Article

An Empirical Examination of Bitcoin's Halving Effects: Assessing Cryptocurrency Sustainability within the Landscape of Financial Technologies

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Abstract: This article explores the significance of Bitcoin halving events within the cryptocurrency ecosystem and their impact on market dynamics. While the existing literature addresses the periods before and after Bitcoin halving, as well as financial bubbles, there is an absence of forecasting regarding Bitcoin price in the time after halving. To address this gap and provide predictions of Bitcoin price development, we conducted a rigorous analysis of past halving events in 2012, 2016, and 2020, focusing on Bitcoin price behaviour before and after each occurrence. What interests us is not only the change in the price level of Bitcoins (top and bottom), but also when this turn occurs. Through synthesizing data and trends from previous events, this article aims to uncover patterns and insights that illuminate the impact of Bitcoin halving on market dynamics and sustainability, movement of the price level, the peaks reached, and price troughs. Our approach involved employing methods such as RSI, MACD, and regression analysis. We looked for the relationship between the price of Bitcoin (top and bottom) and the number of days after the halving. We have uncovered a mathematical model, according to which the next peak will be reached 19 months (in November 2025) and the trough 31 months after Bitcoin halving 2024 (in November 2026). Looking towards the future, this study estimates predictions and expectations for the upcoming Bitcoin halving. These discoveries significantly enhance our understanding of Bitcoin's trajectory and its implications for the finance cryptocurrency market. By offering novel insights into cryptocurrency market dynamics, this study contributes to advancing knowledge in the field and provides valuable information for cryptocurrency markets, investors, and stakeholders.

Keywords: Bitcoin; cryptocurrency; Bitcoin halving; cryptocurrency sustainability; Bitcoin price dynamics; digital assets; trading view; market behaviour

1. Introduction

Since its inception in 2008 (Nakamoto 2008), Bitcoin has been a subject of fascination and speculation, with its price volatility and decentralised nature captivating the interest of investors and enthusiasts worldwide. One of the key events within the Bitcoin ecosystem that has garnered significant attention is the process known as "Bitcoin halving" (M'bakob 2024; Meynkhard 2019; Schär 2020). This periodic phenomenon, encoded into the cryptocurrency's protocol, involves a reduction in the rewards that miners receive for validating transactions on the blockchain (Coinbase 2024; Conway 2024; Crawley 2020; Schär 2020).

Bitcoin is capped at a total of 21 million coins. The foundational code guarantees the existence of only 21 million Bitcoins. This fixed supply of Bitcoin serves as a robust economic assertion and reinforces its valuation framework. Bitcoin is disseminated through the process of mining. The 21 million Bitcoins that are currently available to mine are anticipated to be fully mined by the year 2140. Given the current emission rate, all mineable Bitcoins would be likely to be exhausted before this projected timeframe. Close to 90% of

Bitcoin's overall supply has already been mined, with approximately 900 Bitcoins being mined daily. In order to sustain emission and bolster scarcity, the volume of Bitcoins issued per block undergoes periodic reductions. This mechanism of decreasing Bitcoin issuance per block is commonly referred to as Bitcoin halving. Following a set block height, the quantity of Bitcoins issued per block is halved from the previous amount. Bitcoin experiences a new halving event after every 210,000 blocks or roughly every 4 years.

Four years after Bitcoin's genesis block and after over 10 million Bitcoins and 210,000 blocks had been mined, the first halving occurred on 28 November 2012. The first halving event reduced the Bitcoin mining reward to 25 Bitcoins per block from an initial 50 Bitcoins per block. The second Bitcoin halving occurred on 9 July 2016, and the Bitcoin mining reward reduced from 25 Bitcoins to 12.5 Bitcoins. The last Bitcoin halving happened on 11 May 2020, at the block height of 630,000. Bitcoin's block reward was reduced from 12.5 to 6.25 (Conway 2024).

The Bitcoin halving of 2024 occurred on 19 April 2024, when the block height was 840,000. Bitcoin's block reward was reduced to 3.125.

The Figure 1 below (Hertig 2024) illustrates the developments in tokenomics and miners' rewards as a result of Bitcoin halving. It shows a consistent decrease in block rewards as the supply gradually slows down with each halving (Hertig 2024).
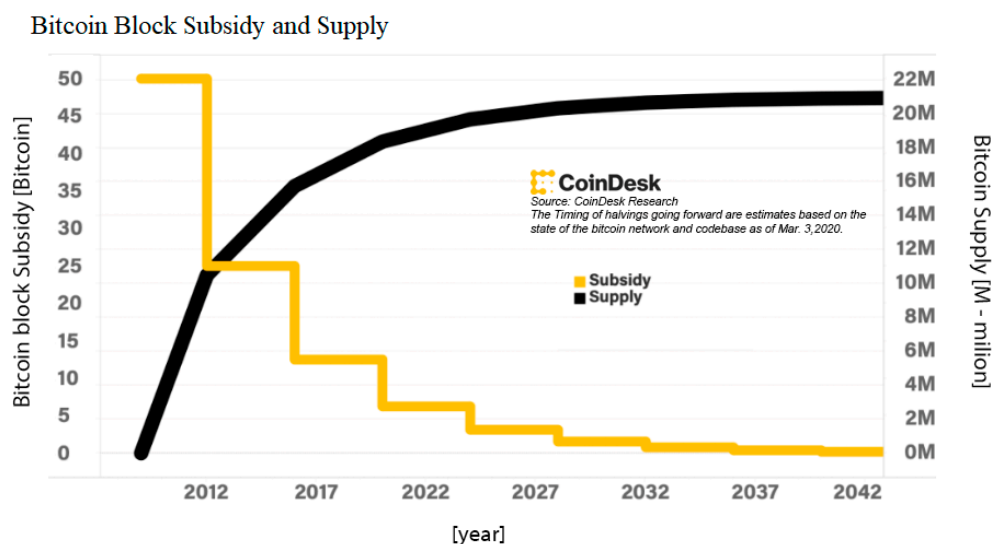

Figure 1. The Bitcoin block subsidy and supply over time (Hertig 2024, modified by the authors).

The Bitcoin supply will have been completely mined by the year 2140, so the miners' encouragement will then be sustained by transaction fees paid by users of the Bitcoin blockchain.

These events have a profound impact on the supply of new Bitcoin entering circulation, leading to discussions and debates about their implications for the market (El Mahdy 2021; Masters 2019; Meynkhard 2019; Pan et al. 2020; Patel 2021; Ramadhani 2022; Schär 2020). Understanding the dynamics of Bitcoin halving events is crucial for grasping the broader trends in the cryptocurrency landscape and anticipating potential price movements. These events serve as pivotal milestones that not only influence Bitcoin's price trajectory but also reflect underlying shifts in market sentiment, investment behaviours, and the overall health of the cryptocurrency ecosystem. Through deciphering the intricate relationship between Bitcoin halving events and market dynamics, researchers and investors can better grasp the underlying forces driving cryptocurrency markets, thereby enabling more informed decision making and strategic planning. Additionally, a deeper understanding of Bitcoin halving events can shed light on the long-term sustainability and viability of Bitcoin as a digital asset, providing crucial insights for stakeholders navigating the ever-evolving cryptocurrency landscape.

This article aims to delve into the historical context of Bitcoin halving events, examining the conditions and prices of Bitcoin before and after each halving. By conducting a systematic analysis of past halving events and comparing their outcomes, this study seeks to shed light on the patterns and trends associated with these milestone occurrences. Additionally, this article explores future expectations and predictions for the upcoming Bitcoin halving event.

