources if Russia, USA and Kazakhstan authorities are not willing to adapt the necessary regulations and development strategies for the country to be less dependent of non-renewable energy sources, as these countries are the biggest Bitcoin mining countries.

A solution which has gained popularity regarding the sustainability of Bitcoin is called proof of stake. This is a common process used amongst other cryptocurrencies like Ethereum. The process consumes less energy. However, the downsides are that it is less secure, resulting in more vulnerability for hacking and stealing (King & Nadal, 2012, p. 2-3). This is naturally of non-interest for the investors and holders of Bitcoin. Then again making Bitcoin less energy intensive could make it a more appealing investment opportunity for many. Alternative cryptocurrencies marketed as been “greener” have been appearing. How much steam these alternatives will garner is difficult to gauge as Bitcoin has such a big market share (Rahman & Dawood, 2021, p. 63).

5.5 Future of Bitcoin

With the innovation of blockchain technology and cryptocurrencies, many countries such as India, Iran, Switzerland, USA, Venezuela, and Singapore are developing national currencies based on blockchain technology (Prasad, 2018, p. 32-36). Some of these countries wish to peg their respective cryptocurrency to oil, gas, precious -minerals and/or -metal prices (Marco, 2017). Their reasonings for these innovations is that it can further develop digital payments and increase the country's economic security. It could also make the economy more transparent, resulting in less black markets, reducing money laundering and tax fraud. Other countries like China, Russia, Japan, Estonia, and Sweden, have shown interest in converting their national currencies into digital currencies. (Burchardi et al., 2023).

The development of blockchain technology has led to innovation across industries. Companies like SyncFab and projects like Hyperledger Sawtooth have used the technology to develop new methods of tracking their supply chains of various products (Lee, 2019, p. 775; Dutta et al., 2020, p. 7). Blockchain's transparency system is used to track the products' origin. The company can then benefit from this by knowing exactly where the product is from. Some producers have been known to lie about the origin of their product resulting in issues regarding ethics. Many companies and consumers alike are concerned with where their products come from, for example many do not wish to support products produced by child labor. It also could be used in the creation process of a product. It could highlight potential improvements for a product or detect where potential failure is located (Saberi et al., 2019, p. 2120).

As mentioned earlier, Bitcoin's reward is reduced 50% every 4 years. This has some interesting implications as Bitcoins price must be kept high for miners to be incentivized to mine and confirm transactions. This effect is seen in our various models as the Bitcoin price has a significant effect on network difficulty.

We have in recent times seen turmoil in the banking sector. This has been positive for the Bitcoin price as it has risen. Some argue that this is caused by lost faith in the current fiat currency system (Macheel, 2023). Therefore, it can be argued that the strength of belief in the current fiat system will impact and shape Bitcoin's future price. This will in turn affect the network difficulty of Bitcoin mining. Investors' perception of Bitcoin will also play a role. Will investors look at Bitcoin as a serious contender to the system in place today as Satoshi

Nakamoto intended? Some people argue that Bitcoin is more like gold. Some see it as a commodity that can be traded and bought.

When one compares the forex exchange market and crypto market, opportunities arise. In relation to transactions to other crypto currencies. When one trades in currency today one often must go through the dollar or the euro. This could also become the case for Bitcoin. If one wishes to trade a cryptocurrency, one must go through Bitcoin for that transaction to be made.

Bitcoin must also overcome the issues of high energy consumption and low capacity of transaction verification. This sets barriers for Bitcoin's development when it comes to becoming a valid payment system. If Bitcoin is to compete with traditional payment systems, this is a hurdle it must overcome. The network per today does not support that high traffic of transactions. It is also awfully slow compared to Visa and Mastercard. These two companies are the market leaders in digital and physical payments and transactions. All of this means that Bitcoin must improve its blockchain storage capacity and enlarge if it is to compete in this field (Malik et al., 2022, p. 7347).

6. Conclusion

Our research topic was:

What factors influence Bitcoin's mining industry, and are cryptocurrencies viable and sustainable in the face of an ongoing energy crisis?

This was researched by investigating what factors influence Bitcoin's energy consumption in relation to the variable network difficulty.

We examined the variables Bitcoin price, transaction fees, natural gas prices, and hashrate per unique miner. We discovered that all variables we chose affect network difficulty. One of our key findings is how different variables' effects changed depending on the lags used. This effect was most noticeable with the Bitcoin price. The impact of changes in Bitcoin price varied across time lags. We also discovered that negative percentage changes were frequently of greater significance and had a much greater effect on network difficulty. This is especially true for the Bitcoin price, transaction fees, and hashrate per unique miner. These findings are consistent with conventional human behavior. Negative movements are commonly found to affect people stronger than positive movements.

In addition to this we also discussed other topics surrounding Bitcoin. Firstly, we discussed energy prices and their impact on network difficulty. Miners seem to be selective in where they decide to mine. Network difficulty also seems to be strongly affected by the development of new equipment. When it comes to Bitcoin and its sustainability aspect many hurdles appear. As of right now cryptocurrencies do not appear to be sustainable. Much of the world's energy does not come from renewable sources. Bitcoins' future is also very much related to sustainability. As the world moves towards net zero emissions, will Bitcoin still have a place? Will it be looked at as a true competitor to the current fiat system? The technology that Bitcoin created seems to be of relevance, and digital currencies also seem to maintain its relevance.

7. Reliability and validity

We will in this part of the paper be discussing the reliability and validity of our research. We would like to show some reflection on the work we have done.

When looking at data from the Cambridge university study some issues arise regarding the IP addresses of miners. The IP addresses could easily have been fake in that the miner could be using a VPN. VPN in the crypto mining industry is not uncommon as miners do not want to be shut down by their respective governments. This practice distorts the geographical results used in the study. The geolocation data could be inaccurate, as the data is prone to being manipulated by the respective miner.

There were also issues regarding data used in our analysis. Certain data was challenging to incorporate in the model. Some data was simply hard to find. While some data only had monthly or quartile timeframes. This meant that certain relevant data had to be left out from our models.

Is our study reliable? For a study to be classified as reliable it must be able to be replicated and give the same results every time. This is the first study of its kind. It is therefore arguably difficult to say if future results of other studies would yield similar results. Especially since the cryptocurrency market is very volatile. The market could also easily be influenced by external factors such as government policies.

