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High crypto volatility : where did it come from, and is it here to stay ?

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"As the value goes up, heads start to swivel, and sceptics soften. Starting a new currency is easy. Anyone can do it. The trick is getting people to accept it because it is their use that gives the 'money' value."

Adam B. Levine

- École d'Économie de la Sorbonne -

Abstract

High crypto volatility: Where did it come from, and is it here to stay?

by Silvio Massimo Baldan, Anna Bock, Gaia Ferrero Regis and Nam Khanh Nguyen

The aim of this research is to examine the price fluctuations of Bitcoin over the past decade and identify a declining trend in its historical volatility. Using daily price data and academic studies, we compare Bitcoin's volatility with that of other significant financial assets such as gold and financial indices like the S&P 500 index. Despite exhibiting significantly higher volatility than traditional assets, our analysis demonstrates that Bitcoin's volatility has decreased over time, albeit still remaining higher than the volatility of these assets. To investigate the causes of Bitcoin's volatility, we propose academic studies using regression analysis to explore the relationship between Bitcoin's volatility and a range of potential factors such as market sentiment and technological advancements. Our research indicates that this correlation should not be ignored. Our study primarily focuses on comprehending the determinants of Bitcoin's volatility, understanding Bitcoin's technology, and using econometric tools to clearly present our data. We believe that enhancing our understanding of Bitcoin's volatility characteristics is crucial to gaining deeper insights into price movements and developing policies towards these revolutionary assets.

Keywords: Bitcoin, Volatility, GARCH model, NFT correlation, Proof-of Work

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Introduction

Cryptocurrencies are gaining in popularity and with it, concerns about their volatility have risen. Cryptocurrencies are a relatively new and still unregulated asset class, and their value is highly unpredictable, resulting in large price swings that can occur in a fairly brief period. Such volatility can result in severe financial losses for investors as well as other implications.

Moreover, since cryptocurrencies lack a legal framework to oversee their usage and trading, they are prone to manipulation, fraud, and hacking, leading to significant volatility impacts. As asset managers and governments are also entering the cryptocurrencies market, the issue of volatility becomes more critical as it can affect the stability of a broader spectrum of the financial system. It therefore becomes clear the crucial importance of having a deeper understanding of volatility in today's context. The objective of this thesis is to offer a detailed examination of cryptocurrency volatility with a focus on its potential decrease, taking into account various factors that can influence it.

In Part 1, we provide an overview of cryptocurrency, focusing on Bitcoin as the most widely used and studied digital currency. We delve into blockchain technology and security concerns, which have been known to contribute to volatility. We also examine the correlation between NFT volatility and cryptocurrency.

Part 2 analyses the social and technological determinants of volatility. We investigate the impact of social and environmental factors, such as country-level adoption and the cryptocurrency-environment relationship, on volatility. We also explore the technological and market factors that influence volatility, including the impact of new technological developments and market correlations.

Lastly, in Part 3, we examine various techniques used to measure volatility, including a statistical approach utilising standard deviation, ARCH, and GARCH models. Finally, we provide a historical analysis of Bitcoin volatility.

Cryptocurrency overview and its impact factors

In order to make the purposes of our research immediately clear and understandable, we decided to start by giving a general and historical overview of cryptocurrencies. This first part will focus on the functioning, definition and initial addressing of the main problems relating to the security and stability of cryptocurrencies. Moreover, we explain why we think Bitcoin could make the most robust case study, before continuing our detailed analysis in the following parts.

2.1 Understanding cryptocurrencies: Definition, Nature, and Properties

The term "Cryptocurrency" denotes a digital or virtual currency whose transaction is verified and its records maintained by a decentralised system through the usage of cryptography, removing the need and the control of a centralised authority. In this thesis, we will provide a detailed technical analysis of the specific features of cryptocurrency that distinguishes it from traditional forms of currency.

Over the last decade, cryptocurrencies have become increasingly popular due to their decentralised nature and ability to provide enhanced security, privacy, and convenience compared to traditional currencies (Yi, 2018). Essentially, they are digital currencies that use cryptography to secure transactions and regulate the creation of new units. This thesis begins with a comprehensive overview of the history of cryptocurrency, including the evolution of blockchain technology, the rise of Bitcoin, the consequent benefits and issues raised, and the regulatory challenges facing the industry. The thesis also explores the potential implications of cryptocurrency for the future of finance and the broader economy.
The history of cryptocurrency can be traced back to the early 2000s when the concept of digital currency was first introduced. The first cryptocurrency to be

effectively developed was Bitcoin, which was introduced in 2009 by an anonymous individual or group, known only by the pseudonym Satoshi Nakamoto (Brandvold, 2015). The creation of Bitcoin was inspired by the need for a decentralised, secure, and independent form of currency that was not controlled by any central authority. In fact the nature of cryptocurrency is based on the principles of decentralisation, cryptography, and peer-to-peer networking. Unlike traditional forms of currency, cryptocurrency operates independently and is not controlled by any central authority, which makes the currency resistant to censorship and control. Furthermore, cryptography is a crucial aspect of cryptocurrency, using mathematical algorithms to secure and verify transactions on the network. Cryptocurrencies employ complex cryptographic protocols to maintain transaction integrity and protect against fraud, hacking, or other security threats. Operating on a peer-to-peer network, cryptocurrency facilitates direct transactions between users, removing the need for intermediaries such as banks or payment processors. This results in a more efficient and cost-effective system compared to traditional currencies, which are often subject to high fees and lengthy processing times. Additionally, most cryptocurrencies have a predetermined fixed supply, meaning that the total number of coins or tokens that will ever exist is known. Moreover, once a transaction is confirmed and added to the blockchain, it cannot be reversed, providing a high level of security for buyers and sellers by eliminating the risk of chargebacks or payment fraud.

Nevertheless, cryptocurrency still remains a debatable subject since governments and financial regulators have struggled to establish a regulatory framework for cryptocurrencies, as they are difficult to classify and regulate. This led to different approaches as some countries have completely banned cryptocurrencies, while others have established different licensing regimes or taxation rules (Lansky, 2018). The common main issue governments and central institutions raise is that the lack of regulation has also made cryptocurrencies vulnerable to fraud and criminal activity. We will explore this topic in detail in the next section.

To support our thesis, we chose to analyse Bitcoin in-depth, given its market dominance and status as a leader in the world of cryptocurrency (Subramanian, 2015). With a market capitalization of over $2.4 trillion USD, Bitcoin currently holds the largest share of the cryptocurrency market, accounting for more than 50% of its total value as of April 1st, 2023 (CoinMarketCap, 2018). This figure is calculated by multiplying the current price of one bitcoin by the total number of bitcoins in circulation. The total market capitalization of all cryptocurrencies is approximately $4.7 trillion USD, derived by adding up the market capitalization of each individual cryptocurrency (CoinMarketCap, 2018). It's important to note that these values are highly volatile and can fluctuate rapidly over short periods of

time. Therefore, these numbers are accurate as of the time of our writing but may change quickly. This means that Bitcoin is the most widely accepted and recognized form of cryptocurrency, making it easier to buy, sell, and trade compared to other cryptocurrencies.
As a prime example of cryptocurrency, Bitcoin retains the key characteristics we just discussed, enabling its users to enjoy greater privacy and anonymity: Bitcoin transactions are designed to be pseudonymous, meaning users can make transactions without revealing their identity. This inherent feature incontestably makes it a more secure and transparent form of currency, as it is managed by a decentralised network of users comprising nodes that validate transactions, which are then verified and recorded on a public ledger called the blockchain. We will delve into this aspect of Bitcoin in the next section of our analysis. It's important to highlight that the blockchain provides complete transparency, allowing anyone to view the details of all transactions that have occurred on the network. Despite these benefits, Bitcoin's price is known to be highly volatile, and it has experienced significant fluctuations. This issue will serve as a starting point for our analysis.

2.2 Blockchain Technology and Volatility: Security Concerns and their Effect

In 1999, Milton Friedman predicted the future by saying:

> " The one thing that is missing but that will soon be developed, is a reliable e-cash. A method whereby on the internet you can transfer funds from A to B, without A knowing B or B knowing A".

While acknowledging that cash payments can eliminate uncertainties surrounding costs and payments, Friedman pointed out that electronic payments involve a certain level of fraud which can only be addressed by involving trusted third parties. The Blockchain technique, which was first introduced by a group of researchers in 1991 to timestamp documents and prevent tampering, found its practical application in the form of Bitcoin, a digital currency created by Satoshi Nakamoto in 2009 (Swan, 2015). Nakamoto's white paper proposed a secure, peer-to-peer transaction system based on proof-of-work protocols that did not require any central authority (Nakamoto, 2008). Although initially developed for cryptocurrency, blockchain technology has potential uses in various other domains. A thorough understanding of its essential components is necessary to explore these possibilities.

2.2.1 What is Blockchain technology?

A blockchain is a distributed ledger that is continuously growing and open to everyone (Treleaven, 2017). The blocks are uniquely identified, linked transaction records that contain data, the hash of the block and the hash of the previous block. The stored data depends on the type of blockchain. In the case of Bitcoin, the details of the previous and ongoing transaction are stored, such as sender, receiver and the amount of coins issued (Swan, 2015). The blocks are sealed cryptographically with a digital fingerprint generated by a hashing function. A Hash identifies a block and all of its contents with a unique series of letters and numbers. The Hash is being calculated once a block is created, so changing something inside the block will change the Hash, thus it is no longer the same block (Treleaven, 2017). Each block is "chained" to the previous one by referring to its hash value, which makes blockchain technology exceptionally secure. The first block called the genesis block, was the first one to be mined. Satoshi Nakamoto mined the Genesis Block on Jan. 3, 2009, and hasn't moved it since. If one tempers with one block, the hash of the block will change, which makes all following blocks invalid as they no longer store a valid hash of the previous block. However, specialised hardware such as Application-Specific Integrated Circuits (ASICs) or Graphics Processing Units (GPUs) designed specifically for cryptocurrency mining can calculate trillions of hashes per second for certain hashing algorithms like SHA-256 (Nakamoto, 2008). This is where the mechanism "Proof-of-Work" is needed.