Through this exploration of Bitcoin halving events, we aim to provide a comprehensive understanding of their impact on the cryptocurrency market and offer insights into what the future may hold for Bitcoin and the broader blockchain ecosystem.

In the white paper by Nakamoto (Nakamoto 2008), the concept of Bitcoin halving was introduced as a mechanism to control the issuance of new coins and maintain scarcity within the blockchain ecosystem. The author emphasised the importance of halving events in regulating the supply of Bitcoin and its impact on mining incentives.

The phenomenon of Bitcoin halving has been a subject of extensive research and analysis within the cryptocurrency community, attracting the attention of scholars, economists, and market analysts. Several studies (binance 2024; bitpanda 2024; Chan et al. 2023; Chaturved 2024; Coinbase 2024; CoinDCX 2024; Conway 2024; Crawley 2020; Cuthbertson 2024; El Mahdy 2021; ET Spotlight Team 2024; Howcroft and Wilkes 2024; Kuhn 2024; Masters 2019; M'bakob 2024; Meynkhard 2019; Pan et al. 2020; Patel 2021; Ramadhani 2022; Samizadeh 2024a, 2024b; Schär 2020; Singla et al. 2023; Valamontes 2024; Whittaker 2024; ig 2024; Zhao 2024) have explored the implications of halving events on the supply dynamics, price stability, and market sentiment of Bitcoin. Conway (Conway 2024) and many other experts (Coinbase 2024; CoinDCX 2024; Cuthbertson 2024; ET Spotlight Team 2024; Jahanshahloo et al. 2023; Meynkhard 2019; Schär 2020) emphasise that the Bitcoin halving is when Bitcoin's mining reward splits in half. It takes the blockchain network about four years to open 210,000 more blocks, a standard set by the blockchain's creators to continuously reduce the rate at which the cryptocurrency is introduced. Halving refers to the reduction of miners' rewards by half. The reward represents the number of coins that miners receive for adding new transactions to the blockchain (Crawley 2020). It is crucial to note that miners earn new Bitcoins for their role in adding transactions to the blockchain and maintaining the system's security. Therefore, halving involves cutting miners' rewards in half, a process integral to the functioning and sustainability of the Bitcoin network.

Some research findings (de la Horra et al. 2019) show that Bitcoin behaves as a speculative asset in the short term. In the long term, however, speculation does not seem to influence demand for Bitcoin.

The results of research work by Curtois et al. (Courtois et al. 2013) about the reward-halving scheme in Bitcoin, consider that the current Bitcoin specification mandates a strong 4-year cyclic property, and they find this property totally unreasonable and harmful and explain why and how it needs to be changed.

In the work of some experts, we can find their thoughts and comparisons of Bitcoin with fiat currencies or gold (Jiménez et al. 2024; Baur and McDermott 2009; Dyhrberg 2016). In fact, the Commodity Futures Trading Commission (CFTC) has stated that Bitcoin is determined to be a commodity (as gold) under the Commodity Exchange Act (Lucking et al. 2019). However, the mining cost is the underlying value of Bitcoin (Jiménez et al. 2024).

Wang et al. (Wang et al. 2020), Meynkhard (Meynkhard 2019), and Cuthbertson (Cuthbertson 2024) point out that it is noteworthy that every transaction made is verified by a miner that solves a difficult mathematical puzzle (a block), avoiding double spending and being recorded in a decentralised ledger in a blockchain. This verification provides a reward to the miner issuing new coins, which is the main incentive to solve this algorithm. However, the reward is not always the same; the Bitcoin protocol was designed to reduce the reward by half every 210,000 blocks, which, in time, is around every four years. This event is named Bitcoin halving, Bitcoin mining difficulty, or halvening; it follows a geometric series diagram and converts Bitcoin into a deflationary currency.

Therefore, Bitcoin's fundamental feature could be the halving effect, occurring every four years. These investigations view this event as a structural change and a potential source of price performance, based on historical data as well as other market-specific influencing factors (Ciaian et al. 2015; Meynkhard 2019; Wang et al. 2020).

The Bitcoin halving cycle suggests that Bitcoin price movement follows specific sequences and is independent of other assets. This has significant implications for Bitcoin, encompassing its risk profile, volatility dynamics, safe haven properties, and hedge properties. For instance, Bitcoin should be negatively correlated to the stock market to exhibit safe haven and hedge properties according to the framework proposed (Baur and McDermott 2009).

However, the Bitcoin halving cycle implies independence (no correlation) of stock market movements. Given the predictability of the Bitcoin price movement, Bitcoin could exhibit time-varying properties that might not be inherent. Furthermore, given the distinctiveness of the three stages within the cycle, there could be certain volatility dynamics that are specific to each stage. While the Bitcoin halving cycle may impact Bitcoin's safe haven status, hedge properties, and volatility dynamics, these findings may not hold significance without significant industrial and institutional exposure and interest (Chan et al. 2023). It is important to note that zero correlation implies no linear relationship between variables, but not necessarily independence. Therefore, further studies are necessary to explore these complex relationships.

Some authors have focused on the price of the Bitcoin and analysis of financial bubbles (Agosto and Cafferata 2020; Azamjon et al. 2016; Bendiksen and Gibbons 2018, 2019; Butek 2016; Deutsch 2018; Fantazzini and Kolodin 2020; John et al. 2022; Kiffer and Rajaraman 2021; M'bakob 2024; Phiri 2022; Prasad 2022; Riposo 2023; Sedlmeir et al. 2020; Wu and Hossain 2023), and others on the prediction of future developments (Cuthbertson 2024; Katanich 2024). Some researchers' works compare the development not only of Bitcoin but also of other cryptocurrencies (Albrecher et al. 2022; Bakhtiar et al. 2023; Cengiz 2021; Gkillas and Longin 2019; Katanich 2024; Kawaguchi and Noda 2022; Lucking et al. 2019; Rashid et al. 2023; Sen and Jena 2022; Singla et al. 2023; Touloupou et al. 2022; Trucíos and Taylor 2023; Vaddadi et al. 2023; Yuan et al. 2022). A different point of view was used in other works (Bâra and Oprea 2024; Eksi and Schreitl 2022; Hayes 2015; Lasi and Saul 2020; Samizadeh 2024a; Jiménez et al. 2024), with use of models to analyse and predict the market and price changes.

Halving presents a complex scenario, signifying different outcomes for distinct stakeholders. From an investor's perspective, halving represents a shift towards reduced Bitcoin creation rates and a potential decline in miner sell-offs. Historical patterns suggest a favourable impact of the anticipated scarcity on investor sentiment, triggering an optimistic outlook towards Bitcoin's valuation and potentially driving increased investment activity. While past mining events have yielded positive outcomes, the influence of halving events on Bitcoin's market price remains subject to fluctuations, heavily contingent on the prevailing market environment.

Leading up to the 2020 halving, Bitcoin's price surged by approximately 40%, fuelled by speculative behaviour among investors and the ensuing market projections. Post-halving, Bitcoin's value soared to triple its previous all-time high, hitting a new peak of USD 67,000.

For miners, halving signifies a diminished reward structure, posing financial challenges. The operation and maintenance of a Bitcoin mining facility entail substantial costs, with miners relying on block rewards to offset these expenditures as a primary revenue source. Upon halving, miners experience a 50% reduction in revenue, significantly impacting their income streams. Considering prevailing market values and operational costs, miners may be compelled to close down mining operations if revenue fails to cover operational expenses adequately. As miners discontinue operations, the overall mining hashrate is anticipated to decline. A drop in mining hashrate has the potential to impede the efficiency of the Bitcoin network, resulting in delayed transaction processing on the

blockchain. Restoration of hashrate levels could occur if Bitcoin's price undergoes sustained growth, encouraging miners to re-enter the mining sphere upon achieving profitability once again.

