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Review

Tracing Knowledge Diffusion Trajectories in Scholarly Bitcoin Research: Co-Word and Main Path Analyses

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Abstract: In the burgeoning field of bitcoin research, a cohesive understanding of how knowledge and insights have evolved over time is lacking. This study aims to address this gap through an exploration of 4123 academic articles pertaining to bitcoin. Utilizing co-word analysis and main path analysis (MPA), it uncovers key themes and seminal works that have substantially influenced the field's progression. The identified clusters, including safe haven, internet of things (IoT), proof of work (PoW), market efficiency, sentiment analysis, digital currency, and privacy, shed light on the multifaceted discourse surrounding bitcoin. The MPA, incorporating both forward and backward local paths, traces an evolving narrative, starting from an in-depth exploration of bitcoin's structure, anonymity, and contrasts against traditional financial assets. It tracks the shift in focus to broader market dynamics, volatility, speculative nature, and reactions to economic policy fluctuations. The analysis underscores the transformation of bitcoin research, from its beginnings as a decentralized, privacy-oriented currency to its role in global economics and green financing, revealing a complex narrative of an innovative financial instrument to a multifaceted entity. Implications drawn from this analysis include the need for further research on the potential integration of bitcoin within emerging technologies like AI and cybersecurity, the implications of bitcoin's interplay with traditional financial systems, and the environmental impacts of bitcoin and blockchain utilization. Overall, the current study not only enhances our understanding of the bitcoin field but also charts its dynamic evolution and stimulates further academic inquiry.

Keywords: bitcoin; safe haven; internet of things; privacy; digital currency; main path analysis

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1. Introduction

Cryptocurrencies have steadily risen in prominence and become a central feature of the global financial landscape (Abakah et al. 2022; Albrecht et al. 2019; Ammous 2018). These digital assets encapsulate a revolution in the way transactions are conducted, challenging traditional monetary systems and the intermediaries involved. The importance of cryptocurrencies cannot be overstated in the context of the 21st century digital economy because they provide opportunities for real-time global transactions, enhanced security measures, and, most intriguingly, decentralization of control (Ahluwalia et al. 2020).

As the world's first cryptocurrency, bitcoin has been at the forefront of the digital revolution in the financial sector (Agrawal et al. 2023; Akyildirim et al. 2020). This decentralized digital currency has not only survived but thrived, becoming a global phenomenon. Today, bitcoin stands as the most recognized and highest-valued cryptocurrency in the world, with a market capitalization exceeding USD 500 billion as of 2023, asserting its enormous impact on the financial landscape (Blockworks 2023). Its peak value of over USD 60,000 per bitcoin in 2021 further underlines bitcoin's importance as a financial asset (Coinbase 2023).

In the realm of academic research, the relevance of bitcoin is even more pronounced. As of July 2023, a Google Scholar search using the title keyword "bitcoin" yielded approximately 43,300 results, showcasing the prolific academic interest in this area. Furthermore, the original bitcoin article has garnered over 28,000 citations in the same year (Nakamoto 2008), clearly illustrating the profound impact and far-reaching implications of bitcoin within the scholarly community.

According to Abdeldayem and Aldulaimi (2020), bitcoin has charted new territory and laid the groundwork for the many digital currencies that have followed. Since its creation in 2008 by the pseudonymous entity Satoshi Nakamoto, bitcoin has not merely survived but thrived (Aggarwal 2019). Today, bitcoin represents the most widely recognized and highly valued cryptocurrency in the world. At its core, bitcoin is a decentralized digital currency that operates without the need for a central authority (Al Mamun et al. 2020). As a result, this constitutes a fundamental departure from traditional currencies issued and regulated by central banks. The decentralization feature of bitcoin enables the shift of control from a single institution to a distributed network of participants (Appukuttan Nair 2019). It aligns with the principles of self-sovereignty and personal autonomy, which are gaining more traction in the digital era.

Transactions with bitcoin are facilitated through a peer-to-peer (P2P) network (Rejeb et al. 2021). Unlike traditional payment systems, where transactions are routed through a central intermediary, the P2P nature of bitcoin allows for direct transfers between parties (Aljabr et al. 2019). This results in lower transaction fees, faster processing times, and a degree of anonymity for users (Andola et al. 2021). The advent of bitcoin has had a substantial impact on the FinTech industry, inspiring the creation of various P2P payment platforms (Andolfatto and Martin 2022). A unique feature of bitcoin is the manner in which transactions are verified. Computers participating in the bitcoin network use cryptography to confirm transactions (Rejeb et al. 2021). This cryptographic verification ensures the security and integrity of bitcoin transactions, making them resistant to fraud and double-spending.