2.2.2 Proof-of-Work vs Proof-of-Stake

In the world of digital currency, one of the biggest challenges has been preventing the issue of double-spending. This term refers to when someone spends the same cryptocurrency twice before the transaction is recorded on the blockchain. Nakamoto solved the double-spend problem by implementing a "distributed timestamp server on a peer-to-peer basis " (Nakamoto, 2008).

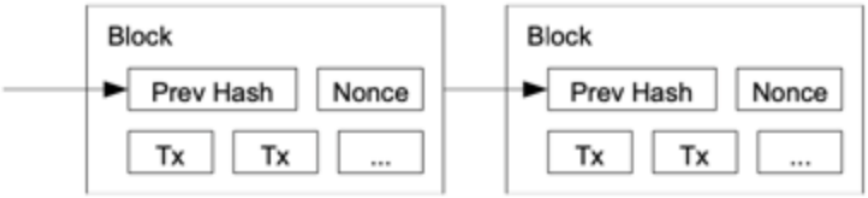

FIGURE 2.1: Proof of Work by S. Nakamoto in White Paper (2008)

This means miners are incentivised to verify the integrity of new crypto transactions before adding them to the distributed ledger. To create a secure timestamp, the computer increments a number (called a "nonce") in the data block until it finds a hash that meets the required number of zero bits (Nakamoto, 2008). Once this is done, it cannot be changed without redoing all the work again. Miners compete to be the first one to solve a complex mathematical problem that requires a lot of computational power. Once the miner solves the puzzle, they broadcast the solution to the network, and other nodes can easily verify that the solution is correct by running the same computation (Antolin, 2023). This is known as "mining" a new block, and the miner who solves the puzzle first is typically rewarded with some cryptocurrency for their effort. In Bitcoins case, it takes about 10 minutes to calculate the PoW and add it to the chain (Antolin, 2023). Instead of a third party to trust with the management, a peer-to-peer network is open to everyone. New transactions are broadcast to all nodes. Once a Proof of Work has been found, each node verifies the block to make sure it hasn't been tampered with. To alter a block on the chain, one must tamper with all preceding blocks, redo the proof-of-work for each block, and gain control of over 50% of the peer-to-peer network.
The other consensus mechanism used in cryptocurrency transactions is called Proof of Stake. Proof of Stake was created as a substitute for Proof of Work, specifically to solve the problems of energy consumption, environmental impact, and scalability (Curry, 2023). In PoS, validators hold and stake tokens to earn transaction fees, unlike in PoW where miners must solve cryptographic puzzles. The selection process for validators is determined by a variety of factors, such as staking age, randomization, or the wealth of the node. To take part in the forging process, users must lock up a set amount of coins in the network as their stake, and the size of their stake determines the probability of being selected as a node (Curry, 2023). Additional selection options are added to ensure that the wealthiest nodes aren't always chosen. Requiring miners to put up a stake makes it less likely for them to engage in fraudulent activities or steal coins, adding an extra layer of security (Treleaven, 2017). Attackers have no real incentive to disrupt the blockchain, as they cannot double-spend or steal coins without sacrificing their investment. However, a lot of security concerns remain that cause investors to lose trust and volatility to peak.

2.2.3 Security concerns causing volatility

The threat of a 51% attack exists in both PoW and PoS but it is even riskier for the attackers (Antolin, 2023). A 51% attack occurs when a single entity or group

controls more than 50% of the nodes on a blockchain network. This gives them the ability to manipulate transactions and potentially reverse transactions that have already been confirmed. However, a strength of Proof of Stake over Proof of Work is that the community has flexibility in mounting a counter-attack (Antolin, 2023). In addition to the concerns related to an attack, also regulatory actions can have a significant impact on the market.

The regulatory environment around cryptocurrency is constantly evolving, and regulatory actions such as bans, restrictions, and crackdowns can cause uncertainty and panic among investors. When a major regulatory action is taken against a particular cryptocurrency, it can lead to a loss of confidence in that cryptocurrency and a sell-off by investors, causing the price to drop. In September 2021, China intensified its crackdown on cryptocurrency, banning all cryptocurrency transactions and mining activities. This caused a significant drop in the price of Bitcoin and other cryptocurrencies as investors feared that other countries might follow suit (Quin, 2021). The security of cryptocurrency exchanges and wallets is another factor that can impact the value of cryptocurrencies, especially when a major exchange or wallet is compromised.

Using a cryptocurrency exchange to buy or sell cryptocurrencies, means trusting the exchange to hold the funds and execute trades. This means that if the exchange is hacked or goes out of business, investors could potentially lose all funds. Additionally, if the exchange is not properly secured, all personal information and trading activity could be compromised. When a major exchange or wallet is hacked, it can lead to a loss of funds for users and a loss of confidence in the security of cryptocurrency as a whole. This can lead to a sell-off of the affected cryptocurrency and a drop in its price. For example, in May 2019, Binance - one of the largest cryptocurrency exchanges in the world - was hacked, resulting in the loss of 7,000 Bitcoins, worth around $40 million at the time. Binance used its SAFU (Secure Asset Fund for Users) to cover the losses and no users lost any funds (Lam, 2009).

This example shows that to mitigate these risks, it's important to choose a reputable exchange with a good track record of security and user protection. However, the safest way of storing cryptocurrency is by using a hardware wallet. A hardware wallet is a physical device that stores the cryptocurrency offline, making it much more difficult for hackers to access the funds. When storing the cryptocurrency on an exchange, investors are essentially trusting the exchange to hold the funds and execute the requested trades. By using a hardware wallet, investors gain greater control over the funds and can access them at any time without relying on a third party.

2.3 Central Bank Digital Currencies

2.3.1 Definition

In recent decades, various technological advancements have disrupted the financial services industry. Despite cash still being largely used, the need for faster and more convenient banking and payment options has prompted Central Banks to develop their own digital currencies. To provide a recent example, in the past few years, the COVID-19 pandemic has led to a surge in digital and contactless payments as social distancing measures have limited the circulation of banknotes. This shift has also resulted in an increase in e-commerce transactions. Although trust in cryptocurrencies remains fragile, this market has developed and gained value over time. As a result, 87 countries, representing over 90% of global GDP, are currently exploring central bank digital currencies (European Data Protection, 2023). In fact, 9 of these countries have already launched state-owned digital currencies, indicating the potential that this market holds (European Data Protection, 2023).

So, what is a Central Bank Digital Currency? The Central Bank Digital Currency (CBDC) is a form of digital currency issued and backed by a central bank. Unlike cryptocurrencies such as Bitcoin, CBDCs are legal tenders and have the full faith and credit of the issuing government (Wadsworth, 2018). CDBC is essentially a digital currency that utilizes the current financial market infrastructure for transaction purposes. This type of currency can either be account-based, where individuals hold bank accounts with the Reserve Bank, or token-based, where currency is held in card or other forms. In a simple way, CBDCs are designated to be a secure and efficient way to make payments and conduct transactions, and they can be used to make purchases online, in-person, and transfer money from one person to another (Brodo, 2017).

2.3.2 Characteristic of CBDCs

The financial industry has been discussing Central Bank Digital Currencies (CBDCs) for some time. If the central bank aims to optimise CBDCs for their basic currency functions, such as serving as a medium of exchange, store of value, and stability as the unit of account in transactions, CBDCs have distinct advantages that make them a viable alternative to cash and banknotes.

One of the most notable benefits of CBDCs is their ability to provide a viable alternative to cash. By utilising digital currencies, transactions can be carried out more quickly and transparently, which may result in reduced transaction costs, improved security, and enhanced efficiency in financial dealings (Cunha, 2021).

Another advantage of CBDCs is their potential to promote financial inclusion. Digital currencies can offer an alternative to conventional banking services that may be inaccessible or unavailable to certain individuals. With CBDCs, anyone with a digital wallet can participate in financial transactions.
Despite these advantages, there are also concerns regarding CBDCs. A major issue is the potential impact on privacy, as central banks would be able to track all transactions, which raises concerns about surveillance and invasions of privacy (Cunha, 2021). Additionally, the introduction of CBDCs could lead to financial instability in the long run, as a central bank's decision to issue or terminate a CBDC could impact the economy and financial markets.
In brief, while CBDCs offer several benefits, there are also risks and challenges associated with their adoption. It is crucial to carefully consider these issues before implementing digital currencies as a mainstream form of payment.
In theory, central banks aim to maintain inflation at a certain level. However, in practice, the choice of the target has seemed somewhat subjective and arbitrary. As a result, the use of monetary policy doesn't always come with expected results due to economic shocks and the divergence of behaviour.
As a response to this, the adoption of interest-bearing CBDCs could enable central banks to establish a constant price level target that would serve as a natural focal point for expectations (Brodo, 2017). Using CBDCs as a tool can help central banks to gain transparency and public accountability. By enabling the conversion from cash to CBDC and reverse, the central bank would be able to provide an appropriate degree of monetary accommodation without regulating the size and composition of its balance sheet (as for the quantitative easing). This would serve as an alternative to the traditional monetary policy and boost the inflation target level (England, 2020).
Despite this, the central bank would still need to retain its role as a lender of last resort during financial crises. This would enable the central bank to expand the quantity of CBDC to provide emergency liquidity (England, 2020). Additionally, issuing CBDCs would require the central bank to invest in new infrastructure to create, issue, and maintain a digital currency network. Therefore, the question arises as to whether this is an effective way to facilitate the situation when it comes to crises.

2.3.3 Conclusion

Based on what we have learned earlier, CBDCs and cryptocurrencies are two

separate digital currencies with varying features and purposes. CBDCs are established and supported by central banks, which are lawful and transparent establishments. Its objective is to provide a safe and efficient means of conducting payment and financial transactions. Even though the implementation of CBDCs is still a work in progress for central banks across the globe, their efforts have demonstrated that digital currency is no longer a subject of speculation. Its potential impact on financial services may be realised in the future.