It seems clear that all of our chosen variables do in fact influence the network difficulty and in turn the energy footprint of Bitcoin mining. It would in this case be unrealistic not to expect that a future study of these variables would yield somewhat similar results regarding network difficulty. As our paper highlights, many other factors should be considered.

8. Future research

Our study certainly opens the door for future research. As the network difficulty and in turn Bitcoin mining energy consumption is such a complicated topic. There are other relevant factors that could be further explored regarding network difficulty. Incorporating more variables such as Dow Jones index, Shanghai index, Euro, Dollar, RMB, cryptocurrency criminal activity and cryptocurrency politics could be highly relevant. This could create better models that would help one understand network difficulty better. One could also look at the mining of other crypto currencies and see how their energy footprint stacks up to Bitcoins.

References

Abrar, W. (2015). Untraceable electronic cash with digicash. *Network and Communication Privacy*. https://doi.org/10.13140/RG.2.1.1900.3040

Alekseenko, A. P. (2022). Ban of Cryptocurrencies in China and Judicial Practice of Chinese Courts. *China and WTO Review*, *8*(2), 361-384. http://dx.doi.org/10.14330/cwr.2022.8.2.06

Amick, S. (2022, 4. October). *McDonald's And Other Businesses Now Accept Bitcoin Payments In Lugano, Switzerland*. Nasdaq, Bitcoin Magazine. https://www.nasdaq.com/articles/mcdonalds-and-other-businesses-now-accept-bitcoin-payments-in-lugano-switzerland

Antoniadis, I., Sariannidis, N., & Kontsas, S. (2018). The effect of bitcoin prices on US dollar index price. *Advances in Time Series Data Methods in Applied Economic Research: International Conference on Applied Economics*, 511-521. https://doi.org/10.1007/978-3-030-02194-8_34

Baffes, J. (1997). Explaining stationary variables with non-stationary regressors, *Applied Economics Letters*, *4*, 69-75. https://doi.org/10.1080/758521836

Bhaskar, N. D., Lee, K. C. (2015). Bitcoin Mining Technology. *Handbook of Digital Currency: Bitcoin, Innovation, Financial Instruments, and Big Data*. 45-65. https://doi.org/10.1016/B978-0-12-802117-0.00003-5

Binance. (2023, 1. June). *Welcome to the Binance Card*. https://www.binance.com/en/cards

Bitcoin Magazine. (2022, 4. July). *WHAT IS THE BITCOIN BLOCK SIZE LIMIT?*. Bitcoin Magazine. https://bitcoinmagazine.com/guides/what-is-the-bitcoin-block-size-limit

Bitpay. (2023, 1. June). *Microsoft*. https://bitpay.com/directory/microsoft/

Bitpay. (2023, 1 June). *Twitch*. https://bitpay.com/directory/twitch/

Bondarev, M. (2020). Energy consumption of bitcoin mining. *International Journal of Energy Economics and Policy*, *10*(4), 525-529. https://doi.org/10.32479/ijeep.9276

Brown, S. H. V. (2021). Gambling on the Blockchain: How the Unlawful Internet Gambling Enforcement Act Has Opened the Door for Offshore Crypto Casinos. *Vanderbilt Journal of Entertainment & Technology Law*, *24*(3), 539-558. https://scholarship.law.vanderbilt.edu/jetlaw/vol24/iss3/3

Browne, Ryan. (2021, 04. June). Bitcoin falls after Elon Musk tweets breakup meme. *CNBC*. https://www.cnbc.com/2021/06/04/bitcoin-falls-after-elon-musk-tweets-breakup-meme.html

Burchardi. K., Gourav. R., Gross. J., Kavuklu. A., Kiff. J., Mikhalev. I., Mishra. A., Song, B., Struchkov. I. (2023). Today's Central Bank Digital Currencies Status. CBDC. https://cbdctracker.org/

Cambridge Center for Alternative Finance. (2019, 31 December). *Cambridge Bitcoin Electricity Consumption Index.* University of Cambridge. https://ccaf.io/cbnsi/cbeci/mining_map

Campbell-Verduyn, M. (2017). *Bitcoin and beyond: Cryptocurrencies, blockchains and global governance*. Taylor & Francis Group.

Canada Energy Regulator. (2023, 3. February). *Provincial and Territorial Energy Profiles – Canada.* https://www.cer-rec.gc.ca/en/data-analysis/energy-markets/provincial-territorial-energy-profiles/provincial-territorial-energy-profiles-canada.html#:~:text=More%20than%20half%20of%20the,of%20hydropower%20in%20the%20world.

Chainanalysis. (2023). *The 2023 Crypto Crime Report*. https://go.chainalysis.com/rs/503-FAP-074/images/Crypto_Crime_Report_2023.pdf

Chandran, Nyshka. (2015, 12. March). *Chinese yuan dominates 80% of Bitcoin trades*. CNBC. https://au.finance.yahoo.com/news/chinese-yuan-dominates-80-bitcoin-042805022.html

Chohan, Usman. W. (2022). A History of Bitcoin. *SSRN Electronic Journal*. https://doi.org/10.2139/ssrn.3047875

Coinbase Inc. (2023, 20. March). *Coinbase Card*. https://www.coinbase.com/card

Dutta, P., Choi, T. M., Somani, S., & Butala, R. (2020). Blockchain technology in supply chain operations: Applications, challenges and research opportunities. *Transportation research part e: Logistics and transportation review, 142*. https://doi.org/10.1016/j.tre.2020.102067

ElBahrawy, A., Alessandretti, L., Kandler, A., Pastor-Satorras, R., & Baronchelli, A. (2017). Evolutionary dynamics of the cryptocurrency market. *Royal Society open science*, *4*(11). https://doi.org/10.1098/rsos.170623

F2pool. (2023, 15. April). *Mining Revenue Comparison*. https://www.f2pool.com/miners?currency_code=btc

Fantazzini, D., & Kolodin, N. (2020). Does the hashrate affect the bitcoin price?. *Journal of Risk and Financial Management*, *13*(11), 263. https://doi.org/10.3390/jrfm13110263