The primary aim of this study is to investigate the impact of Bitcoin halving events on market dynamics and sustainability within the cryptocurrency ecosystem. Through a meticulous analysis of past halving events, our study aims to provide insights into the patterns and implications of Bitcoin price movements before and after each occurrence. Furthermore, our findings reveal projected peaks and troughs following the Bitcoin halving of 2024, contributing significantly to our understanding of Bitcoin's trajectory and its broader implications for the cryptocurrency market.

The structure of this research article is organised to provide a comprehensive analysis of Bitcoin halving events and their effects on market dynamics. The article begins with an introduction section, which outlines the objectives of the study and provides background information on Bitcoin halving events. Following the introduction, the methodology section details the analytical approach used in the study, including data collection methods and analysis techniques. The results section presents the findings of the analysis, including projected peaks and troughs following the Bitcoin halving. The discussion section interprets the results, discusses their implications, and concludes with insights into the broader significance of the study's findings for the cryptocurrency market. Finally, the conclusion provides a clear summary of the study's key findings and their implications. Furthermore, it identifies possible limitations of the study and suggests future lines of research.

2. Methodology

This study utilises a methodology that involves data analyses and comparison of historical data related to Bitcoin halving events. The analysis focuses on understanding the conditions and price movements of Bitcoin both before and after each halving. The analysis is structured to provide a comprehensive examination of the impact of these events on the cryptocurrency market and to draw meaningful insights for future predictions.

To begin, extensive historical data related to Bitcoin prices, market trends, and halving events were collected from reputable sources, including cryptocurrency exchanges, market data providers, and blockchain analytics platforms (Bitstamp 2024 on Tradingview). These data formed the foundation for the comparative analysis of the previous three Bitcoin halving events that occurred in 2012, 2016, and 2020.

The analysis involves a detailed examination of price trends and market behaviour in the lead-up to each halving event and in the subsequent months that followed. This study's data analysis serves as a crucial step in extracting meaningful insights from the collected data. It involves the comprehensive examination and interpretation of historical data surrounding Bitcoin halving events. Through the application of analytical and logical reasoning, the analysis seeks to summarise the gathered data and identify patterns, relationships, and trends in Bitcoin price movements before and after each halving. This process entails meticulous scrutiny of various data points, including price levels, to gain a deeper understanding of the impact of Bitcoin halving events on market dynamics and sustainability within the cryptocurrency ecosystem.

Moreover, as part of the analysis, we use technical analysis indicators including relative strength index (RSI) and moving average convergence divergence (MACD). In this way, we try to provide a comprehensive view of how the halvings over the years of Bitcoin's existence have affected its prices and how the aforementioned indicators have proved to be useful in its analysis.

The relative strength index (RSI) is a momentum indicator that measures the magnitude of recent price changes to analyse overbought or oversold conditions. The moving average convergence divergence, or more commonly known as the MACD, is a widely used technical trading tool. MACD is used to find turning points in the market that indicate buy and sell signals.

The methodology includes statistical analysis and visualisation techniques to present the data in a clear and concise manner. Charts and graphs are utilised to illustrate the key findings and trends emerging from the analysis of previous halving events, facilitating a deeper understanding of the market dynamics at play.

In addition to the retrospective analysis, this study also incorporates qualitative assessments and expert opinions to inform the predictions and expectations for the upcoming Bitcoin halving event. By synthesizing historical data with expert insights, this methodology seeks to offer a well-rounded perspective on the potential outcomes and scenarios that may unfold in the aftermath of the next halving event.

Overall, this methodology is designed to provide a framework for analysing and comparing Bitcoin halving events, offering valuable insights into the historical trends and future expectations for the cryptocurrency market. Through a meticulous and systematic approach, this study aims to contribute to the growing body of knowledge on the impact of halving events on Bitcoin and the broader blockchain ecosystem.

We set two research questions:

- Research question 1: Bitcoin, as a deflationary currency, has a fixed supply of 21 million BTC. Demand changes over time and depends on various factors. Bitcoin halving occurs every 4 years, when miners' block rewards are slashed in half, thus decreasing the amount of BTC produced daily. The Bitcoin price is determined through supply and demand. A finite supply of Bitcoin mitigates inflation and deflation risks. Can we assume that when the supply decreases, the price increases?

Hypothesis 1. *The Bitcoin price increased to reach its peak within 6 months after the halving in each of the monitored periods.*

- Research question 2: What is the relationship between Bitcoin halving events and the timing of price peaks and troughs in the cryptocurrency market?

Hypothesis 2. *Following Bitcoin halving events, there is a consistent pattern where price peaks occur 6 months after the halving, followed by a subsequent decline leading to a trough at 18 months post-halving.*

We set alternative hypotheses for each research question:

Research Question 1, Alternative Hypothesis: The relationship between Bitcoin supply and price is not directly proportional; other factors such as market sentiment, regulatory changes, and technological advancements also significantly influence Bitcoin price movements. While a decrease in Bitcoin supply may initially lead to price increases due to scarcity, the market response may vary depending on factors such as investor behaviour, adoption rates, and external economic conditions.

Research Question 2, Alternative Hypothesis: There is no consistent pattern in the timing of price peaks and troughs following Bitcoin halving events; market dynamics may vary across different halving cycles due to changing market conditions and external influences. The relationship between Bitcoin halving events and the timing of price peaks and troughs is influenced by multiple factors, including market sentiment, investor behaviour, and macroeconomic trends, leading to variations in the timing and magnitude of price movements.

We followed the following steps to carry out data processing and evaluation of the hypotheses:

- We obtained historical data of the Bitcoin daily price from 18 of July 2010 to 19 of March 2024, in csv format from a publicly available dataset (kaggle 2024). Kaggle is a popular data-science competition website that provides free public datasets. Kaggle.com was used as a data source due to its comprehensive dataset 'Bitcoin

daily (July 2010–March 2024)', which sources its data from Investing.com, a platform commonly utilized in academic research.

- We used the mathematical and statistical analysis to describe the Bitcoin price developments in specific time periods: the 1st period was after the 1st Bitcoin halving (28 November 2012–8 July 2016); the 2nd period was after the 2nd Bitcoin halving (9 July 2016–10 May 2020), and the third period was after the 3rd Bitcoin halving (11 May 2020–19 March 2024). We also used regression analysis, graphical display of data, and the rainbow chart.

- We used regression analysis to evaluate the hypotheses. The main purpose of regression analysis is to examine and characterise the interrelationships between variables. Its task is to find a mathematical function, also called a regression function, or regression model that will best describe the course of dependence between variables. In our case, this involved a simple analysis in which we dealt with one independent variable; the dependent variable Y depends on the independent variable X. For the purposes of the regression analysis, we set the independent variable as the number of days after the halving event. This variable represents the time elapsed since the Bitcoin halving event occurred. We set the dependent variable as the Bitcoin price, with special attention to the peaks and troughs. This variable reflects the value of Bitcoin at the highest price peak or lowest price trough following each halving event.

Regression analysis is a widely utilised statistical technique in financial research. It is used to understand the relationship between one or more independent variables and a dependent variable. The application of regression analysis allows the examination of relationships between variables and the estimation of their impact on outcomes.