2.4 NFT Volatility and Cryptocurrencies Correlation

In this part we're going to deep dive into the correlation between NFT's volatility and cryptocurrencies. This relation is complicated and multifaceted, as both NFTs and cryptocurrencies are highly volatile and subject to market fluctuations. First, we'll be giving a brief explanation of NFT and their appearance on the market, successively concentrating on the link between cryptocurrencies and the underlying ownership rights.

Before the development of blockchain technology, there were few and unreliable systems for proving ownership of digital assets. But long research in this domain allowed for the creation of NFTs, an acronym that stands for Non Fungible Tokens. As defined by Binance Academy, an NFT is a cryptographic token that represents a one-of-a-kind asset (Academy, 2022). NFTs can be created for both physical and digital assets and serve as a way to confirm authenticity and ownership within a blockchain system, such as Ethereum. Unlike fungible tokens, NFTs are not interchangeable with one another, creating a sense of rarity in the digital world.

These NFT have multiple purposes, such as digital identity, certificates, licensing, video games or fine art. In early 2021 and during all the first semester of 2022, NFT generated a wave of hype and interest between young investors, as many digital artwork exploited this technology, becoming viral and intensively traded (Ante, 2021).

The NFT hype coincided with a bull market in the cryptocurrencies, and for this reason we considered it quite important to deep dive into the topic to better understand the possible link between the two. Due to the fact that the market for NFTs did not exist until recently, there is a lack of extensive research on the subject. However, one study conducted by Michael Dowling, a professor at Dublin City University, titled "Is Non-Fungible Token Pricing Driven by Cryptocurrencies?" investigated this topic (Dowling, 2021). Hence while the paper will be the foundation of this section. However, it has to be mentioned that the paper was released in early 2021, before NFTs became really popular for the mainstream.

The paper mentions that individuals involved in the NFT market are likely to have ties to the cryptocurrenc one. This is due, in part, to the fact that purchasing an NFT often requires the use of cryptocurrencies as a form of payment, which can be challenging for many people. This also implies that there is a strong crossover between traders in the NFT market and the cryptocurrency market (Dowling, 2021). However, already the abstract makes it clear that the spillover index, which was explained in previous sections, does not indicate a significant volatility transmission. This shows that the correlation between the two is trivial. Moreover, there is minimal spillover within the NFT markets, suggesting that these markets have unique characteristics that differentiate them from one another.

FIGURE 2.2: 50-week Net spillovers NFTs and cryptocurrencies, February 2020 to March 2021 (Dowling, 2021)

Furthermore, a study from June 2021 by L. Ante supports the assertions made by Dowling. However, the study posits that a decrease in the value of cryptocurrencies leads to a reduction in purchasing power, potentially causing a dampening effect on the NFT market (Ante, 2021). Conversely, when cryptocurrencies appreciate in value, investors tend to explore new or alternative investment opportunities, which is particularly relevant in the case of ETH, the standard unit of NFTs. Dowling stated that the volatility transmission in NFT pricing appears to be different from that in cryptocurrency pricing (Dowling, 2021). This presents intriguing implications for investment portfolios, as assets with low correlation are highly sought-after for their diversification properties.
Nevertheless, it suggests that it would be helpful to use what we know about how cryptocurrency prices behave when we are trying to understand NFT prices. As

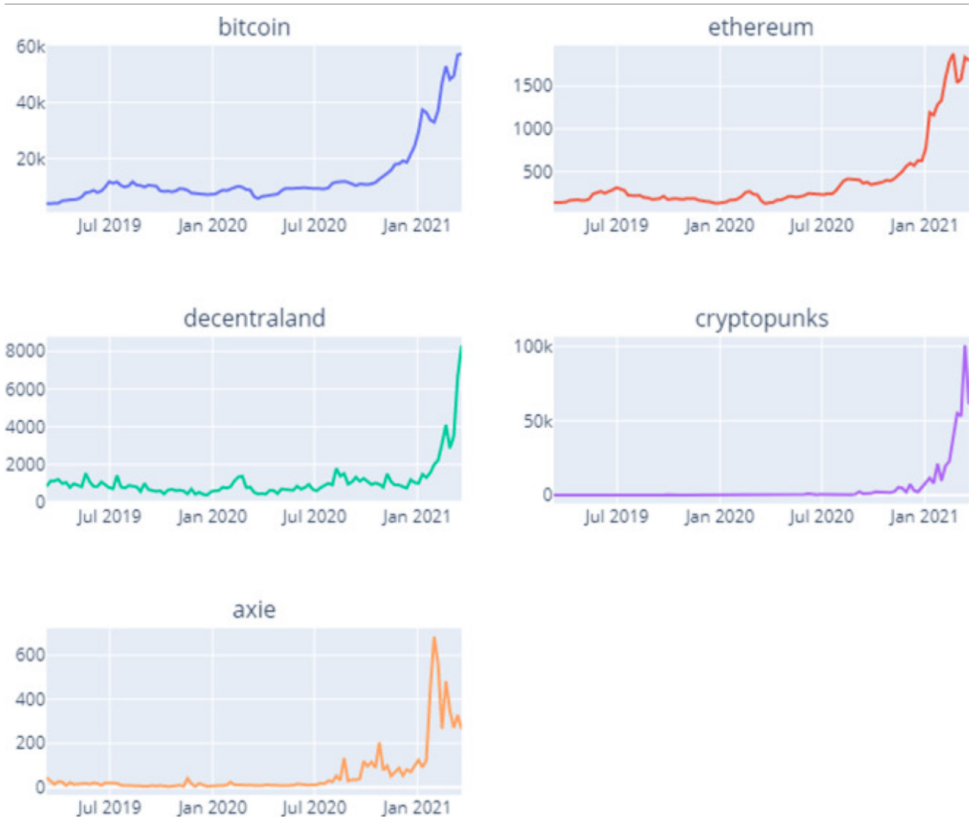

FIGURE 2.3: Weekly pricing plots for NFTs and cryptocurrencies, March 2019 to March 2021 (Dowling, 2021)

the research on cryptocurrencies has intensified in the last few years, using this knowledge to understand NFT pricing and value can help us assess new correlations, giving investors new tools to evaluate such volatile and speculative assets (Dowling, 2021).

In conclusion, NFTs are a revolutionary development in the digital world, providing a secure and reliable way to prove ownership and authenticity of unique assets. While analysing the NFT hype, we can easily say that it coincided with a bull market in cryptocurrencies. Nevertheless, many researches suggested that the NFT market is very little influenced by the cryptocurrency one, resulting in an insignificant correlation. However, the findings have important implications for investment portfolios, highlighting the importance of diversification and the potential benefits of using knowledge about cryptocurrency to better understand NFT pricing and value.

Social and Technological Determinants of Volatility

The world of cryptocurrencies is constantly evolving, influenced by a range of social, environmental, and technological factors. In this thesis, we explore two key factors, social and environmental and two main technological improvements that have a remarkable impact on cryptocurrencies' volatility. Specifically, in the following sections, we will discuss the impact of media coverage, government regulations, public sentiment, mainstream business adoption, energy consumption, and climate change on cryptocurrencies volatility. We will also examine the role of two significant technological improvements, as Segwit and Lightning Network, in reducing Bitcoin's volatility. By understanding these factors, we can gain valuable insight into the complex dynamics and volatility of the cryptocurrency market. Moreover, the technological improvements and widespread adoption of cryptocurrencies, associated with greater environmental consciousness, could anticipate a decrease in volatility.

3.1 Social and Environmental Factors

Since the inception of the pioneering cryptocurrency Bitcoin in 2009, blockchain and its applications to cryptocurrency transactions have attracted a lot of interest and popularity. Known to be exceptionally volatile, cryptocurrencies, such as all other kinds of traded assets, are influenced by a wide range of social and environmental factors, which can directly impact their volatility and create challenges for investors and regulators alike (Ephraim, 2023). According to the site coinmarketcap.com, on August 13, 2020 there were 6442 cryptocurrencies in circulation, and many are the factor affecting their volatility over time, but we believe that the social and environmental factors are two of the most important ones that need to be taken into account. Thus, in this first part, we'll be deep diving into the wide array of these factors, analysing their implication on cryptocurrencies volatility.

The social factors can be defined as the external variables that affect how individuals sees, utilises or invest in cryptocurrencies. We identified four main categories of factors.
The first one is the media coverage, as news reports, social media fads, and other media can influence how the public views cryptocurrencies and whether they buy, sell, or hold onto them (Gourang, 2019). In this specific category, we can mention the high influence of Twitter on these kinds of financial decisions. For instance, favorable news reports regarding the use of cryptocurrencies by well-known individuals, companies, or government policies in favour of their use might raise interest in cryptocurrencies and drive up their prices. Moreover, the volume of media coverage can impact volatility: a high volume of media coverage on a specific cryptocurrency or event can create a "hype cycle," in which demand and prices rise quickly, only to fall just as quickly as the news cycle shifts to another topic. Then we examine the government regulations, we consider that laws limiting or promoting the usage of cryptocurrencies might significantly affect their value. For instance, laws that increase the cost or difficulty of purchasing, selling, or holding cryptocurrency can reduce demand and cause price dips, whereas policies that promote adoption can boost demand and cause price gains. These regulatory changes can generate sudden price movements as investors try to predict government decisions. Also, fiscal regulations fall in this category, affecting overall investor decisions. Moreover, public sentiment is one of the most powerful social factors of all, as the general public's attitudes and beliefs concerning cryptocurrency showcase a strong impact on these kinds of assets. People may be more likely to buy and hold cryptocurrency if they believe it is a valuable investment or a viable alternative to traditional currencies, increasing demand and driving up prices. Furthermore, public sentiment can be influenced by the actions of other investors. When prices are rising, investors who are experiencing "FOMO" (fear of missing out) may enter the market, causing prices to rise even more. When prices are falling, investors may panic and sell, causing prices to fall even further.
Finally, the adoption by mainstream businesses may raise cryptocurrencies' assets' value, as in the case of Tesla. This is due to its increasing acceptance and usability, which raises its perceived value and cryptocurrency legitimacy and thus its demand.
In conclusion, social factors play an important role in shaping individuals' and organisations' behaviour and decision-making in relation to cryptocurrency, with a clear impact on its volatility.
If social factors are impacting the volatility of these digital assets, this is true also for the environmental factors. These can be defined as events or conditions that