Finklea, K. M. (2017, 10. March). *Dark web*. Congressional Research Service. https://a51.nl/sites/default/files/pdf/R44101%20(1).pdf

Gerken, Tom (2023, 1. February). *Elon Musk's Tesla lost $140m on Bitcoin in 2022.* BBC. https://www.bbc.com/news/technology-64428257

Gschossmann. I., Rocher. E., Van der Kraaij. A., Benoit. P. (2022). *Mining the environment – is climate risk priced into crypto-assets?*. European Central Bank. https://www.ecb.europa.eu/pub/financial-stability/macroprudential-bulletin/html/ecb.mpbu202207_3~d9614ea8e6.en.html

Guadamuz, A., & Marsden, C. (2015). Blockchains and Bitcoin: Regulatory responses to cryptocurrencies. *First Monday*, *20*(12). https://ssrn.com/abstract=2704852

Hari, Krishnan R,. Sai, Saketh Y,. & Venkata Tej Vaibhav M. (2015). *International Journal of Advanced Computer Science and Application; West Yorkshire*, *6*(9), 115-124. https://doi.org/10.14569/IJACSA.2015.060915

Household Energy Price Index. (2023, 5. March). *Monthly update*. https://www.energypriceindex.com/price-data

Houy,N. (2019). Rational mining limits Bitcoin emissions. *Natural Climate Change*, *9*, 655. https://doi.org/10.1038/s41558-019-0533-6

IBM Corp. (2023). *What is data storage?*. https://www.ibm.com/topics/data-storage#:~:text=File%20storage%2C%20also%20called%20file,hierarchy%20of%20directories%20and%20subdirectories.

International Energy Agency. (2020, 31. December). *China*. IEA. https://www.iea.org/countries/china

International Energy Agency. (2020, 31. December). *Kazakhstan*. IEA. https://www.iea.org/countries/kazakhstan

International Energy Agency. (2020, 31. December). *United States*. IEA. https://www.iea.org/countries/united-states

Ju, L., Lu, T., & Tu, Z. (2016). Capital flight and bitcoin regulation. *International Review of Finance*, *16*(3), 445-455. https://doi.org/10.1111/irfi.12072

Kabaklarli, E. (2022). Green FinTech: sustainability of Bitcoin. *Digital Finance*, *4*, 265-273. https://doi.org/10.1007/s42521-022-00053-x

Kaplan, T. (2023, 10. February). *Crypto markets are undergoing a 'flight to quality,' says Goldman Sachs digital assets chief.* CNBC. https://www.cnbc.com/2023/02/10/goldman-sachs-digital-asset-chief-lays-out-blockchain-strategy.html

Katterbauer, K., Syed, H., & Cleenewerck, L. (2022). The impact of the legalization of Bitcoin in the Central African Republic–a legal analysis. *INTERGOVERNMENTAL RESEARCH AND POLICY JOURNAL*. https://doi.org/10.13140/RG.2.2.14390.16967

Kethineni, S., & Cao, Y. (2020). The rise in popularity of cryptocurrency and associated criminal activity. *International Criminal Justice Review*, *30*(3), 325-344. https://doi.org/10.1177/1057567719827051

Kiayias, A., & Zindros, D. (2020). Proof-of-work sidechains. *International Conference on Financial Cryptography and Data Security*, 21-34. https://doi.org/10.1007/978-3-030-43725-1_3

King, S., & Nadal, S. (2012). Ppcoin: Peer-to-peer crypto-currency with proof-of-stake. *self-published paper*, *19*(1), 1-6. https://bitcoin.peryaudo.org/vendor/peercoin-paper.pdf

Kohli, V., Chakravarty, S., Chamola, V., Sangwan, K. S., & Zeadally, S. (2023). An analysis of energy consumption and carbon footprints of cryptocurrencies and possible solutions. *Digital Communications and Networks*, *9*(1), 79-89. https://doi.org/10.1016/j.dcan.2022.06.017

Kreuser, J. L., & Sornette, D. (2018). Bitcoin bubble trouble. *Swiss Finance Institute Research Paper*,*18*(24) 30-39. https://doi.org/10.1002/wilm.10672

Kristoufek, L. (2015). What are the main drivers of the Bitcoin price? Evidence from wavelet coherence analysis. *PloS one*, *10*(4), 1-15. https://doi.org/10.1371/journal.pone.0123923

Kubal, J., & Kristoufek, L. (2022). Exploring the relationship between Bitcoin price and network's hashrate within endogenous system. *International Review of Financial Analysis*, *84*, 1-74. https://doi.org/10.1016/j.irfa.2022.102375

Küfeoğlu, S., & Özkuran, M. (2019). Bitcoin mining: A global review of energy and power demand. *Energy Research & Social Science*, 58. https://doi.org/10.1016/j.erss.2019.101273

Lee, D. K. C., Guo, L., & Wang, Y. (2017). Cryptocurrency: A new investment opportunity?. *SSRN Electronic Journal*. http://dx.doi.org/10.2139/ssrn.2994097.

Lee, J. Y. (2019). A decentralized token economy: How blockchain and cryptocurrency can revolutionize business. *Business Horizons*, *62*(6), 773-784. https://doi.org/10.1016/j.bushor.2019.08.003

Lee, S., Yoon, C., Kang, H., Kim, Y., Kim, Y., Han, D., Son. S & Shin, S. (2019). Cybercriminal minds: an investigative study of cryptocurrency abuses in the dark web. *Internet Society*, 1-15. https://doi.org/10.14722/ndss.2019.23055

Ley Bitcoin. (2021). *DECRETO N° 57* (LEY-2021-06-08-57). Asamblea Legislativa. https://www.jurisprudencia.gob.sv/DocumentosBoveda/D/2/2020-2029/2021/06/E75F3.PDF

Li, J., Li, N., Peng, J., Cui, H., & Wu, Z. (2019). Energy consumption of cryptocurrency mining: A study of electricity consumption in mining cryptocurrencies. *Energy*, *168*, 160-168. https://doi.org/10.1016/j.energy.2018.11.046

Macheel, Tanaya. (2023, 16. March). *Bitcoin gains amid growing investor concern over global banking crisis.* CNBC. https://www.cnbc.com/2023/03/16/bitcoin-posts-gain-in-midst-of-mounting-global-banking-crisis-.html