In this study, regression analysis was employed to model the relationship between the number of days after the halving event and the Bitcoin price, with a focus on identifying peak or trough points. Regression analysis allows us to understand relationships (using regression analysis, we can understand how one variable changes depending on changes in other variables). In this way, we can test hypotheses about relationships between variables and make assumptions for further analyses. Regression analysis can provide a starting point for more complex analyses or models. Similarly to other authors (Bakhtiar et al. 2023; Sen and Jena 2022; Trucíos and Taylor 2023; Wu and Hossain 2023), we used regression analysis. Overall, regression analysis plays a crucial role in this study by providing a systematic framework for exploring the relationship between Bitcoin halving events and price dynamics, thereby enhancing our understanding of market behaviour within the cryptocurrency ecosystem.

3. Results

We focused on the three previous Bitcoin halving events that took place in 2012, 2016 and 2020 (Dierks 2024), as shown in Figure 2 below (Techopedia 2024). First, we describe the data for individual years, so that we can then proceed to comparisons. The data were available by Bitstamp (Bitstamp 2024) on Trading View online platform, where we created the graphs and charts.
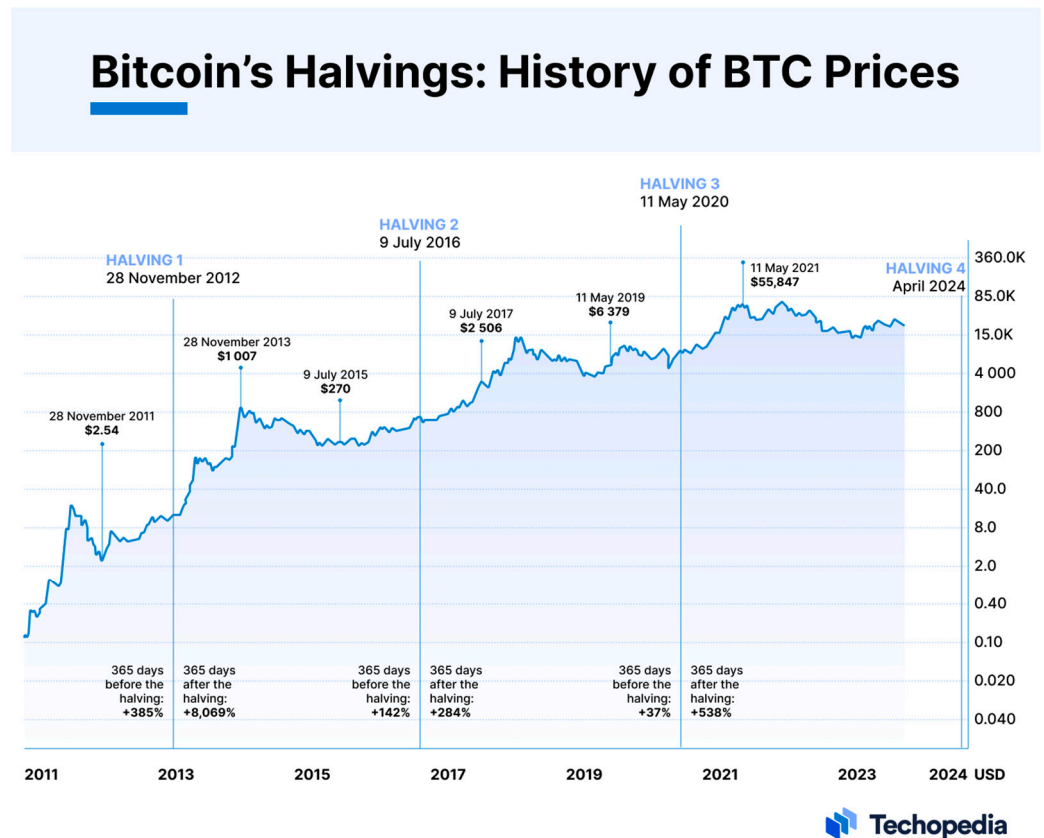
Figure 2. The Bitcoin halvings and the price of Bitcoin over time (1 BTC/USD) (Techopedia 2024).

3.1. First Bitcoin Halving

The first Bitcoin halving took place on 28 November 2012, which was approximately four years after its launch. The Bitcoin market was relatively new and small at this time, and there were very little data available to develop an accurate technical analysis of Bitcoin's price. The first halving cut the mining reward in half, from 50 BTC to 25 BTC per block. This event represented a significant moment in the history of bitcoin, as it demonstrated the viability of the cryptocurrency economic model.

After the first halving, the price of Bitcoin rose from about USD 12 to USD 260 within a year. It took about 400 days for the price to peak after the halving. This increase in price was caused by a decrease in supply, which made Bitcoin more scarce and therefore more valuable. The halving caused an increase in competition among miners and thus increased the cost of mining it, which also led to an increase in the price of Bitcoin.

The Figure 3 shows the price of Bitcoin and the levels of the MACD and RSI indicators at the time of the first Bitcoin halving. The x-axis shows the time period (day, month, year). In the upper graph, the y-axis shows the price of Bitcoin in USD. In the middle graph, the y-axis of the RSI chart shows the variation in RSI value, typically in the range of 0 to 100. In the last graph, MACD measures the convergence and divergence of two moving averages. The absolute difference between them is plotted on the y-axis. Values oscillate around a value of zero (this axis description applies to all subsequent charts created in TradingView, namely Figures 3–8).

Figure 3. The 1st Bitcoin halving—28 November 2012. (Authors, data source: Bitstamp 2024).

On the chart, we can see that the MACD indicator was below zero at the time of the first halving and the signal line became divergent from the line chart, meaning that the Bitcoin market was in a bullish trend at that moment. The intersection of the MACD curve with the signal line was reached at the beginning of November, and the Bitcoin market thus entered a bullish trend approximately three weeks before the halving. The MACD curve together with the signal curve remained above the zero value even after the halving event, which indicated that the price could continue to rise.

During the first Bitcoin halving, the RSI indicator was at a level around 70, which indicates an overbought market, which may lead to a drop in price.

From the analysis of the first halving period, several signs of a bullish trend can be seen. Since Bitcoin was a new cryptocurrency with a small user community at the time, it was difficult to predict the direction of the future price movement.

3.2. The Period between the First and Second Halvings

After the first halving, Bitcoin went through a period of consolidation and its prices gradually increased. In March 2013, Bitcoin reached a new all-time high and crossed the mark of USD 20. Overall, Bitcoin was able to reach USD 260 within a few months after the halving. This massive price increase was followed by a correction and its price dropped to around USD 10. The price of Bitcoin eventually stabilized in the range of USD 80–100 over the course of the following year; this was, therefore, a significant increase compared to the pre-halving price. During this period between the first and second halving, the Bitcoin ecosystem became more mature, which we observe according to the increased price of Bitcoin (which reflects increased demand and expansion of the Bitcoin network's user and transaction volume). The proof is also the increased number of active addresses from 43,851 (November 2012) to 442,000 (June 2016) (bitinfocharts 2024), and the market capitalization growth: Bitcoin's market capitalization increased significantly during this period, from approximately USD 1 billion in November 2012 to over USD 10 billion by July 2016 (coinmarketcap 2024). There was also a noticeable increase in the number of merchants and businesses accepting payments in Bitcoin. Companies like Microsoft, Dell, and Overstock.com began accepting Bitcoins for their products and services, expanding the cryptocurrency's real-world utility (Pacheco 2024). This demonstrated its resilience and scalability, further solidifying its position as a viable alternative to traditional financial systems. It was able to do this despite the problems caused by the collapse of the Mt. Gox exchange (the largest cryptocurrency exchange at the time).