affect the physical world and affect cryptocurrencies trading and mining. These environmental factors can also affect prices and contribute to volatility. We'll be analysing two major factors: energy consumption and climate change.
Energy consumption is one of the most important environmental factors to examine. In fact, significant quantities of energy are required for cryptocurrency mining, the process through which new coins are created (Corbet, 2019). The processing power necessary to validate transactions on the blockchain network is mostly responsible for this energy consumption (in this context we'll keep a more general view, while analysing the energy consumption differences between Proof of Concept and Proof of Stake in the next section). Concerns have been raised in recent years about the environmental impact of cryptocurrency mining, which frequently uses non-renewable energy sources such as coal (Badea, 2021). The environmental impact of cryptocurrency mining has prompted calls for tighter regulation, which could have an impact on the cryptocurrency market's demand and supply. Additionally, changes in energy costs or the availability of renewable energy sources can have an impact on mining profitability, which in turn can affect supply and demand in the industry.
Moreover climate change has a direct impact on cryptocurrencies in multiple ways. First weather patterns and natural disasters can have a major impact on the energy infrastructure that enables cryptocurrency mining (Wendl, 2022). Extreme climate conditions, like hurricanes, floods, or wildfires, might disrupt electricity supplies, potentially reducing mining profitability and the supply of new coins on the market. Additionally, natural disasters can disrupt internet infrastructure, potentially making it difficult or impossible for investors to buy or sell cryptocurrency. Second, concerns about the harmful effects of cryptocurrency mining have led some investors to consider the sustainability of various cryptocurrencies into their investment preferences, pushing them towards other opportunities.
Finally, environmental issues such as energy consumption, climate change, and natural disasters can all have a significant impact on cryptocurrency values and increase volatility. As the cryptocurrency industry expands and develops, it will be essential to assess the environmental implications of cryptocurrency mining and to monitor the market's potential influence of environmental concerns. In the next section we'll be discussing more in detail the cryptocurrency and environmental relations and their impact on volatility.

3.1.1 Cryptocurrency-Environment Relations and their Impact on Volatility

In this section we'll analyse the environmental relations of cryptocurrencies

and their volatility. First we'll deep dive into the more general problem, linked to resource consumption, then we'll concentrate on the case of Bitcoin and will then explore the difference between Proof of Work and Proof of Stake with regards to the resources consumption. In conclusion we'll be exploring the link between cryptocurrencies and energy markets.

The climate challenge:

The consumption of a significant amount of electricity in the acquisition and use of any cryptocurrency is easily noticeable, as these digital assets are commonly known as peer-to-peer electronic cash, which allows for real-time transactions without the need for financial institutions. The world faces two pressing issues today, namely sustainable development and climate change. Information and communication technology plays a crucial role in tackling these challenges. While technology can assist in reducing energy and resource consumption, its growing usage simultaneously drives up energy and resource demand, resulting in various emissions being released into the atmosphere. Against this backdrop, the increasing interest in various cryptocurrencies has triggered intense debate within academia, spanning from questioning their usefulness to examining their sustainability impact due to the current technology used for mining and the e-waste generated from these activities.

The case of Bitcoin:

The level of concern over the energy consumption associated with Bitcoin mining has recently intensified. PoW and PoW / PoS hybrid schemes are currently used for Bitcoin mining. There are currently developed two tools for estimating electricity consumption by the Bitcoin network: First, the Cambridge Bitcoin Electricity Consumption Index (CBECI), developed recently by the University of Cambridge and secondly, the Bitcoin Energy Consumption Index (BECI) realized by Digiconomist. On September 30, 2019, according to the two indexes, the network annually consumed between 73.1 and 78.3 terawatt-hours (TWh) of electricity. Moreover, the analysis shows that the total Bitcoin footprint is 55.88 Mt CO2, therefore comparable to the footprint of Peru. While its annualised energy consumption is up to 100.18 TWh, comparable to the power consumption of Kazakhstan. Finally, the electronic waste accounts for 55.91 kt, comparable to the small IT equipment waste of the Netherlands. Bitcoin's estimated energy consumption is heavily reliant on a variety of factors, including device efficiency and electricity prices throughout the mining process. Furthermore, renewable energy sources are increasingly being used in Bitcoin mining initiatives around the world. According to Kamiya's (2019) research, China accounts for 60% to 70% of overall Bitcoin mining, with the majority of these mining centers located in distant regions of the country with abundant wind or hydropower resources,

making them a more cost-effective option. Although the environmental impact of Bitcoin mining has been highlighted, Liana Badea's research suggests that Bitcoin still represents a financially feasible substitute to official currency (Badea, 2021).

Gold mining & recycling	gross yearly cost: USD$105 billion+USD$40 billion
	energy used (GJ): 475 million + 25 million
	tonnes CO_2 produced: 54 million + 4 million
Paper currency & minting	gross yearly cost: USD$28 billion
	energy used (GJ): 39.6 million
	tonnes CO_2 produced: 6.7 million
Banking system	gross yearly cost: USD$63.8 billion (for electricity use); USD$1870 billion (all expenses)
	energy used (GJ): 2340 million
	tonnes co_2 produced: 390 million
Bitcoin mining	gross yearly cost: USD$0.375 billion
	energy used (GJ): 3.97 million
	tonnes CO_2 produced: 0.66 million

Source: authors' adaptation after [77]

FIGURE 3.1: Environmental impact of Bitcoin mining comparison

Badea's estimation reveals that the environmental expenses related to Bitcoin mining are lower than those of paper money issuance, gold mining, and banking systems (Badea, 2021). However, the ecological implication of Bitcoin mining remains a main problem and it will not be solved only by applying renewable energy: the only way forward is to change the PoW algorithm with "Proof of Stake".

PoS vs PoW:

As previously discussed in the point 1.2: Blockchain Technology and Volatility: Security Concerns and their Effect, there are two primary consensus algorithms utilised in blockchain technology. PoW (Proof of Work) is the earliest and most commonly used consensus algorithm (Hu et al., 2021). PoW involves the mining process, where nodes validate transactions through brute-force computing power. To address the problem of high resource consumption in PoW, the PoS (Proof of Stake) algorithm was introduced in 2012 (Nadal, 2012). In PoS, nodes are referred to as validators instead of miners. Validators deposit stakes of the cryptocurrency they own, which are refundable.

Proof of Work Consensus is known to have a significant environmental impact due to its high resource consumption. In order to validate transactions, miners use computational power to solve complex mathematical problems, resulting in the wastage of resources like hardware, space, money, and energy. The electricity consumption for transaction verification in 2018 alone was estimated to be 0.3% of

the world's total electricity consumption, which led to a carbon footprint of 34.73 Mt CO2. This carbon footprint is comparable to that of Denmark or 723,140 VISA transactions, or watching YouTube for 48,872 hours. Additionally, this process generates 11.49 kt of electronic waste, which is similar to the e-waste generated by Luxembourg.

The PoS algorithm offers a more energy-efficient and environmentally friendly alternative compared to PoW (Sriman, 2020). Unlike PoW, PoS does not require specialised hardware to participate in the validation process, which means that manufacturers do not need to use resources to build dedicated equipment. In PoS, only the selected validating miner computes a hash, resulting in significantly lower levels of electricity consumption and carbon emissions compared to PoW. The environmental impact of PoS is estimated to be a thousand times lower than that of PoW (Usman, 2018). Additionally, PoS is highly scalable and can handle large transaction volumes without having a significant impact on the environment.

In conclusion, the choice of consensus algorithm in blockchain technology can have a significant impact on the environment. PoS offers a more energy-efficient and environmentally friendly alternative to PoW, which is known for its high resource consumption. We will now discuss the relationship between cryptocurrencies and energy market's volatility.

The linkages between markets play a vital role in determining returns and volatility, which have a significant impact on portfolio management and hedging decisions. Shaen Corbet and Brian Lucey showed a strong positive correlation between Bitcoin returns and the volatility of electricity prices in China and Russia, indicating a significant interplay between Bitcoin and electricity companies in these major mining pool regions (Corbet, 2019). However, while there is also a positive correlation between Bitcoin price volatility and Japanese electricity companies, it is not significant. In addition, the study found a significant relationship between the pricing volatility of Bitcoin and selected international utility ETFs, although the magnitude of this relationship is relatively small. Furthermore, the authors found that the price volatility of Bitcoin is negatively related to the price of Carbon Credits, whereas no significant relationship was identified between the largest cryptocurrency market and the largest green energy ETFs analysed. These findings suggest that intermarket linkage plays a crucial role in international finance, affecting returns and volatility spillovers and, consequently, has significant implications for portfolio and hedging decision-making.

In conclusion, the link between cryptocurrency-environment relations and volatility can be analysed by considering the environmental impact of cryptocurrency mining, which has been identified as a significant contributor to greenhouse gas

emissions. As the demand for cryptocurrencies increases, so does the demand for mining, leading to an increase in energy consumption and carbon emissions (Attarzadeh, 2022). This environmental impact can in turn affect the value and volatility of cryptocurrencies, as investors and governments may become more hesitant to support or invest in them due to concerns over their sustainability and impact on the environment. Additionally, regulatory measures aimed at reducing the environmental impact of cryptocurrency mining, such as carbon taxes or restrictions on energy consumption, may also contribute to volatility by increasing the cost of mining and potentially reducing profitability for miners. The research paper "The environmental impact of cryptocurrencies using proof of work and proof of stake consensus algorithms: A systematic review" from Moritz Wendl et al offers a graph that synthesises perfectly what we just discussed (Wendl, 2022).