Mackenzie, S. (2021, 18. December). *Inside China's underground crypto mining operation, where people are risking it all to make bitcoin.* CNBC. https://www.cnbc.com/2021/12/18/chinas-underground-bitcoin-miners-.html

Malik, N., Aseri, M., Singh, P. V., & Srinivasan, K. (2022). Why bitcoin will fail to scale?. *Management Science*, *68*(10), 7323-7349. https://doi.org/10.1287/mnsc.2021.4271

Manning, L. (2022, 7. November). *South African Grocery Giant Pick N Pay Accepts Bitcoin*. Nasdaq. https://www.nasdaq.com/articles/south-african-grocery-giant-pick-n-pay-accepts-bitcoin

Marco, Daniel Garcia. (2017, 4. December). El presidente de Venezuela, Nicolás Maduro, anuncia la creación del "petro", una criptomoneda respaldada "en petróleo, oro, gas y diamantes". *BBC Mundo Caracas*. https://web.archive.org/web/20180109003215/http://www.bbc.com/mundo/noticias-america-latina-42217808

Moorthy, D. (2018). A study on rising effects of cryptocurrency in the regulations of Malaysian legal system. *International Journal of Business, Economics and Law*, *15*(4), 35-41. https://ijbel.com/wp-content/uploads/2018/05/LAW-71.pdf

Nakamoto, S. (2008). Bitcoin: A peer-to-peer electronic cash system. *Decentralized business review*. https://bitcoin.org/bitcoin.pdf

National Bureau of Statistics of China. (2023, 4. April). *Consumer Price Index (The same month last year=100)*. https://data.stats.gov.cn/english/easyquery.htm?cn=A01

Nasdaq data link. (2023, 1. May). *Bitcoin Difficulty, 2015-2023, weekly*. https://data.nasdaq.com/data/BCHAIN/DIFF-bitcoin-difficulty

Nasdaq data link. (2023, 1. May). *Bitcoin Hash Rate, 2015-2023, weekly*. https://data.nasdaq.com/data/BCHAIN/HRATE-bitcoin-hash-rate

Nasdaq data link. (2023, 1. May). *Bitcoin Market Price USD, 2015-2023, weekly*. https://data.nasdaq.com/data/BCHAIN/MKPRU

Nasdaq data link. (2023, 1. May). *Bitcoin Total Transaction Fees, 2015-2023, weekly*. https://data.nasdaq.com/data/BCHAIN/TRFEE

Nasdaq data link. (2023, 1. May). *Bitcoin Number of Unique Bitcoin Addresses Used, 2015-2023, weekly*. https://data.nasdaq.com/data/BCHAIN/NADDU

Nasdaq data link. (2023, 1. May). *Total Bitcoins, 2015-2023, weekly*. https://data.nasdaq.com/data/BCHAIN/TOTBC-total-bitcoins

Nguyen, T., De Bodisco, C., & Thaver, R. (2018). FACTORS AFFECTING BITCOIN PRICE IN THE CRYPTOCURRENCY MARKET: AN EMPIRICAL STUDY. *International Journal of Business & Economics Perspectives*, *13*(1), 106-125. https://www.researchgate.net/publication/327601839_FACTORS_AFFECTING_BITCOIN_PRICE_IN_THE_CRYPTOCURRENCY_MARKET_AN_EMPIRICAL_STUDY

O'Dwyer, K. J., & Malone, D. (2014). Bitcoin mining and its energy footprint. *China-Ireland International Conference on Information and Communications Technologies*, 280-285. https://doi.org/10.1049/cp.2014.0699

Pérez-Solá, C., Delgado-Segura, S., Herrera-Joancomartí, J., Navarro-Arribas, G. (2018). *Analysis of the SegWit adoption in Bitcoin*. Department of Information and Communications Engineering, Universitat Autonoma de Barcelona. 230-233.

Prasad, E. (2018). Central banking in a digital age: Stock-taking and preliminary thoughts. *Fiscal & Monetary Policy*. http://iepecdg.com.br/wp-content/uploads/2018/04/es_20180416_digitalcurrencies.pdf

Rahman, A., & Khan Dawood, A. (2021). Bitcoin and Future of Cryptocurrency. *Ushus Journal of Business Management*, *18*(1), 61-66. https://doi.org/10.12725/ujbm.46.5

Rodeck, D., & Adams, M. (2023, 23. May). *Understanding Blockchain Technology*. Forbes. www.forbes.com/advisor/investing/cryptocurrency/what-is-blockchain/

Rose, C. (2015). The evolution of digital currencies: Bitcoin, a cryptocurrency causing a monetary revolution. *International Business & Economics Research Journal*, *14*(4), 617-622. https://doi.org/10.19030/iber.v14i4.9353

Rosstat. (2023, 5. March). *115111002000302000001* Средние потребительские цены (тарифы) на товары и услуги. https://showdata.gks.ru/report/277328/?filter_1_0=2022-08-01+00%3A00%3A00%7C-56%2C2022-09-01+00%3A00%3A00%7C-56%2C2022-10-01+00%3A00%3A00%7C-56%2C2022-11-01+00%3A00%3A00%7C-56%2C2022-12-01+00%3A00%3A00%7C-56%2C2023-01-01+00%3A00%3A00%7C-56%2C2023-02-01+00%3A00%3A00%7C-56&filter_2_0=347623&filter_3_0=110268&rp_submit=t

Saberi, S., Kouhizadeh, M., Sarkis, J., & Shen, L. (2019). Blockchain technology and its relationships to sustainable supply chain management. *International Journal of Production Research*, *57*(7), 2117-2135. https://doi.org/10.1080/00207543.2018.1533261

SAMRUK ENERGY. (2023, 5. March). *Аналитический обзор*. SAMRUK ENERGY. *https://www.samruk-energy.kz/ru/press-center/analytical-review#2023*

Schmidt, U. & Zank, H. (2005). What is Loss Aversion? *The Journal of Risk and Uncertainty*, *30*(2), 157-167. https://doi.org/10.1007/s11166-005-6564-6

Simser, J. (2015). Bitcoin and modern alchemy: in code we trust. *Journal of Financial Crime*, *22*(2), 156-169. https://doi.org/10.1108/JFC-11-2013-0067