This period was characterised by significant fluctuations in the price and overall instability of the Bitcoin market. External factors also influenced the market, such as the

interest of institutional investors in Bitcoin. The Bitcoin ecosystem continued to grow, the number of merchants accepting Bitcoin as a payment method increased, and significantly more venture capital began flowing into Bitcoin startups. Bitcoin's price gradually increased until the second halving, which occurred in 2016 (Meynkhard 2019).

The Figure 4 shows the price together with the indicators in the period between the first and second halving. Using indicators of technical analysis, it is possible to observe significant changes in the market. For example, the MACD indicator showed that the market was in an upward trend in the first third of the selected period and also at the end of the period before the second Bitcoin halving. On the MACD line chart, the crossings of the MACD curve and the signal curve are marked by red ellipses, indicating so-called bullish crossovers, which symbolize reversals to bullish trends and indicate that the price may continue to rise.

Figure 4. Period between 1st and 2nd Bitcoin halvings (Authors, data source: Bitstamp 2024).

The RSI indicator showed that there was overbuying several times during this period. However, this condition has always turned out to be a temporary price correction rather than a long-term price reduction. It is clear from the chart that the Bitcoin market was in an overbought state between the first and second halving.

From the analysis of the period between the first and second halving, it follows that this time period was characterised by great instability and significant price fluctuations, which could cause possible changes in trends and market overbuying. New markets and trading platforms also appeared, which increased the volume of trading and, thus, also market liquidity.

3.3. The Second Bitcoin Halving

In July 2016, the second Bitcoin halving event took place, which resulted in the reduction of the mining reward per block from 25 BTC to 12.5 BTC. This event was linked to increased public interest in Bitcoin, which was also caused by more businesses and merchants starting to accept it as a payment method, despite the prevailing instability in the global market. The second halving, unlike the first, had a shorter consolidation, after which the price rebounded quickly, culminating in a surge that saw its value increase significantly from around USD 600 to over USD 19,000 by December 2017. This increase was mainly attributed to a supply shock due to the process of halving the reward and also due to greater appreciation of its function as a store of value. From this, the company promised itself better protection against the economic uncertainties prevailing at the time.

In Figure 5, the MACD indicator shows that the Bitcoin market was in a bullish period during the second halving as the MACD curve was at zero and the signal line became divergent from the line chart. This indicated that the price should continue to rise.

Figure 5. The 2nd Bitcoin halving—9 July 2016 (Authors, data source: Bitstamp 2024).

The RSI indicator, on the other hand, shows that the Bitcoin market was overbought at the time of the second halving. The price managed to stay at a relatively stable level and the corrections were low, temporary, and not long-term.

Based on the results of the analysis, it was shown that during the second halving, the volatility was lower compared to the period between the first and second halving. The period was marked by possible changes in trends, the overbought state of the Bitcoin market, a significant number of new investors, and an increased volume of transactions. Bitcoin continued to be in a cycle of constant instability and price fluctuations. However, at the same time, the growing interest in cryptocurrency indicated the potential for price growth and the development of the cryptocurrency market.

3.4. The Period between the Second and Third Bitcoin Halvings

The period of significant growth in the price of Bitcoin that began in late 2017 was the result of a variety of factors, including increased media attention, the launch of new Bitcoin futures markets, and the entry of new entrants into the market. Notably, this followed a two-year bear market period. During this period, the price of Bitcoin rose from around USD 600 to its all-time high of nearly USD 20,000. Nevertheless, the price later collapsed when the market went through a correction and lost almost 80% of its value. This correction lasted until the end of 2018 and the beginning of 2019, during which the price of Bitcoin ranged from USD 3000 to USD 6000. This value was significantly higher than before the second halving. After this period, the market started to recover again, and the price of Bitcoin gradually increased.

In Figure 6, we can see how the MACD indicator indicated a strong bullish trend. It is a convenient illustration of when bullish and bearish crossovers perfectly mirrored the price movement and showed a change in trend. During both significant increases in the price of Bitcoin, the MACD curve and the signal curve were above the zero level of the MACD chart.

Figure 6. The period between 2nd and 3rd Bitcoin halvings (Authors, data source: Bitstamp 2024).

The RSI showed that at the time when the price of Bitcoin increased during 2017, the market was overbought, but not unsustainably overbought, so the bullish trend could continue for some time. However, instead of falling, Bitcoin continued to rise and RSI remained elevated for several months, leading some traders to lose significant profits. At the beginning of 2018, a change followed, which is seen in the graph—this change represented the transition of an overbought market to an oversold market.

An analysis of the development of the price of Bitcoin between the second and third halvings pointed to a strong bullish trend that persisted for almost the entire four years. This period in the Bitcoin market was characterized by high price growth and several milestones.

3.5. The Third Bitcoin Halving

The third Bitcoin halving was on 11 May 2020, and it meant a reduction of the reward from 12.5 BTC to 6.25 BTC. It took place in a different market environment compared with the previous ones. Bitcoin was already known and used by the general public, its liquidity had increased significantly, interest increased among institutions that had significant influence on the overall market, and the movements of their assets were more voluminous compared to those of individual traders. These institutional investments are also believed to have had a significant impact on Bitcoin during the third halving. Another significant impact was the COVID-19 pandemic, which significantly affected the overall global economy. The price of Bitcoin surged just before the halving, hitting a near three-month high of USD 10,000, but the effects of the halving were not as dramatic as expected. A few days after the halving, the price had undergone only minor fluctuations, and over time, within two months, the price climbed to USD 12,000, which represented a 20% increase.

The MACD indicator (Figure 7) was below the zero level a month before the halving, which represents a bearish trend. There was a bullish crossover when the MACD curve crossed the signal curve downward, which indicated an increase in the price of Bitcoin. After the halving, the indicator was mostly negative and in a bearish trend. However, it gradually stabilized and diverged positively after a few weeks, indicating a potential move to a bullish trend.

This was also confirmed by RSI, which just before the halving indicated that the market was overbought; after the halving, these indications gradually decreased and indicated an approaching bullish trend.

Figure 7. The 3rd Bitcoin halving—11 May 2020 (Authors, data source: Bitstamp 2024).

3.6. The Period after the Third Bitcoin Halving

The third halving confirmed to Bitcoin traders the opinion that this cryptocurrency had potential for long-term investment. The immediate impact of the halving on the price was not as significant as initially expected. This halving was followed by about a six-month period of reduced volatility and consolidation.

Further price development was subsequently replaced by turbulent growth after a calm halving period, when the price of Bitcoin climbed from USD 8000 to a new historical high of USD 60,000 by April 2021. This increase was significantly supported by the growing interest of investors. The price later fell by more than 50%, trading at USD 30,000. After a few months, the price of Bitcoin went through another rally and rose to more than USD 65,000, more than six times the price compared with that before the third halving.

Figure 8 shows the price of Bitcoin in the period from the third halving to today, with the MACD and RSI indicators, which reflect the movement of the price of Bitcoin. Green circles mark bullish crossovers, which show the beginnings of bullish trends, that is, that the price has started to rise; red circles indicate that the price will fall.

Figure 8. The period after the 3rd Bitcoin halving (Authors, data source: Bitstamp 2024).

With the RSI indicator, we can see when the curve exceeded the level of 70. This proves that the market was considerably overbought. In both cases of market overbuy, there was a correction and thus, a price reduction.