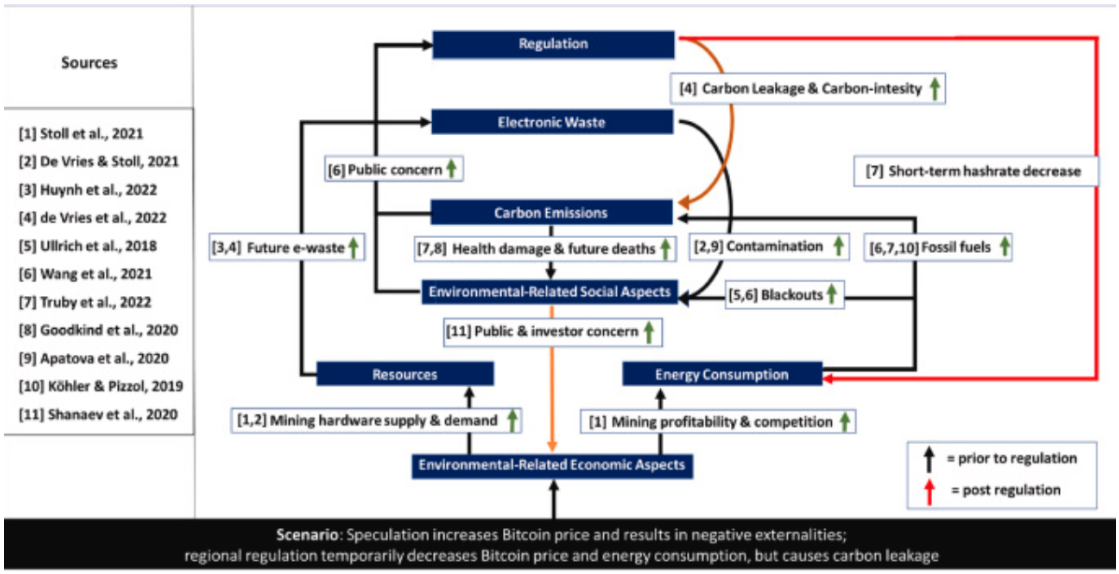

FIGURE 3.2: Environmental impact of cryptocurrencies

3.1.2 Country-level Adoption and its Implications on Cryptocurrency Volatility and Relation between Regulation and Volatility

In recent years, country-level adoption of cryptocurrencies has risen. Multiple studies have analysed the phenomena, and showed how countries experiencing high inflation or unstable monetary policies could benefit from the adoption of cryptocurrencies as legal tenders. In fact, two research papers from Ciaian and Saiedi showed how country adoption can enable readier access to digital financial products and offer services at a lower cost, increasing financial inclusion and connecting local populations to broader global markets (Pavel, 2016) (Saedi, 2020).

Among all cryptocurrencies, Bitcoin has emerged as the most prominent and widespread one, with a growing number of enterprises, such as Tesla, accepting it as payment. In addition to businesses, institutions are demonstrating growing curiosity in cryptocurrencies, utilising them for purposes such as speculation, investment, storing value, and making payments. Although country adoption (CA) of Bitcoin has its benefits, it also presents various challenges, these include the complexity of acquiring Bitcoins, high fixed adoption costs, dependence on network externalities, lack of an authoritative body for dispute resolution, lack of Bitcoin denominated credits, deflationary pressure, and issues with cybersecurity. The high volatility of Bitcoin's price is also a significant challenge that must be considered when assessing the feasibility of country adoption.

The potential of Bitcoin to serve as a substitute for traditional currencies such as the US dollar, Euro, or Yen has been largely debated. The literature on this subject is divided into two opposing views. Some studies argue that Bitcoin does not function as a genuine currency and instead resembles speculative investments. Conversely, other research emphasises the positive aspects of Bitcoin, considering it as a global virtual currency with immense potential for the future. The research paper "The Future of Bitcoin: Mapping the Global Adoption of World's Largest Cryptocurrency Through Benefit Benefit Analysis", analysed the "Profile of a Country" that would mostly benefit from Bitcoin adoption (Darlington, 2014). The study pointed out three main characteristics for a country to benefit the most from the CA: in the first place it would be characterised by high levels of inflation or unpredictable monetary policies. Secondly, the country must possess a high prevalence of corruption and counterfeit activities. Lastly, a significant portion of the population should not have access to secure financial institutions. In essence, Bitcoin is most suitable for nations that are economically disadvantaged, have weak financial systems, and operate under unsteady fiscal conditions. The case of Venezuela exemplifies these characteristics, as the country experienced a surge in inflation, a decline in confidence in the government's monetary policies, and a growing interest in Bitcoin, as evidenced by the popularity of Bitcoin mining (Kliber, 0201). Similarly, during the financial crisis in Cyprus from 2012 to 2013, there was a notable increase in the use of Bitcoin (Subramanian, 2015).

Bitcoin's severe price volatility is a standout feature when compared to traditional currencies. The relationship between country adoption of crypto and crypto volatility can be complex. As crypto adoption increases, demand for it also tends to increase, resulting in higher market valuations and reduced volatility. This is due to higher adoption levels leading to more stability in the cryptocurrency market, with a larger market cap, increased trust, and a broader base of long-term investors, resulting in fewer sharp price fluctuations.

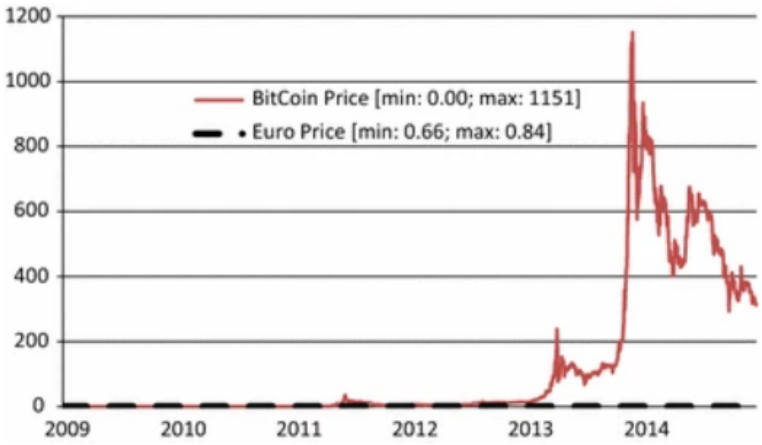

FIGURE 3.3: Bitcoin's extreme volatility (Pavel, 2016)

We'll now examine the relationship between cryptocurrency volatility and regulation.

There is no global consensus on the status of Bitcoin, as there are no international laws regulating it. This has resulted in varying viewpoints among countries, with regulations constantly evolving. For instance, the US Internal Revenue Service considers Bitcoin as barter, while Finland views it as a priced commodity and Germany classifies it as a private currency. While the European Central Bank sees Bitcoin as a virtual currency. Since its introduction in 2009, Bitcoin's value has exhibited extreme volatility, with its price surging to around $1100 in 2013 before plummeting to $225. In contrast, the exchange rate between the US dollar and Euro remained within a ±20 % range during the same six-year period (Pavel, 2016). Multiple research papers tried to analyse which kind of information and shocks would affect the Bitcoin price. For instance, in the academic paper "The digital agenda of virtual currencies: Can Bitcoin become a global currency?" the authors found out that the digital currency is not influenced by most scheduled US macroeconomic news announcements, such as government budget deficits, inflation, or even monetary policy announcements. But on the other hand, bitcoin responds with increased volatility to announcements of forward-looking indicators, such as the consumer confidence index, and regulatory changes. For example, when China banned cryptocurrency trading and initial coin offerings (ICOs) in 2017, the price of Bitcoin dropped by almost 30% in just a few days. Similarly, when the US Securities and Exchange Commission (SEC) delayed its decision on whether to approve a Bitcoin ETF in 2018, the price of Bitcoin dropped by over 10% (Lyócsa, 2020).

In conclusion, the relationship between cryptocurrency volatility and regulation is a complex and multifaceted one. While higher adoption levels can lead to

more stability in the cryptocurrency market, regulatory changes can have a significant impact on the price of Bitcoin. The lack of global agreement on the status of Bitcoin and the constant evolution of regulations make it difficult to predict how cryptocurrency markets will behave in the future.

3.2 Technological and Market factors

3.2.1 Technological influence on volatility

In the following part, we examine in detail the technological factors that contribute to the volatility of Bitcoin. Our analysis suggests that the technological advancements, including the implementation of Segregated Witness (SegWit) and Lightning Network, have positively impacted Bitcoin's stability and reduced its volatility. It is known that the value of Bitcoin has fluctuated significantly over the years, making it difficult to be effectively used as a store of value or even a simple medium of exchange. In this section, we will analyze the technological factors that have contributed to the volatility of Bitcoin and how technological advancements have impacted its stability (Legotin, 2018). The most significant factor contributing to the volatility of Bitcoin is its scalability issue. The limited number of transactions per block has led to an increase in transaction fees and longer transaction processing times during peak periods. This scalability issue has made Bitcoin less efficient and less practical for everyday use, contributing to its high volatility (Poon, 2016). Let's analyze in more detail two technological factors which alleviated this issue:

Segregated Witness (SegWit):
SegWit was first proposed by Pieter Wuille, Bitcoin Core developer, in December 2015 and implemented in 2017. The implementation of Segregated Witness (SegWit) was aimed at improving the efficiency and scalability of the Bitcoin network. SegWit separates transaction signatures (witnesses) from the transaction data, allowing for more transactions to fit within each block and increasing the overall capacity of the network. Although SegWit was not implemented intentionally to lessen the volatility of Bitcoin, it did have some positive market-related effects. By lowering transaction costs, SegWit helped to lessen the volatility of Bitcoin. Prior to SegWit, the Bitcoin network's transaction capacity was constrained, which caused transaction fees to increase during periods of heavy demand. Users were forced, as a result, to postpone their transactions, which increased traffic and fees. After the adoption of SegWit, more transactions were able to fit into each block, lowering transaction costs and increasing the usability of Bitcoin for

more users (Brown, 2022).
By enhancing network security, SegWit additionally decreased the volatility of Bitcoin. SegWit increased the difficulty for hackers to carry out "transaction malleability attacks" by separating transaction data from transaction signatures. These assaults had previously been used to tamper with transaction data, create doubt in the market, and raise volatility. In general, SegWit's adoption served to increase the effectiveness, scalability, and security of the Bitcoin network, which in turn had some favorable market consequences. While it did not completely eradicate volatility, it did assist to lessen some of the causes of it.