Skelton, Andy. (2012, 15. November). *Pay Another Way: Bitcoin*. Wordpress. https://wordpress.com/blog/2012/11/15/pay-another-way-bitcoin/

Statistics Canada. (2023, 06. June). *Electric power selling price index, monthly*. https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=1810020401&pickMembers%5B0%5D=1.1&cubeTimeFrame.startMonth=01&cubeTimeFrame.startYear=2010&cubeTimeFrame.endMonth=12&cubeTimeFrame.endYear=2022&referencePeriods=20100101%2C20221201

ST. Louis Fed. (2023, 1. May). *Henry Hub Natural Gas Spot Price. Frequency: Weekly, Ending Sunday, Average, 2015-2023.* Fred economic data St. Louis. https://fred.stlouisfed.org/series/DHHNGSP

Suratkar, S., Shirole, M., & Bhirud, S. (2020, September). Cryptocurrency wallet: A review. *International conference on computer, communication and signal processing*, 1-7. https://doi.org/10.1109/ICCCSP49186.2020.9315193

Szabo, N. (1997). Formalizing and securing relationships on public networks. *First monday*, *2*(9). https://doi.org/10.5210/fm.v2i9.548

Tellez, A. (2021, 29. July). *Bank Of America Listed Among Heavyweights Invested In $300 Million Blockchain Funding Round*. Forbes.

https://www.forbes.com/sites/anthonytellez/2021/07/29/bank-of-america-listed-among-heavyweights-invested-in-300-million-blockchain-funding-round/

TENAGA NASIONAL. (2021, 31. December). *UNDERSTANDING YOUR ELECTRICITY BILL*. https://www.mytnb.com.my/residential/understand-your-bill/pricing-tariff

Theiri, S., Nekhili, R., & Sultan, J. (2023). Cryptocurrency liquidity during the Russia–Ukraine war: the case of Bitcoin and Ethereum. *The Journal of Risk Finance*, *24*(1), 59-71. https://doi.org/10.1108/JRF-05-2022-0103

Tijan, E., Aksentijević, S., Ivanić, K., & Jardas, M. (2019). Blockchain technology implementation in logistics. *Sustainability*, *11*(4). https://doi.org/10.3390/su11041185

Trautman, L. J. (2014). Virtual currencies; bitcoin & what now after liberty reserve, silk road, and Mt. Gox?. *Richmond Journal of Law and Technology*, *20*(4). http://dx.doi.org/10.2139/ssrn.2393537

United Nations. (2022, 1. June*). For a livable climate: Net-zero commitments must be backed by credible action.* https://www.un.org/en/climatechange/net-zero-coalition

Ülger, Ö. (2018). The role of money laundering and tax fraud bitcoin as a virtual currency. *Politico Economic Evaluation of Current Issues*, 36-48. https://www.researchgate.net/publication/330181518_THE_ROLE_OF_MONEY_LAUNDERING_AND_TAX_FRAUD_BITCOIN_AS_A_VIRTUAL_CURRENCY

U.S.BUREAU LABOR OF STATISTICS. (2023, 31. April). *Average energy prices for the United States, regions, census divisions, and selected metropolitan areas.* https://www.bls.gov/regions/midwest/data/averageenergyprices_selectedareas_table.htm

Varian, H.R. (1992). *Mircroeconomic Analysis* (3. edt). W. W. Norton & Company.

VERIVOX. (2023, 31. May). *VERIVOX-VERBRAUCHERPREISINDEX STROM*.VERIVOX. https://www.verivox.de/strom/verbraucherpreisindex/#:~:text=Der%20Verbraucherpreisindex%20Strom%20zeigt%20die,der%2030%20wichtigsten%20%C3%BCberregionalen%20Anbieter

Vranken, H. (2017). Sustainability of bitcoin and blockchains. *Current opinion in environmental sustainability*, *28*, 1-9. https://doi.org/10.1016/j.cosust.2017.04.011

Vujičić, D., Jagodić, D., & Ranđić, S. (2018, March). Blockchain technology, bitcoin, and Ethereum: A brief overview. *International symposium infoteh-jahorina*, 1-6. https://doi.org/10.1109/INFOTEH.2018.8345547

Xie, R. (2019). Why China had to ban cryptocurrency but the US did not: a comparative analysis of regulations on crypto-markets between the US and China. *Washington University Global Studies Law Review*, *18*(2), 457-491. https://openscholarship.wustl.edu/law_globalstudies/vol18/iss2/9

Zohuri, B., Nguyen, H., Moghaddam, M. (2022) What is the Cryptocurrency? Is it a Threat to Our National Security, Domestically and Globally?. *International Journal of Theoretical & Computational Physics*, *3*(1), 1-14. https://www.researchgate.net/publication/358380563_What_is_the_Cryptocurrency_Is_it_a_Threat_to_Our_National_Security_Domestically_and_Globally