Since the third halving, a lot has happened with the Bitcoin market, and this has also been reflected in its price movements. From the analysis of individual periods, we can see that Bitcoin halving is the "catalyst" of price increases, leading to new historical highs. To observe the development of the price of Bitcoin over the entire period of its "life", we have to display the prices in logarithmic values. Such a view is offered by the Rainbow Chart, a tool used to analyse the historical long-term price movements of Bitcoin, which uses a colourful rainbow scheme to display different price levels (Blockchaincenter 2023).

Looking at the past behaviour of Bitcoin (Figure 9), we see that the price was always within the first three lower bands at the time of the halving. Subsequently, it reached its peak—the dark red phase. The exception was the most recent halving of 2020, after which the highest price stopped at the dark orange band. As the next halving is expected to happen in April 2024, we can see that Bitcoin is currently volatile and significant rises and subsequent falls can be seen within a few days.
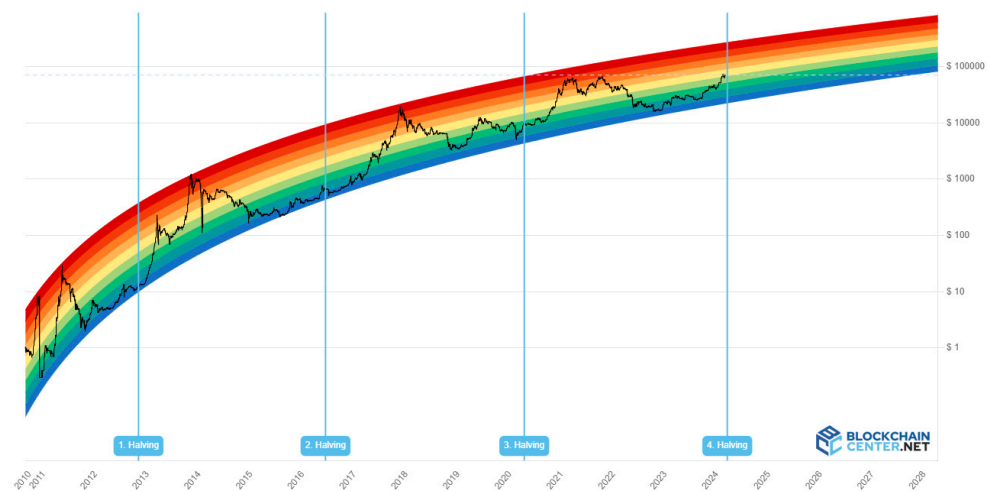

Figure 9. Rainbow chart of Bitcoin halvings (Blockchaincenter 2023).

3.7. Hypothesis Evaluation

We have provided a detailed analysis of the historical price movements of Bitcoin following previous halving events. We display the results in Figure 10.
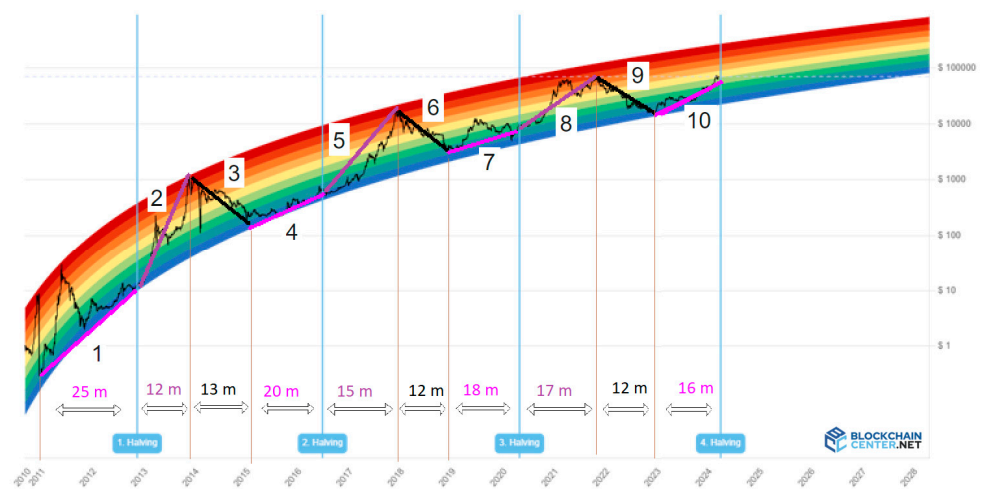

Figure 10. Rainbow chart of Bitcoin halvings with markers of changes (Blockchaincenter 2023, modified by the authors).

From the previous halvings, we can see that due to decreasing supply and increasing demand, the price of Bitcoin increased significantly after each halving (in the long run). However, the consequences of the halvings led to the formation of bubbles in over a year and a crash in the months following the peak. This was evidenced by the three previous halvings. The development of the economic cycle began in November 2010, when Bitcoin reached its first bottom with a market price of USD 0.06. This was followed by a rally that lasted 37 months (point 1, the first pink and purple line, Figure 10) and stopped at the first peak in December 2013 at a price of USD 1147. The price peak occurred 12 months after the halving (point 2, the first purple line, Figure 10). A decline followed that lasted 13 months and ended on the second day of January 2015 at USD 152 (point 3, the first black line, Figure 10). Then, the economy improved again and continued to grow for 35 months (point 4, the second pink and purple line, Figure 10), reaching a second peak in December 2017 at USD 19,987. The price peak occurred 15 months after the halving (point 5, the second purple line, Figure 10). However, there was another decline after that, which lasted for 12 months and ended on the third day in December 2018 with a price of USD 3130 (Number 6, the second black line, Figure 10). After this decline, the economy recovered again, and it took another 35 months for the value of Bitcoin to reach its third peak in November 2021 at USD 69,040 (point 7, the third pink and purple line); the peak occurred 17 months after the halving (point 8, the third purple line). There was another decline after that, which lasted for 12 months and ended on the 23rd day in November 2022 with a price of USD 16,195 (point 9, the last black line, Figure 10). We saw new historical highs on 13 March 2024, when the price rose to USD 73,135 per 1 BTC, 16 months after the previous fall (point 10, the fourth pink line, Figure 10). Over the next few days, it dropped to a "bottom" of USD 61,906 (19 March 2024) to oscillate again. As of today, 31 March 2024, the price for 1 BTC is USD 71,256.

Mathematical evaluation of the hypothesis was carried out using statistical analysis techniques including simple regression analysis. We used GraphPad Software. Figure 11 shows the results from regression analysis after each of three Bitcoin halvings. Calculations and results are presented in Table 1. The *p* value is less than 0.0001, deviation from zero is significant, and deviation from linearity is also significant. As in many experiments, the relationship between X (days after Bitcoin halving) and Y (Bitcoin price in USD) is curved, making linear regression inappropriate. From the development of the curve, however, it can be seen that even if it not a linear dependence, the resulting curve shows certain similar signs in the period after the second and third halvings (peak around day 537, trough around day 907).

Table 1. Results from simple linear regression analysis (Authors, data source: kaggle 2024).