Lightning Network:
The Lightning Network is a second-layer scaling solution that allows for instant transactions and micro-payments. The technology enables users to create payment channels that operate off-chain, reducing the number of transactions that need to be processed on the blockchain. This means that congestion is avoided since these off-chain transactions don't need to be broadcasted to the entirety of Bitcoin's network. This technology has significantly increased the capacity of the whole network, reducing transaction fees and times, ultimately reducing Bitcoin's volatility (Poon, 2016). Moreover, the successful development of a more efficient mining hardware gradually improved transactions' security which has a clear and direct effect on users' confidence, which then helps stabilising the market and therefore Bitcoin's volatility. This is due to improved competition: according to a report by CoinShares the average efficiency of mining passed from over 2000 Joules per terahash (J/TH) in 2013 to 40 J/TH in 2019. In the following years, the situation has just improved: as of April 2023, the total hash rate of Bitcoin's network is over 250 million trillion hashes per second : (250 exahashes per second) (CoinMarketCap, 2018). This is a clear demonstration of the advancements made by mining technology over the past decade. Miners have the possibility of better competing for their rewards which helps to maintain stability in the hash rate and to improve security against potential outsiders' attacks.
Our analysis suggests that these advancements have positively impacted Bitcoin's stability and reduced its volatility. While other factors such as market sentiment and regulatory changes may still impact Bitcoin's volatility, technological advancements have provided a path to addressing the large scalability issue of the blockchain network and improving the efficiency of Bitcoin as a digital currency. It is clearly a big step towards a more secure stability, even if other aspects have to be taken into consideration. These include market sentiment, which will be discussed in the next section.

3.2.2 Market Correlation and its Impact on Volatility

In this section, we will examine the relationship between financial markets, investor sentiment, and Bitcoin's volatility. To do so, we will analyse the findings of several studies, including Gandal et al.'s analysis from 2018, Urquhart's research in 2018, and Dyhrberg's study from 2016. Additionally, we will also compare these earlier evaluations with more recent ones, such as Nguyen's assessment in 2022 and Ángeles López-Cabarco's manuscript from 2021. Examining market correlations can be particularly informative during times of financial crisis, as investors often consider stocks as potential hedging assets against inflation. This prompts the inquiry of whether Bitcoin has progressed from being an alternative currency to a legitimate asset and hedging instrument

3.2.3 Bitcoin's volatility compared to S&P 500 Index and NASDAQ

The initial segment of our analysis entails a comparison of the 30-day volatility levels of Bitcoin, NASDAQ, and the S&P 500 index. Typically, the 30-day volatility is determined by computing the standard deviation of daily returns over the preceding 30 trading days. Furthermore, we will examine the shared factors that impact the volatility of both cryptocurrencies and a major stock index, which is expected to be highly informative.

Between 2009 and the late 2010s, Bitcoin's divergence from the broader economy was a double-edged sword. On one hand, it functioned as a safe haven for investors seeking an asset class that was not affected by the turbulence of the stock markets. On the other hand, the heightened awareness of both retail and institutional investors since 2017 has seemingly established a correlation between the prices of both the stock and cryptocurrency markets. In the following, we are going to look at the variety of factors that influence both the stock market and the price of Bitcoin. The impact of supply and demand on the pricing of goods and services is a widely recognized phenomenon. This effect extends beyond traditional markets and affects equities as well as emerging digital currencies such as Bitcoin. The limited supply of Bitcoin, capped at 21 million units, combined with an increasing demand, has contributed to the significant rise in its value. This trend has also spilled over to other cryptocurrencies, as investors explore these alternatives for potential investment opportunities.

Between late 2021 and mid-2022, the prices of cryptocurrencies exhibited similar fluctuations to those of equities. The chart below compares the price of Bitcoin (BTC) with that of the S&P 500 (SPX) and the Nasdaq 100 (NDX). The SPX measures the performance of large-cap stocks, while the NDX tracks the performance

of the 100 largest non-financial companies listed on the exchange, many of which are technology-related. From November 2021 to May 2022, the graph shows the price history of SPX, NDX, and BTC, with all three assets experiencing similar ups and downs, albeit with BTC exhibiting considerably greater volatility. This suggests that traders and investors view and treat Bitcoin much like a stock.
It appears that the observed correlation between cryptocurrency prices and equities does not stem from any inherent relationship between Bitcoin and stocks. Rather, investors and traders are inadvertently creating this correlation by trading Bitcoin using the same strategies and methods as the asset classes with which they are most familiar. Traders can't seem to agree whether low volatility is a positive or a negative for Bitcoin. Some traders interpret this as calm before the storm and as "an artificially induced last gasp before the crypto asset embarks on a road to irrelevance." (Bank, 2022). Others see it as a bullish signal for Bitcoin. There are more and more periods where Bitcoin's 30-day volatility was lower than that of the Nasdaq and S&P 500. One example that is shown in the graph was July till October 2022, where Nasdaq's 30-day volatility sits at 2.1%, S&Ps at 1.9% compared to BTCs 1.4%. This could be a sign that Bitcoin's volatility is decreasing or becoming more of a safe asset in times of high volatility in the stock market-which traders saw as stable investment before.

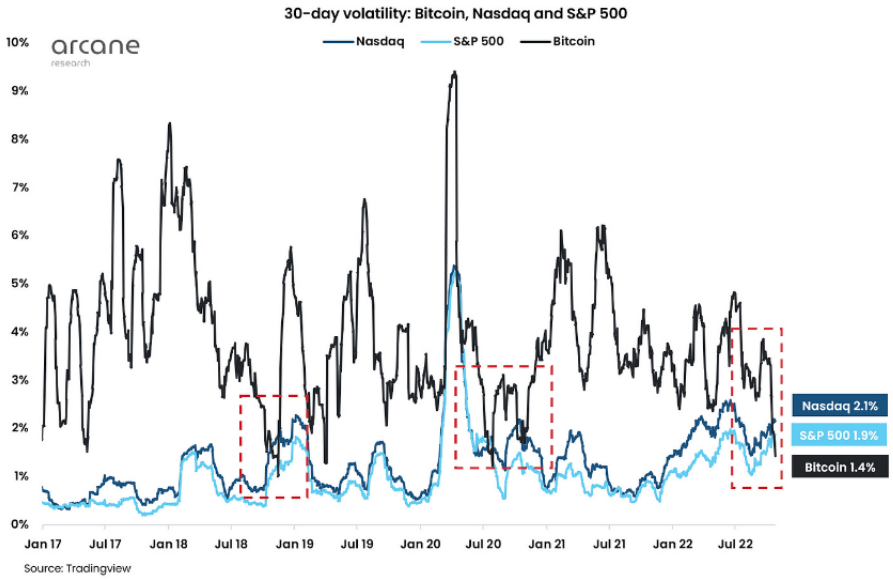

FIGURE 3.4: 30-day volatility: Bitcoin, NASDAQ and S&P 500 (Mellerud, 2022)

3.2.4 Correlation in times of uncertainty

In recent years we've seen periods of high uncertainty in the economy as a

whole and the increasing risk of a financial crisis 2.0. Thus, it will be interesting to look at what happens with the volatility of Bitcoin in these periods. Approximately one year ago, K.Q. Nguyen conducted research that was based on a study carried out by Conlon and MacGee in 2020. The aforementioned study posited that Bitcoin does not serve as a reliable safe haven for securities since it augments portfolio risk during periods of heightened uncertainty (Nguyen, 2022). Nguyen asserts that during uncertain times such as the Covid-19 crisis, the relationship between the stock market and Bitcoin varies. He discovered that during such periods, there is a phenomenon known as the "volatility spillover effect," in which changes in volatility in one asset or market affect the volatility of other assets or markets. This effect is of particular importance in risk management and portfolio diversification. In the case that an investor is exposed to multiple assets or markets that are susceptible to the same volatility spillover effect, their portfolio may become riskier and less diversified than intended (Nguyen, 2022). Finally, Nguyen concluded that the stock market and Bitcoin are more correlated during periods of high uncertainty. His quartile regression analysis found the Covid-19 period was outstandingly uncertain and his conclusions were also to be applied to other periods. Nguyen did not find any effect of the volatility spillover effect from Bitcoin on the stock market. According to him, these findings make sense as cryptocurrency is trivial when compared to the stock market (Nguyen, 2022).
Similar research was already conducted in 2018 by Gandal and al., which also found that the correlation between Bitcoin and the stock market was stronger during periods of high market uncertainty: when Bitcoin prices were highly volatile, the stock market was volatile too. The research from Gandal and al. explains that there is a strong positive correlation between Bitcoin and stock market volatility (Gandal, 2018). Their study focused on daily data of three major stock market indices (S&P 500, NASDAQ, and Dow Jones) collected from January 2013 to September 2017. They used multiple statistical methods to show that there is a strong positive correlation between Bitcoin returns and the VIX. The acronym “VIX” stands for CBOE Volatility Index, commonly known as the “ fear index”. The VIX is calculated by using options prices on the S&P 500 to estimate the expected 30-day volatility of the index. The higher the VIX, the greater the expected volatility, and the higher the level of fear or uncertainty in the market.
During times of high uncertainty, investors may become more risk-averse and seek to diversify their portfolios to reduce their exposure to potential losses. The stock market and Bitcoin may be correlated during periods of high uncertainty because they are both considered alternative investments that investors may turn to as a hedge against traditional assets like currencies or commodities that are perceived as risky or volatile. In addition, both the stock market and Bitcoin may

be influenced by similar factors during periods of high uncertainty, such as economic indicators, political events, and global news events. This can lead to a similar response in both markets, as investors may react in a similar way to these events.