Appendix

R code used in analysis.

```
#### data for 2015-2023 weekly####

setwd("C:/Users/marku/OneDrive/Dokumenter/master r 1")

#### load package####
library(dplyr)
library(openxlsx)
library(tidyverse)
library(stargazer)
library(sf)
library(rms)
library(olsrr)
library(modelr)
library(spdep)
library(tidyquant)
library(xts)
library(quantmod)
library(lubridate)
library(xts)
library(quantmod)
library(tseries)
library(forecast)
library(ggplot2)
library(data.table)
library(quantmod)
library(padr)


#### load data####

data2 <- read.xlsx("new_data 1.xlsx", detect□ates   TRUE,
                   na.strings = "NA")



datal <- data2 %>% select(Date, nettwork_diff,Bitcoin_price, brent_oil price, Mining rev, bitcoins_mined_weekly,
Average_block_size, unique users_bitcoin, WTI oil_price, Opec oil_price, hashrate)

#### creat new variables####
datal <- datal %>%
  mutate(nettwork diff pct= Delt(nettwork diff))

#### test different lags for bitcoin price####
## lag 2 ##
datal <- datal %>% mutate(price_neg_2   Delt(Bitcoin price,k=2))
datal <- datal %>% mutate(price_pos 2   Delt(Bitcoin_price,k=2))


data1$price_neg_2 <- ifelse(data1$price neg_2 > 0, 0, data1$price neg_2)
data1$price_pos 2 <- ifelse(data1$price_pos 2 < 0, 0, data1$price_pos 2)

ml<- lm(nettwork_diff pct~ price pos 2 + price neg 2, data= datal)
summary(ml)

## lag 4 ##

datal <- datal %>% mutate(price_neg_4   Delt(Bitcoin_price,k=4))
datal <- datal %>% mutate(price_pos 4   Delt(Bitcoin_price,k=4))
```

```
data1$price_neg_4 <- ifelse(data1$price neg_4 > 0, 0, data1$price neg_4)
data1$price_pos 4 <- ifelse(data1$price_pos 4 < 0, 0, data1$price_pos 4)

m2 <- lm(nettwork_diff_pct ~ price_pos 4 + price neg 4, data= data1)
summary(m2)


## lag 8 ##
data1 <- data1 %>% mutate(price_neg_8   Delt(Bitcoin_price,k=8))
data1 <- data1 %>% mutate(price_pos 8   Delt(Bitcoin_price,k=8))


data1$price_neg_8 <- ifelse(data1$price neg_8 > 0, 0, data1$price neg_8)
data1$price_pos 8 <- ifelse(data1$price_pos 8 < 0, 0, data1$price_pos 8)

m3 <- lm(nettwork_diff pct~ price_pos 8 + price neg 8, data= data1)
summary(m3)

## lag 12 ##
data1 <- data1 %>% mutate(price_neg_11   Delt(Bitcoin_price,k=11))
data1 <- data1 %>% mutate(price pos 11   Delt(Bitcoin price,k=11))


data1$price_neg_11 <- ifelse(data1$price neg_11 > 0, 0, data1$price neg_11)
data1$price_pos 11 <- ifelse(data1$price_pos 11 < 0, 0, data1$price_pos 11)

m4 <- lm(nettwork_diff_pct ~ price_pos 11 + price neg_11, data= data1)
summary(m4)


## lag 16 ##
data1 <- data1 %>% mutate(price_neg_26   Delt(Bitcoin_price,k=26))
data1 <- data1 %>% mutate(price_pos 26   Delt(Bitcoin_price,k=26))


data1$price_neg_26 <- ifelse(data1$price neg_26 > 0, 0, data1$price neg_26)
data1$price_pos 26 <- ifelse(data1$price_pos 26 < 0, 0, data1$price_pos 26)

m5 <- lm(nettwork_diff_pct ~ price_pos 26 + price neg_26, data= data1)
summary(m5)

data1 <- data1 %>% mutate(price_neg_52   Delt(Bitcoin_price,k=52))
data1 <- data1 %>% mutate(price pos 52   Delt(Bitcoin price,k=52))


data1$price_neg_52 <- ifelse(data1$price neg_52 > 0, 0, data1$price neg_52)
data1$price_pos 52 <- ifelse(data1$price_pos 52 < 0, 0, data1$price_pos 52)

m6 <- lm(nettwork_diff_pct ~ price_pos 52 + price neg_52, data= data1)
summary(m6)


stargazer(m5,m6, type   "text",  out   "bitcoin_price 2.html", title   "Network Difficulty model (weekly)")


## lag 26 ##
data1 <- data1 %>% mutate(price_neg_20   Delt(Bitcoin_price,k=52))
data1 <- data1 %>% mutate(price_pos 20   Delt(Bitcoin_price,k=52))


data1$price_neg_20 <- ifelse(data1$price neg_20> 0, 0, data1$price neg_20)
data1$price_pos 20 <- ifelse(data1$price_pos 20 < 0, 0, data1$price_pos 20)

m6 <- lm(nettwork_diff_pct   price_pos 20 + price neg 20, data= data1)
summary(m6)



#### test variable natural gas####

gas data<- read.xlsx("natural gas.xlsx", detectDates   TRUE,
                      na.strings = "NA")


gas_data <- gas_data %>% mutate(Date = gsub("\\/",".",Date))
gas data$Date <- mdy(gas data$Date)

gas_data <- pad(gas_data)
gas data<- gas data%>% na.locf()

data1 = merge(data1, gas data, by="Date")

#### test natural gas####
## 2, 5, 6, 13 ##

data1 <- data1 %>% mutate(price_neg_gas_2   Delt(Natural_gas_price,k=2))
data1 <- data1 %>% mutate(price pos gas 2   Delt(Natural gas price,k=2))
```

```
data1$price_neg_gas_2 <- ifelse(data1$price neg_gas_2 > 0, 0, data1$price neg_gas_2)
data1$price_pos gas 2 <- ifelse(data1$price_pos gas 2 < 0, 0, data1$price_pos gas 2)

N1 <- lm(nettwork_diff_pct ~ price_pos_gas 2 + price neg_gas 2, data= data1)
summary(N1)


data1 <- data1 %>% mutate(price_neg_gas_13   Delt(Natural_gas_price,k=13))
data1 <- data1 %>% mutate(price_pos gas 13   Delt(Natural gas_price,k=13))


N2 <- lm(nettwork_diff_pct ~ price_pos_gas 13 + price neg_gas 13, data= data1)
summary(N2)

N3 <- lm(nettwork diff_pct ~ price_pos gas 2 + price_neg_gas 2 + price_pos_gas 13 + price neg_gas 13, data
summary(N3)

                                                                                                   data1)


stargazer(N1,N2,N3, type=  "text", out   "Natural gas.html", title   "Network Difficulty model (weekly)")