Simple Linear Regression		Halving 1	Halving 2	Halving 3
Best-fit values	Slope	0.4505	7.620	35.69
	Y-intercept	0.000	0.000	0.000
	X-intercept	0.000	0.000	0.000
	1/slope	2.220	0.1312	0.02802
Std. Error	Slope	0.009220	0.1004	0.6595
	Y-intercept			
95% Confidence Intervals	Slope	0.4324 to 0.4686	7.423 to 7.817	34.40 to 36.98
	Y-intercept	0.000 to 0.000	0.000 to 0.000	0.000 to 0.000
	X-intercept	−60.90 to 58.82	−42.38 to 41.44	−60.03 to 58.18
Goodness of Fit	Sy.x	246.2	3044	20,148
Is slope significantly non-zero?	F	2388	5760	2929
	DFn, DFd	1, 1287	1, 1401	1, 1408
	P value	<0.0001	<0.0001	<0.0001
	Deviation from zero?	Significant	Significant	Significant

Table 1. *Cont.*

Simple Linear Regression		Halving 1	Halving 2	Halving 3
Runs test	Points above line	740	673	799
	Points below line	548	729	610
	Number of runs	21	40	3
	P value (runs test)	<0.0001	<0.0001	<0.0001
	Deviation from linearity	Significant	Significant	Significant
Equation		$Y = 0.4505 \times X + 0.000$	$Y = 7.620 \times X + 0.000$	$Y = 35.69 \times X + 0.000$
Data	Number of X values	1288	1402	1409
	Max number of Y replicates	1	1	1
	Total number of values	1288	1402	1409
	Number of missing values	0	0	0
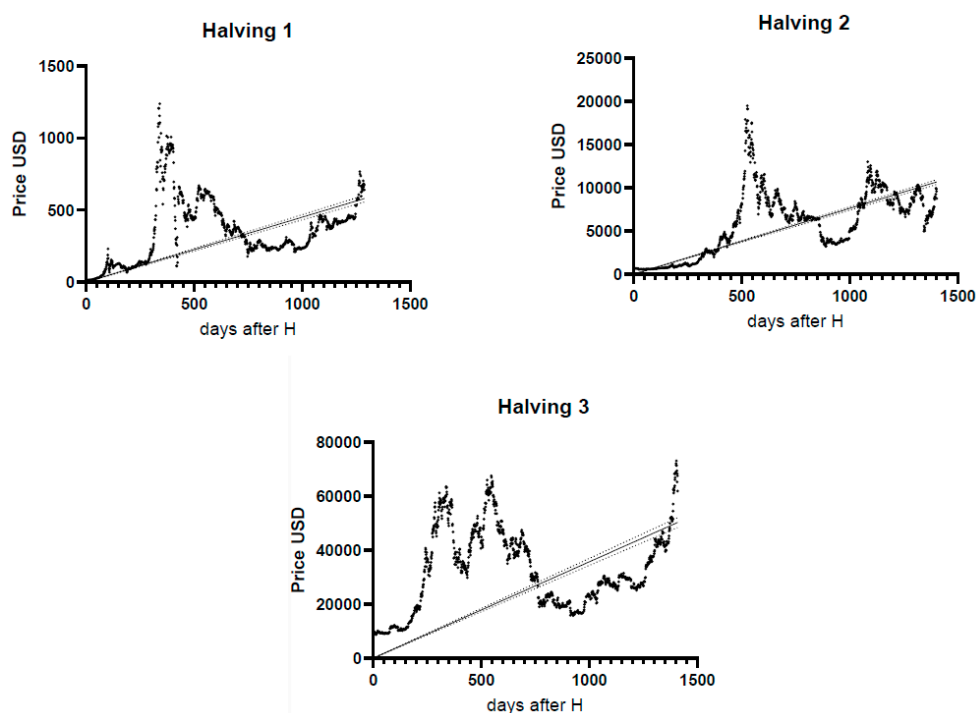
Figure 11. Results from regression analysis after each of Bitcoin halving (H), x—days after halving, y—Bitcoin price in USD (Authors, data source: kaggle 2024).

In our work, we can abstract away the other variables that affect the price of Bitcoin, but just like in theory and in practice, the price of Bitcoin depends on supply and demand.

Due to the fact that Bitcoin is constantly traded back and forth on crypto exchanges, its price is in constant flux; exchanges set the price based on the last trade that was made. The stock exchange acts only as a trade intermediary.

Bitcoin's price is also affected by its supply, the market's demand, availability, competing cryptocurrencies, and investor sentiment (crypto 2024). Bitcoin supply is limited—there is a finite number of Bitcoins, and the final coins are projected to be mined in 2140. Bitcoin halving events are important from the point of view of slowing down the increase in supply.

Hypothesis 1. *The Bitcoin price increased to reach the peak within 6 months after the halving in each of the monitored periods.*

In this context, 6 months $\geq x_t$, where x—number of months after the Bitcoin halving that the Bitcoin price reaches the top, t—time order of Bitcoin halving (1, 2, 3).

The results show the peaks were reached after $x_1 = 12$, $x_2 = 15$, and $x_3 = 17$ months following the Bitcoin halving events; 6 months < x_1, 6 months < x_2, and also 6 months < x_3.

Hypothesis 1 was not confirmed.

Hypothesis 2. *Following Bitcoin halving events, there is a consistent pattern where price peaks occur 6 months after the halving, followed by a subsequent decline leading to a trough at 18 months post-halving.*

Here, 6 months = x_t, where x—number of months after the Bitcoin halving that the Bitcoin price reached the top, t—time order of Bitcoin halving (1, 2, 3).

Additionally, 18 months = z_t, where z—number of months after the Bitcoin halving that the Bitcoin price reached the bottom, t—time order of Bitcoin halving (1, 2, 3)

The results show the peaks were reached after $x_1 = 12$, $x_2 = 15$, and $x_3 = 17$ months following the Bitcoin halving events, and the bottoms were reached after $z_1 = 25$, $z_2 = 27$, and $z_3 = 29$ months following the Bitcoin halving events. Results:

- 6 months < x_1 and 18 months < z_1;
- 6 months < x_2 and 18 months < z_2;
- 6 months < x_3 and 18 months < z_3.

Hypothesis 2 was not confirmed.

The data indicate that there is a mathematical model:

$$m_t = m_{(t-1)} + 2, \tag{1}$$

m_t—the number of months after the next halving that the Bitcoin price will reach the peak/bottom; $m_{(t-1)}$—the number of months after the last halving that the Bitcoin price reached the top/bottom in the previous period.

If the suppositions are correct, the next peak will be reached 19 months and the trough 31 months after Bitcoin halving 2024, which means that if the Bitcoin halving takes place in April 2024, the next Bitcoin price peak will be reached in November 2025, and the bottom in November 2026.

4. Discussion

The concept of Bitcoin halving plays a pivotal role in both the economic dynamics and the sustainability of the cryptocurrency. From an economic standpoint, Bitcoin halving introduces a unique scarcity element into the cryptocurrency. Through diminishing the rate at which new Bitcoins are introduced into the market, Bitcoin halving effectively curtails the supply side of the equation. This approach aligns with the escalating demand for Bitcoin, resulting in a continual reduction in its supply rate to meet the growing market appetite.

The Bitcoin system is a decentralized monetary system in that any participant can potentially verify and record transactions onto a public ledger. Bitcoin is a decentralized digital currency that operates without government authority. It depends on a peer-to-peer network to perform the verification and recording functions. When a buyer uses the cryptocurrency Bitcoin to pay for a transaction, the transaction record is transparent in that it is viewed and verified by all participants of the peer-to-peer network. The process of validating transactions, mining, requires miners who are rewarded in Bitcoin. These rewards make a new supply of Bitcoins. In comparison with the traditional fiat currencies, Bitcoin is a deflationary currency, which significantly changes the view of the traditional concept of supply and demand. The supply is fixed at 21 million and there is no further "reprinting" of money; the money supply is released gradually. With each confirmation of a transaction, that is, the process of mining, the miner receives a reward in Bitcoins. We can say that mining is the emission of money. However, these rewards are halved every 4 years. Thus, this halving reduces the supply increment in the Bitcoin market. Therefore, the "amount" of Bitcoins cannot be increased; the supply is limited in time, but the demand is affected by various factors, such as the popularity of cryptocurrencies, the uncertainty

of economic policy, and others, and changes every day. Bitcoin ETF issuers are buying more than 10–12 times the amount of BTC produced daily, leading to a 2% price increase of roughly USD 1000 per day, which conditions the increase in the price of Bitcoin.