3.2.5 A Bidirectional Relation

The question still lingers as to whether it is the stock market that is truly driving the volatility of cryptocurrencies or if they simply share common factors that move them in tandem. In this section, we aim to address this inquiry by presenting the ongoing discourse within the research.
Even if correlations do not imply a causality rule, Bitcoin may actually have implications for the broader financial system. The study conducted by Gandal et al. in 2018 did not align with the study by Nguyen presented in the previous section. He agreed that fluctuations in the stock market have a significant impact on the volatility of Bitcoin, however, he found a bidirectional causality. Bidirectional causality, also known as reciprocal causation or mutual causation, refers to a situation where two variables or factors have a cause-and-effect relationship that operates in both directions. In other words, each variable not only influences the other but is also influenced by it in a continuous feedback loop. The results are explained by the authors using several hypotheses such as investor sentiment and news events, which show the importance of investors' perception of Bitcoin as a store of value or as a speculative asset. Investors may be heavily influenced by broader market sentiment and confidence, instead of just Bitcoin's value or fluctuations trend.
Similarly, Bouri et al. examined the impact of VIX on Bitcoin volatility. They found that the VIX had a consistent positive correlation on Bitcoin volatility (Bariviera, 2020). This indicates that an increase in the VIX led to an increase in Bitcoin volatility. The authors suggested that this might be because Bitcoin investors consider it a safe haven asset during times of financial instability, which was exactly the same conclusion of Urquhart's study (Urquhart, 2017). Following the two analyses, during periods of high volatility in the stock market, investors may seek alternative investments like Bitcoin, which can lead to increased volatility in the cryptocurrency market and similarly, if there is a significant event in the cryptocurrency market, there may be a cause of fear and uncertainty that could also lead to increased volatility in the stock market (Urquhart, 2017). Therefore, we have a bidirectional relationship according to Gandal et al. and a one sided influence according to Nguyen.

3.2.6 Macroeconomic factors

Dyhrberg examined the impact of macroeconomic factors such as interest rates, inflation, and GDP growth on Bitcoin volatility. The study found that macroeconomic factors have a significant impact on Bitcoin volatility, using a quantitative research design to examine it (Dyhrberg, 2016). Daily data from January 2011 to June 2015 was used to estimate the conditional volatility of these assets and Bitcoin. In order to compute the correlation she used the GARCH (Generalised Autoregressive Conditional Heteroskedasticity) model which we will se in more detail in part 3 of our analysis. Dyhrberg found a weak positive correlation between Bitcoin volatility and stock market volatility, as measured by the VIX index (Dyhrberg, 2016). Specifically, the study found that a one percent increase in the VIX index was associated with a 0.094 percent increase in Bitcoin volatility. However, the correlation was not statistically significant at the 5% level (Dyhrberg, 2016). The study also found no significant correlation between Bitcoin volatility and commodity market volatility, as measured by the S&P GSCI index. Even if Dyhrberg's study opens some doubts about the statistical significance of the positive correlation, we can undoubtedly say that most of the studies analyzed describe a positive correlation (strong positive for some of them) between the volatility of Bitcoin and the volatility of the financial markets. The idea that can be drawn is that everything is closely linked to market sentiment and that it is still too early to be able to affirm a strong correlation with certainty. However, these studies show that the response is increasingly unanimous and gains in strength every day more.

3.2.7 Is Bitcoin the new Gold?

The comparison between Bitcoin and gold is not new, as both assets have been used as a store of value throughout history. Gold has been used as a safe haven asset for centuries due to its scarcity, durability, and value. On the other hand, Bitcoin is a decentralized digital currency that has gained popularity in recent years due to its potential to revolutionize the financial industry and its decentralized nature.

While there are similarities between the two assets, including their use as a store of value, there are also differences. One significant difference is that gold is a physical asset, while Bitcoin is entirely digital. Another difference is that gold has been used as a safe haven asset for centuries, while Bitcoin is a relatively new asset that is still being adopted by mainstream investors. Despite these differences, some argue that Bitcoin has the potential to replace gold as the ultimate store of value due to its decentralized nature, limited supply, and potential to be

used as a currency. Others argue that gold will always be the ultimate store of value due to its physical nature and long history as a safe haven asset.
According to the Dyhrberg study, there is a strong positive correlation between Bitcoin volatility and gold volatility (Dyhrberg, 2016). This means that as gold becomes more volatile, Bitcoin also becomes more volatile. The study found that a one percent increase in gold volatility was associated with a 0.439 percent increase in Bitcoin volatility, and this correlation was statistically significant at the 1% level (Dyhrberg, 2016). Despite this correlation, the study concluded that Bitcoin behaves more like a risky asset than a safe haven asset. In fact, Bitcoin is more closely related to the stock market than to other traditional safe-haven assets like gold. Additionally, the study found a significant negative correlation between Bitcoin volatility and the exchange rate between the US dollar and the euro.
A later study by T. Klein in 2018 contradicted Dyhrberg's results based on data up to December 2017. Klein explains that in the case of gold or silver, if the asset's value goes up today, it will likely have higher volatility tomorrow (Klein, 2018). This is known as an inverse leverage effect, which is a common feature of gold and silver. The study suggests that Bitcoin returns have an asymmetric response to market shocks, similar to precious metals, with an increase in volatility following price increases (Klein, 2018). The study also demonstrates that during market distress, Bitcoin behaves differently from Gold, with Bitcoin showing a positive coupling effect and declining in shock-like situations, while Gold exhibits the flight-to-quality property. The findings confirm that Bitcoin is not a hedge against equity investments, as demonstrated in a portfolio application, but the sample size is limited, and more research is necessary to make a firm conclusion.
The study also suggests that cryptocurrencies will remain highly volatile and exhibit strong movements in both directions, given the uncertainty surrounding their future development (Klein, 2018). The research's findings hold for other cryptocurrencies and a short time period. Therefore, from an econometric perspective, Bitcoin as an asset does not resemble any other conventional asset.

3.2.8 Conclusions

In conclusion we can say that the directions of correlations aren't a consensus in economic research and evolved over time. As Bitcoin's volatility decreases, it tends to exhibit characteristics similar to those of a high-risk tech stock listed on the NASDAQ. When its volatility decreases even further, it starts to resemble a stock that might be found on the S&P 500. Therefore, volatility can be considered

as an indicator of risk, where high volatility suggests a more significant level of risk associated with the investment.
Furthermore, research has revealed that the level of volatility in Bitcoin fluctuates over time. Consequently, during periods of heightened volatility in traditional stock markets, Bitcoin can serve as a secure and stable investment option. However, during times of relative stability in the stock markets, Bitcoin may be viewed as an attractive opportunity for investors seeking high-risk, high-reward investments.

Volatility measurements

In the previous parts of our analysis we have seen numerous academic studies using different statistical methods to reach a conclusion supported by reliable data. Therefore, in this section, we will analyse some of the most common statistical approaches, for clarity and informational purposes.
This section will cover various statistical techniques for measuring volatility, which will be used to analyse Bitcoin's historical volatility.
Volatility refers to a statistical calculation that measures how much a security or market index's returns are spread out over a specific time frame. Generally, when a security is more volatile, it is considered to be riskier. Volatility refers to the level of uncertainty or risk associated with the extent to which an asset's value changes. When a security has higher volatility, its value can potentially vary over a wider range. The percentage change in value over time is used to calculate volatility across different indicators.
As a useful tool for investors, volatility comes in different types, but in this case, we'll be focusing on Historical Volatility (HV), also referred to as statistical volatility, which indicates the fluctuations of underlying securities by measuring price changes over predetermined periods of time. Generally, this measure is calculated by determining the average deviation from the average price of a financial instrument in the given time period.
In addition to the various types of volatility, there are also many methods available to measure it. For the purposes of this discussion, we will concentrate on two particular methods: the standard deviation, as well as the ARCH and GARCH models.

4.1 A Statistical Approach

4.1.1 Standard deviation

Among all asset classes, cryptocurrencies are known for their unparalleled volatility. To measure the extent of this volatility, we can use a statistical tool

called standard deviation. Standard deviation provides us with an idea of how much the returns of an asset, such as cryptocurrency, vary around their average or mean return. A higher standard deviation indicates that the returns are more dispersed in the market, while a lower standard deviation suggests that the returns are more stable.

In this context, volatility measures the distribution of returns from their mean. The definition of volatility used in this part is the historical definition, used to determine the average deviation from the average price over time. The calculation of volatility uses the following formula:

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

The currency price at closing is used (time series of currency prices), the xi is calculated by using the natural logarithm, which is its logarithm to the base of the mathematical constant e (exponential, approximately equal to 2,718281).

$$x_i = ln\left(\frac{P_1}{P_0}\right)$$

P1, P0= closing price in currency chosen (BTC, ETH,..);
xi=return at time i;
n= number of returns;
m= mean return;
s= standard deviation.

In summary, standard deviation is a vital tool for measuring the volatility of cryptocurrencies. Applying this statistical method, investors can gain valuable insights into the potential risks linked with investing in cryptocurrencies, enabling them to make informed investment decisions. We now consider the example of Bitcoin, which stands out as one of the most volatile assets in the recorded history of the financial markets. The cryptocurrency's initial trading years, spanning from 2010 at a nominal value of 0.10 dollars per BTC to 2013 when the price soared to 1,200 dollars, saw extraordinary levels of volatility. Investors in Bitcoin during this period enjoyed an unprecedented return of 130,000%, which translates to an increase in value by a factor of 13,000, realized within a time frame of less than three years.