#### bitcoin transaction volum ####
transaction<- read.xlsx("transaction fees.xlsx", detectDates   TRUE,
                   na.strings = "NA")



transaction$Number of transactions


data1 - merge(data1, transaction, by-"Date")

#### graph transaction fees####


data1 %>% ggplot(aes(x-Date,y-Cost_per transaction)) + geom_line(col-"red",size-0.75) + theme_bw()


####T1####

data1 <- data1 %>% mutate(Cost_per_transaction_neg   Delt(Cost_per_transaction,k-1))
data1 <- data1 %>% mutate(Cost_per transaction_pos   Delt(Cost_per transaction,k-1))


data1$Cost_per transaction_neg <- ifelse(data1$Cost_per_transaction_neg > 0, 0, data1$Cost_per_transaction_neg)
data1$Cost_per transaction_pos <- ifelse(data1$Cost_per transaction_pos < 0, 0, data1$Cost_per transaction_pos)

T1<- lm(nettwork_diff_pct ~ Cost_per transaction neg+ Cost_per transaction_pos , data -
data1) summary(T1)

#### T2 ####

data1 <- data1 %>% mutate(Cost_per_transaction_neg_2   Delt(Cost_per_transaction,k-2))
data1 <- data1 %>% mutate(Cost_per_transaction_pos 2   Delt(Cost_per transaction,k-2))


data1$Cost_per transaction_neg_2 <- ifelse(data1$Cost per transaction neg 2 > 0, 0,
data1$Cost_per_transaction_neg_2)
data1$Cost_per_transaction_pos_2 <- ifelse(data1$Cost_per transaction_pos 2 < 0, 0,
data1$Cost_per transaction_pos 2)

T2 <- lm(nettwork_diff_pct ~ Cost_per transaction neg 2 + Cost_per transaction_pos 2 , data   data1)
summary(T2)


T4 <- lm(nettwork_diff pct~ Cost per transaction, data   data1)
summary(T4)



stargazer(T1,T2, type   ''text'', out   "Transaction.html", title   "Network Difficulty model (weekly)")


#### T3 ####

data1 <- data1 %>% mutate(Number_of_transactions_neg   Delt(Number_of_transactions,k-5))
data1 <- data1 %>% mutate(Number_of transactions_pos   Delt(Number_of transactions,k-5))


data1$Number_of_transactions_neg <- ifelse(data1$Number of transactions neg> 0, 0,
data1$Number_of_transactions_neg)
data1$Number_of_transactions_pos <- ifelse(data1$Number of transactions_pos < 0, 0,
data1$Number of transactions pos)
```

```
T3 <- lm(nettwork_diff_pct ~ Number of transactions neg+ Number of transactions_pos, data
summary(T3)                                                                                     datal)



datal <- datal %>% mutate(Average_block size neg    Delt(Average_block_size,k-1))
datal <- datal %>% mutate(Average block_size_pos    Delt(Average_block size,k-1))


data1$Average_block_size_neg <- ifelse(data1$Average_block_size_neg > 0, 0, data1$Average block_size_neg)
data1$Average_block_size_pos <- ifelse(data1$Average_block_size_pos < 0, 0, data1$Average_block_size_pos)

Al<- lm(nettwork_diff_pct ~ Average_block_size neg+ Average_block_size_pos + price neg_transaction, data   datal)
summary(Al)


test<-  lm(Delt(Cost_per_transaction)~Average_block_size  neg+  Average_block_size_pos,  data      datal)
summary(test)



plot(data1$Cost_per transaction)

ol <- lm(nettwork_diff_pct ~ price_pos_gas  + price neg_gas + price_pos coal+ price neg coal+ price neg_oil +
price_pos_oil, data - datal)
summary(ol)

#### unique users bitcoin ####

#3# #4# #5# #10# #26#

datal <- datal %>% mutate(unique users_bitcoin_neg_4-Delt(unique_users_bitcoin,k-4))
datal <- datal %>% mutate(unique_users_bitcoin_pos 4-Delt(unique_users bitcoin,k-4))


data1$unique users_bitcoin neg_4 <- ifelse(data1$unique users_bitcoin neg 4 > 0, 0,


datal$unique_users_bitcoin_neg_4)
datal$unique_users_bitcoin_pos_4 <- ifelse(datal$unique users_bitcoin_pos 4 < 0, 0,
datal$unique users bitcoin pos 4)

Ul <- lm(nettwork_diff_pct ~ unique users_bitcoin neg_4 + unique_users_bitcoin_pos 4, data    datal)
summary(Ul)



datal <- datal %>% mutate(unique_users_bitcoin_neg_12=Delt(unique_users_bitcoin,k=12))
datal <- datal %>% mutate(unique_users_bitcoin_pos 12=Delt(unique users_bitcoin,k=12))


datal$unique_users_bitcoin_neg_12 <- ifelse(datal$unique users_bitcoin neg 12 > 0, 0,
datal$unique_users_bitcoin_neg_12)
datal$unique_users_bitcoin_pos_12 <- ifelse(datal$unique users_bitcoin_pos 12 < 0, 0,
datal$unique users_bitcoin_pos 12)

U2 <- lm(nettwork_diff_pct ~ unique users_bitcoin neg_12 + unique users_bitcoin_pos 12, data    datal)
summary(U2)


datal <- datal %>% mutate(unique_users_bitcoin_neg_26=Delt(unique_users_bitcoin,k=26))
datal <- datal %>% mutate(unique_users_bitcoin_pos 26=Delt(unique users_bitcoin,k=26))


datal$unique users bitcoin neg 26 <- ifelse(datal$unique users_bitcoin neg_26 > 0, 0,
datal$unique=users=bitcoin=neg=12)
datal$unique_users_bitcoin_pos_26 <- ifelse(datal$unique users_bitcoin_pos 26 < 0, 0,
datal$unique users_bitcoin_pos 12)

U3 <- lm(nettwork diff_pct ~ unique users_bitcoin neg_26 + unique users_bitcoin_pos 26, data    datal)
summary(U3)



stargazer(Ul,U2,U3, type= "text", out    "unique users.html", title   "Network Difficulty model (weekly)")

#### unique hashrate ####

datal$hashrate
datal$unique users bitcoin

datal <- datal %>% mutate(unique hashrate=(hashrate/unique users_bitcoin))

plot(datal$hashrate)
plot(datal$unique_hashrate)
plot(datal$unique_hashrate_neg_4)