Essentially, this practice reinforces Bitcoin's position as a formidable store of value. The deliberate reduction of supply relative to an ever-increasing demand ensures that Bitcoin accrues greater worth over extended periods. Beyond conventional demand–supply principles, Bitcoin halving's impact on the cryptocurrency's valuation transcends mere economic metrics, resonating deeply with market sentiments and the universal preference for limited resources.

An estimated 3 million Bitcoins are presently inaccessible due to forgotten wallet credentials, misplaced storage devices, or Bitcoin holdings belonging to deceased individuals. The irreversible loss of a significant portion of these Bitcoins underscores the deflationary nature of Bitcoin, a characteristic that is further amplified by the periodic halving events.

In terms of sustainability, Bitcoin mining plays a dual role by incentivizing miners to secure the network while validating transactions. Miners actively safeguard the integrity of the blockchain, protecting it from potential adversarial activities. As long as new Bitcoins continue to be minted, miners are inclined to participate in the validation process, thereby upholding the network's security.

Bitcoin halving not only maintains the equilibrium of supply but also bolsters the mining ecosystem. Through fostering scarcity, driving valuation up, and moderating Bitcoin's emission rate, halving acts as a compelling incentive for an expanding network of miners committed to safeguarding the blockchain for the long haul.

Even though our hypotheses were not confirmed, data analysis suggests that we have uncovered a mathematical model $m_t = m_{(t-1)} + 2$, where m_t is the number of months after the next halving that the Bitcoin price will reach the peak/bottom; $m_{(t-1)}$ is the number of months after the last halving that the Bitcoin price reached the top/bottom in the previous period. If the assumptions are correct, the next peak will be reached 19 months and the trough 31 months after Bitcoin halving 2024, which means that if the Bitcoin halving takes place in April 2024, the next Bitcoin price peak will be reached in November 2025 and the bottom in November 2026. Several studies, including that by Cuthbertson (Cuthbertson 2024), have concluded that the halving in 2012 saw Bitcoin's value shoot up by 80 times, while the 2016 halving preceded a 300 per cent rise in Bitcoin's value. In the 16 months following the 2020 halving, the price of Bitcoin rose more than 600 per cent. The simplest explanation for these price increases is the basic economic principle of supply and demand: if the supply suddenly drops but demand stays the same, the price will inevitably rise. However, the decentralised and semi-anonymous nature of Bitcoin means it is difficult to attribute specific gains or losses to a specific event. Commentators mention the fact that after the halving we can expect an increase in the price of Bitcoins, but not in connection with the time interval. Research (M'bakob 2024) examined the price fluctuations of Bitcoin and Ethereum in 2013, 2017, and 2021 to determine whether these periods could be characterized as cyclical speculative bubbles and to assess the role of halving in the formation of these potential bubbles. Results showed that the largest price fluctuations of Bitcoin and Ethereum follow a cyclical pattern with a duration of approximately 3 years and 4 months.

Notably, no prior study has attempted to quantify when Bitcoin's price peak and trough will occur relative to halving events. Therefore, our findings represent a significant contribution to the existing body of knowledge. These forecasts hold substantial importance for the cryptocurrency financial market, investors, and stakeholders, providing valuable insights for strategic decision making.

5. Conclusions

In conclusion, this study has delved into the intricacies of Bitcoin halving events, shedding light on their historical significance and impact on the cryptocurrency market. Through a meticulous analysis of past halving events in 2012, 2016, and 2020, with use

of data analysis and comparison, RSI, MADC, and regression analysis, this research has unveiled compelling insights into the patterns and trends surrounding these milestone occurrences. We have uncovered a mathematical model $m_t = m_{(t-1)} + 2$. According to this model, we can predict when will the next peak/trough occur.

The comparative analysis of price movements, market behaviour, and investor sentiment before and after each halving event has revealed a nuanced interplay between supply dynamics, demand shifts, and price discovery mechanisms within the Bitcoin ecosystem. While past halving events have been associated with periods of heightened volatility and speculative fervour, they have also demonstrated a long-term positive trajectory for Bitcoin's price.

Looking back at the recent 2024 Bitcoin halving event, predictions and expectations varied, with a prevailing sentiment of rising Bitcoin prices. This study has provided a thorough assessment of past halving events, utilising historical data, expert insights, and market trends to inform our analysis. To understand the potential outcomes of the recent halving event, several factors needed consideration: market sentiment, supply and demand dynamics, technological development, regulatory environment, global economic conditions, and market speculation.

Market sentiment: Investor sentiment towards Bitcoin and cryptocurrency markets can significantly impact price movements. Positive sentiment, driven by factors such as increased adoption, positive regulatory developments, or favourable macroeconomic conditions, may lead to bullish outlooks for the upcoming halving event.

Supply and demand dynamics: Changes in the supply and demand for Bitcoin, influenced by factors such as mining activity, institutional adoption, and macroeconomic trends, can affect price expectations. A decrease in the rate of new Bitcoin issuance following the halving, combined with increasing demand from investors or institutional buyers, could contribute to optimistic price forecasts.

Technological developments: Innovations in blockchain technology, scalability solutions, and improvements to the Bitcoin network infrastructure may impact market perceptions of Bitcoin's long-term value proposition. Positive developments, such as the implementation of scaling solutions like the Lightning Network or advancements in privacy features, could bolster confidence in Bitcoin's utility and drive price expectations higher.

Regulatory environment: Regulatory developments and government policies concerning cryptocurrencies can influence market sentiment and investor confidence. Clarity and favourable regulatory frameworks may attract institutional investment and support bullish outlooks for Bitcoin leading up to the halving event.

Global economic conditions: Macroeconomic factors, such as inflationary pressures, geopolitical tensions, or economic uncertainty, can impact Bitcoin's perceived value as a store of wealth or hedge against traditional financial risks. Deteriorating economic conditions may fuel demand for Bitcoin as a safe haven asset, contributing to positive price expectations.

Market speculation: Speculative trading activity and investor behaviour play a significant role in shaping short-term price movements in cryptocurrency markets. Speculative trends, driven by factors such as FOMO (fear of missing out) or herd mentality, can amplify price volatility and influence market outlooks for the halving event.

By analysing these potential factors and conducting a comprehensive assessment of market dynamics, researchers and investors can develop more informed outlooks for the upcoming halving event. Further studies in areas such as investor behaviour and cryptocurrency exchange-traded funds (ETFs) are recommended to deepen our understanding.

As Bitcoin continues to evolve and mature as a digital asset, the lessons learned from previous halving events serve as valuable guideposts for understanding the cyclic nature of supply reduction and its impact on market dynamics. Through synthesizing historical trends with future predictions, this research contributes to a deeper understanding of Bitcoin's trajectory and the broader implications of halving events on the cryptocurrency landscape.

In conclusion, ongoing research and analysis are vital for navigating the complexities of Bitcoin halving events and their implications for investors, stakeholders, and enthusiasts. By staying vigilant and studying these pivotal moments in Bitcoin's lifecycle, we can gain valuable insights into the evolving cryptocurrency market and its resilience in the face of economic and technological changes.

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