4.1.2 ARCH model and GARCH model

In econometrics, the AutoRegressive Conditional Heteroskedasticity (ARCH)

is a statistical model used to analyze time-series data that exhibits volatility clustering, or the phenomenon where high volatility is followed by more high volatility and low volatility is followed by more low volatility. This model assumes that the variance of the error term in a regression model varies over time and that the error term in one period is dependent on the error term in previous periods. The ARCH model is commonly used in financial modeling for risk management and forecasting, particularly in the valuation of derivatives, asset pricing, and portfolio optimization. ARCH-type models are sometimes considered to be in the family of stochastic volatility models, although this is strictly incorrect since at times t the volatility is completely pre-determined given previous values. The model can be estimated using maximum likelihood estimation or Bayesian techniques.

An ARCH(q) model can be estimated using ordinary least squares (OLS). This procedure is as follows:
1. Estimate the best fitting autoregressive model AR(q)

$$y_t = a_0 + a_1 y_{t-1} + \ldots + a_q y_{t-q} + \varepsilon_t = a_0 + \sum_{i=1}^{q} a_i y_{t-i} + \varepsilon_t$$

2. Obtain the squares of the error and regress them on a constant and q-lagged values:

$$\hat{\varepsilon}^2 = \hat{\alpha}_0 + \sum_{i=1}^{q} \hat{\alpha}_1 \hat{\varepsilon}^2_{t-i}$$

where q is the length of ARCH lags.

3. The null hypothesis is that, in the absence of ARCH components, we have 0=0 for all i=1, . . . ,q. The alternative hypothesis is that, in the presence of ARCH components, at least one of the estimated 0coefficients must be significant. In a sample of T residuals under the null hypothesis of no ARCH errors, the test statistic T'R2 follows 2 distribution with q degrees of freedom, where T' is the number of equations in the model which fits the residuals vs the lags (T'=T-q). If T'R2 is greater than the Chi-square table value, we reject the null hypothesis and conclude there is an ARCH effect in the autoregressive moving average (ARMA) model. If it is smaller than the Chi-square table value, we do not reject the null hypothesis.

The Generalized Autoregressive Conditional Heteroscedasticity (GARCH) model, developed by Dr. Tim Bollerslev in 1986, is a statistical approach used to estimate

and predict time-varying volatility in financial markets. It models the variance of asset returns as a function of past errors and their conditional variance. The GARCH model considers the presence of heteroscedasticity, which means that the volatility of asset returns changes over time. The GARCH model is widely used in finance and economics for forecasting financial markets' volatility and risk management. With the GARCH model's help, investors can forecast the volatility of asset prices and create better investment strategies that take into account the risk associated with market fluctuations. Since its creation, many variations of GARCH have emerged, such as NGARCH, IGARCH, EGARCH, GARCH-M, QGARCH etc. The variance of the error term in GARCH models is assumed to vary systematically, conditional on the average size of the error terms in previous periods. In other words, it has conditional heteroskedasticity, and the reason for the heteroskedasticity is that the error term is following an autoregressive moving average (ARMA) pattern. This means that it is a function of an average of its own past values. In this case, the GARCH (p,q) model (where p is the order of the GARCH terms δ^2 and q is the order of the ARCH terms ε^2), we have:

$$y_t = x'_t b + \varepsilon_t$$

$$\epsilon_t | \psi_{t-1} \sim \mathcal{N}(0, \sigma_t^2)$$

$$\sigma_t^2 = \omega + \alpha_1 \epsilon_{t-1}^2 + \cdots + \alpha_q \epsilon_{t-q}^2 + \beta_1 \sigma_{t-1}^2 + \cdots + \beta_p \sigma_{t-p}^2 = \omega + \sum_{i=1}^{q} \alpha_i \epsilon_{t-i}^2 + \sum_{i=1}^{p} \beta_i \sigma_{t-i}^2$$

The GARCH model works by modeling the variance of a time series as a function of its own past values, as well as the past values of its own squared errors. Specifically, the model assumes that the variance of the time series at time t depends on the variance at the previous time step, as well as the squared error at the previous time step. Additionally, the model is estimated using maximum likelihood estimation and once estimated, it can be used to forecast future volatility. In financial applications, it has the ability to forecast stock prices and the amount of risk of the assets.

To conclude, the GARCH model has been used by numerous studies, as we have previously mentioned, with the purpose of determining the volatility of Bitcoin during a specific time frame. This leads us to the next and final section, in which we will try to properly identify a trend in Bitcoin's historical volatility, using academic papers to support our analysis.

4.1.3 Historical Volatility of Bitcoin

The historical volatility of Bitcoin has drawn the attention of both investors and academics as a relatively new asset class. The term "historical volatility"

refers to the extent of price fluctuations in an asset over a specific time frame. In this part we will evaluate Bitcoin's historical volatility employing academic articles to strengthen the analysis. From its inception, the price of bitcoin has displayed significant volatility. Bitcoin's price rose from $13 to over $ 1,000 in 2013, only to fall down to $ 200 in the months that followed (CoinDesk, n.d.). Early in 2021, Bitcoin's market capitalization exceeded $ 1 trillion, although it has also historically undergone large price drops (CoinDesk, n.d.). The purpose of our analysis is to demonstrate how Bitcoin's volatility started a decreasing trend in the last few years, supporting our statements with verified datas. In part 2.2 we arrived at the conclusion that Bitcoin's volatility is affected by various determinants such as market sentiment and volatility : A relatively recent study conducted by Urquhart and Zhang used a variety of econometric methods to examine the volatility persistence of Bitcoin (Urquhart, 2017). Based on their study, Bitcoin's price shocks have a considerable long-lasting effect. In addition, the authors discovered that the volatility of Bitcoin is asymmetrical, with negative shocks having a greater impact on volatility than positive shocks. The study then comes to the conclusion that market inefficiencies, including information asymmetry and market manipulation have an impact, as we previously said, on Bitcoin's volatility. Our previous analyses have investigated the determinants of Bitcoin's volatility and the possible market fluctuations it could trigger, in this section we propose three articles ,having the volatility of Bitcoin as their main subject, with the only purpose of seeing how the trend of the same volatility is changing throughout the years. We'll start proposing a study conducted by Yermack , who used daily returns data from January 2011 to October 2014 to examine the volatility of Bitcoin. With an average daily return volatility of 5.61%, the study indicated that Bitcoin's volatility was much higher than that of other currencies and gold (Yermack, 2015). The study also found that as the market grew more established and liquid, Bitcoin's volatility gradually dropped. Katsiampa conducted another study, using daily returns data from July 2010 to May 2017 to assess the volatility of Bitcoin (Katsiampa, 2017). Despite an increase in trading volume and liquidity, the study indicated that Bitcoin's volatility was extremely persistent and had not lessened over time. The analysis also discovered that Bitcoin's volatility was far higher than the one of gold and other major currencies. Moreover, a research by Bariviera et al. used data from January 2011 to June 2017 to analyse, once again, the volatility of Bitcoin. With an average daily return volatility of 3.74%, the study indicated that Bitcoin's volatility have been declining over time (Bariviera, 2020). Nevertheless, the analysis also discovered that Bitcoin's volatility was still greater than that of other major currencies and gold. Still, the fact that the gap has narrowed over time, is very promising.

Conclusion

In conclusion, this thesis has covered a broad range of aspects related to cryptocurrency volatility and its impact on various types of investors. While our analysis has focused on Bitcoin as a central player due to its history and market capitalization, our findings have broader implications for the cryptocurrency market as a whole. Through the analysis of multiple papers we showed that there is a decreasing trend in the volatility of Bitcoin, indicating a greater level of stability, which can be attributed to various factors such as increasing market cap and growing awareness and adoption of cryptocurrency.
We have also highlighted the significance of understanding and mitigating the risks associated with investing in cryptocurrencies. One of the biggest challenges in adoption remains security concerns, such as the threat of potential attacks, hacks of exchanges and wallets, and regulatory environments. The safest way to store and hold cryptocurrency is thus on a hardware wallet.
Furthermore, we have provided valuable insights into the relationship between CBDCs and cryptocurrencies and their impact on financial services. CBDCs have demonstrated that digital currency is no longer a subject of speculation, and their potential impact on financial services may be realised in the future.
We have also discussed the impact of social and environmental factors on the volatility of cryptocurrencies. Social factors such as media coverage, government regulations, public sentiment, and mainstream business adoption play a crucial role in shaping the behaviour of individuals and organisations in relation to cryptocurrencies. On the other hand, environmental factors such as energy consumption and climate change can also impact the demand, supply, and profitability of cryptocurrencies, leading to increased volatility. It is essential to consider these factors when investing or regulating the cryptocurrency market.
The environmental impact of cryptocurrencies is also a significant issue that needs to be addressed. The choice of consensus algorithm in blockchain technology can have a significant impact on the environment, with PoS offering a more energy-efficient and environmentally friendly alternative to PoW.
Finally, we have emphasised the importance of technological improvements such

as Segwit and the Lightning Network in reducing Bitcoin's volatility. These improvements demonstrate that technological factors have a direct effect on Bitcoin's volatility and should be taken into serious consideration when studying it. Overall, our thesis provides valuable insights into the cryptocurrency market and underscores the significance of understanding and mitigating the risks associated with investing in cryptocurrencies. While Bitcoin's volatility may still be higher than that of traditional assets, the trend suggests that it is becoming more stable over time. This could make it a more attractive investment option for those seeking a store of value or a hedge against inflation.

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Declaration of Originality

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We hereby declare that this thesis represents our original work and that we have used no other sources except as noted by citations.
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Paris, May 13, 2023

Silvio Massimo Baldan, Anna Bock, Gaia Ferrero Regis and Nam Khanh Nguyen