plot(datal$unique hashrate_pos 4)

datal %>% ggplot() + geom_point(aes(x=Date,y=unique hashrate_neg_4),col="red") +
geom_point(aes(x=Date,y=unique_hashrate_pos_4),col="black") + theme_bw() + labs(title    "Hashrate per unique user")
datal %>% ggplot() + geom_point(aes(x=Date,y=unique_hashrate_neg_9),col="red") +
geom_point(aes(x=Date,y=unique_hashrate_pos 9),col="black") + theme_bw() + labs(title    "Hashrate per unique user")
```

```
#4# #6# #7# #8# #9#

#### lag 4 ####

datal <- datal %>% mutate(unique_hashrate_neg_4=Delt(unique_hashrate,k=4))
datal <- datal %>% mutate(unique_hashrate_pos 4=Delt(unique_hashrate,k=4))

datal$unique_hashrate_neg_4 <- ifelse(data1$unique_hashrate_neg_4 > 0, 0, data1$unique hashrate_neg_4)
data1$unique hashrate_pos 4 <- ifelse(data1$unique hashrate_pos 4 < 0, 0, data1$unique_hashrate_pos 4)

UH4 <- lm(nettwork diff pct~ unique hashrate neg 4 + unique hashrate pos 4, data= datal)
summary(UH4)

#### lag 9 ####

datal <- datal %>% mutate(unique_hashrate_neg_9=Delt(unique_hashrate,k=9))
datal <- datal %>% mutate(unique hashrate_pos 9=Delt(unique_hashrate,k=9))

datal$unique_hashrate_neg_9 <- ifelse(datal$unique_hashrate_neg_9 > 0, 0, datal$unique hashrate_neg_9)
datal$unique hashrate_pos 9 <- ifelse(datal$unique hashrate_pos 9 < 0, 0, datal$unique_hashrate_pos 9)


UH9 <- lm(nettwork diff_pct ~ unique hashrate neg_9 + unique hashrate_pos 9, data    datal)
summary(UH9)



stargazer(UH4,UH9, type= "text", out    "unique users hashrate.html", title   "Network Difficulty model

(weekly)") #### descriptive table####



datal <- datal %>% mutate(Bitcoin price_pct=Delt(Bitcoin_price))
datal  <- datal  %>% mutate(Natural gas_price_pct=Delt(Natural gas price))
datal <- datal %>9o mutate(Cost per transaction_pct=Delt(Cost per
transaction))
datal <- datal %>% mutate(unique hashrate_pct=Delt(unique hashrate))

descriptive_table<- datal %>%
dplyr::select(nettwork_diff_pct,Bitcoin_price_pct,Natural_gas_price_pct,Cost_per  transaction_pct,unique  hashrate
pct)

stargazer(descriptive, type ="html", title= "Descriptives
statistics",
          out="descriptives.html")


#### multi variable regression####


datal <- datal %>% mutate(price_neg_gas_4    Delt(Natural_gas_price,k=4))
datal <- datal %>% mutate(price_pos gas 4    Delt(Natural gas_price,k=4))


datal$price_neg_gas_4 <- ifelse(datal$price neg_gas_4 > 0, 0, datal$price neg_gas_4)
datal$price_pos gas 4 <- ifelse(datal$price_pos gas 4 < 0, 0, datal$price_pos gas 4)


#### lag 4 multi####

multti2 <- lm(nettwork_diff pct~ price_pos_4 + price neg 4 + unique hashrate neg_4 + unique hashrate_pos 4 +
price_neg_gas_4 + price_pos_gas 4 , data= datal)
summary(multti2)

#### lag 12 multi####

datal <- datal %>% mutate(price neg_l2    Delt(Bitcoin_price,k=l2))
datal <- datal %>% mutate(price_pos 12    Delt(Bitcoin_price,k=l2))



datal$price_neg_l2 <- ifelse(datal$price neg_l2 > 0, 0, datal$price neg_l2)
datal$price_pos 12 <- ifelse(datal$price_pos 12 < 0, 0, datal$price_pos 12)


datal <- datal %>%
mutate(unique_hashrate_neg_l2=Delt(unique_hashrate,k=l2)) datal <- datal
%>% mutate(unique_hashrate_pos 12=Delt(unique hashrate,k=l2))

datal$unique_hashrate_neg_l2 <- ifelse(datal$unique_hashrate_neg_l2 > 0, 0, datal$unique hashrate_neg_l2)
datal$unique hashrate_pos 12 <- ifelse(datal$unique_hashrate_pos 12 < 0, 0, datal$unique_hashrate_pos 12)
```

```
datal <- datal %>% mutate(price neg_gas_l2    Delt(Natural_gas_price,k=l2))
datal <- datal %>% mutate(price_pos gas 12    Delt(Natural gas_price,k=l2))


datal$price_neg_gas_l2 <- ifelse(datal$price neg_gas_l2 > 0, 0, datal$price neg_gas_l2)
datal$price_pos gas 12 <- ifelse(datal$price_pos gas 12 < 0, 0, datal$price pos gas 12)

multti3 <- lm(nettwork diff_pct ~ price_pos_l2 + price neg 12 + unique hashrate neg 12 + unique hashrate_pos 12 +
price_neg_gas_l2 + price_pos gas 12, data= datal)
summary(multti3)

stargazer(multti2, type    "text 11, out     "rnul ti _ variable 1.html", title   "Network Difficulty multivariable
(weekly)")
stargazer(multti3, type "text", out    "multi_variable 2.html", title "Network Difficulty multivariable
(weekly)")

#### bitcoin in circulation, transaction fee, hashrate, bitcoin price####

graph<- read.xlsx("graph_data.xlsx", detectDates = TRUE,
                   na.strings = "NA")

graph%>% ggplot() + geom_line(aes(x=Date,y=hashrate),col="blue") + theme bw()

graph 2 <- read.xlsx("circulation_bitcoin.xlsx", detectDates = TRUE,
                   na.strings = "NA")

graph 2 %>% ggplot() + geom_line(aes(x=Date,y=Bitcoin in circulation),col="red", size=0.75) + theme_bw()

graph 3 <- read.xlsx("bitcoin_popularity.xlsx", detectDates = TRUE,
                     na.strings = "NA")

graph_3 %>% ggplot(aes(x=Date,y=popularity)) + geom_line(col="red",size=0.75) + geom smooth(method=lm, col="black")
+ theme_bw()


graph 3 <- read.xlsx("bitcoin_popularity.xlsx", detectDates = TRUE,
                     na.strings = "NA")

graph_3 %>% ggplot(aes(x=Date,y=popularity)) + geom_line(col="red",size=0.75) + geom smooth(method=lm, col="black")
+ theme bw()
```