Bitcoin functions as digital cash and facilitates peer-to-peer transactions without necessitating a central authority such as a bank or government. This characteristic of bitcoin affords a degree of autonomy and freedom in personal financial management, which is a concept not plausible with traditional currencies (Silva Ramalho and Igreja Matos 2021). For example, individuals in developing countries who are underbanked or unbanked can now participate in digital transactions and engage in financial activities that were once inaccessible (Cunha et al. 2021). Moreover, bitcoin has assumed a crucial role in international remittances, an area traditionally dominated by financial institutions notorious for high fees and extended processing times. With its global recognition, bitcoin enables the rapid, economical transfer of funds across borders. This development holds significant implications for migrant workers who often depend on remittances to financially support their families back home (Ammous 2015). In addition, bitcoin has surfaced as a novel asset class for investment (Anamika and Subramaniam 2023). Its finite supply, juxtaposed with rising demand, has induced dramatic increases in its value, garnering it the moniker 'digital gold' (Al-Khazali et al. 2018). Some investors perceive bitcoin as a protective hedge against inflation, similar to the historical use of gold (Almeida and Gonçalves 2023b). Nevertheless, it is crucial to underscore that bitcoin's price exhibits high volatility, thus implicating potential risks in its investment (Rejeb et al. 2021). Consequently, bitcoin transcends its identity as merely a digital currency. It heralds new paradigms for executing transactions, transmitting value, and managing data, thereby becoming an indispensable component in the continuously evolving digital ecosystem.

Given bitcoin's growing importance, academic research on the subject is booming. There are a plethora of review papers examining various aspects of bitcoin, from its economic implications to the technological innovations it has spurred. For example, Aysan et al. (2021) provide a comprehensive overview of bitcoin's research evolution over a decade by evaluating 4495 documents from various perspectives. The study of Merediz-Solà and Bariviera (2019) narrows down its focus to bitcoin alone, analyzing 1162 papers to

discern research clusters, emerging topics, and leading scholars across diverse disciplines. Moreover, Chatterjee et al. (2018) delve into the technological challenges and innovations associated with bitcoin, providing insights into its potential and limitations. Manimuthu et al. (2019) examine the transformation of bitcoin and its potential impact on global financial transactions, highlighting the implications and challenges for both users and the business community. Finally, Orastean et al. (2019) offer an evaluation of bitcoin literature based on the structures and networks of science, analyzing 887 documents published between 2012 and 2019 to identify patterns and trends in academic research in this field.

Despite the profound insights provided by these reviews, they fall short of thoroughly probing the intricate web of relationships among pivotal themes and topics within bitcoin research. They offer isolated perspectives on various aspects of bitcoin, such as its technological attributes, economic implications, and societal impact. However, the lack of analysis of how these elements interconnect and influence each other presents a critical gap in our comprehensive understanding of the subject matter. Our study aims to bridge this gap by employing co-word and main path analyses, which represent innovative methodologies rarely used in existing reviews. Co-word analysis is a potent tool in bibliometrics that allows researchers to identify the co-occurrence of keywords within the body of literature (Rejeb et al. 2020), thereby unveiling the thematic structures and their evolution over time. It will enable us to discern what topics frequently appear together, hinting at potential areas of correlation or causation that warrant further investigation. Simultaneously, the main path analysis (MPA) will map the trajectory of the research field's development. By identifying the 'main paths' or most influential strands of research, researchers can understand the historical flow of ideas and concepts that have shaped the discourse on bitcoin.

As a result of this dual-method approach, the study uncovers key findings that demonstrate the progression of bitcoin research through various thematic clusters. These include safe haven, internet of things (IoT), proof of work (PoW), market efficiency, sentiment analysis, digital currency, and privacy. Each cluster illuminates different facets of the discourse surrounding bitcoin and marks significant waypoints in the field's evolution. The findings from MPA demonstrate a complex and evolving narrative of bitcoin research. Early works challenged established ideas, while later studies delved into portfolio management, risk hedging, and price discovery dynamics. Additionally, MPA revealed the impact of external events such as the COVID-19 pandemic on bitcoin's role as a safe haven and its interplay with global economies. The current study further suggests several fruitful areas for future research. Future studies could delve into topics such as the potential integration of bitcoin within emerging financial ecosystems, the interplay between bitcoin, artificial intelligence, and cybersecurity, and the environmental implications of bitcoin and blockchain utilization.

Therefore, this study not only provides a synthesis of current bitcoin research but also outlines potential future directions, which could involve an in-depth analysis of bitcoin's role as a safe haven asset, an examination of privacy and trust issues within the bitcoin ecosystem, research into the potential role of bitcoin and blockchain technologies in promoting sustainable development, and an expansion of research on the market dynamics of bitcoin and other cryptocurrencies. These findings hold considerable significance, not only in enhancing our understanding of the bitcoin field but also in mapping its dynamic evolution. By identifying pivotal contributions and illuminating intricate pathways of knowledge diffusion within the bitcoin research field, this study extends beyond traditional review methodologies and contributes meaningful new insights to the existing body of literature.

2. Methodology

2.1. Data Collection

For this study, the Scopus database was chosen as the primary data source due to its recognized status and acceptance within the scholarly community. Scopus is hailed for its comprehensive coverage, high-quality data, and wide-ranging, influential journal listing, making it an optimal choice for research endeavors such as MPA and bibliometric studies

(Rejeb et al. 2022b; Sweileh 2018). The process followed in our review is demonstrated in Figure 1.

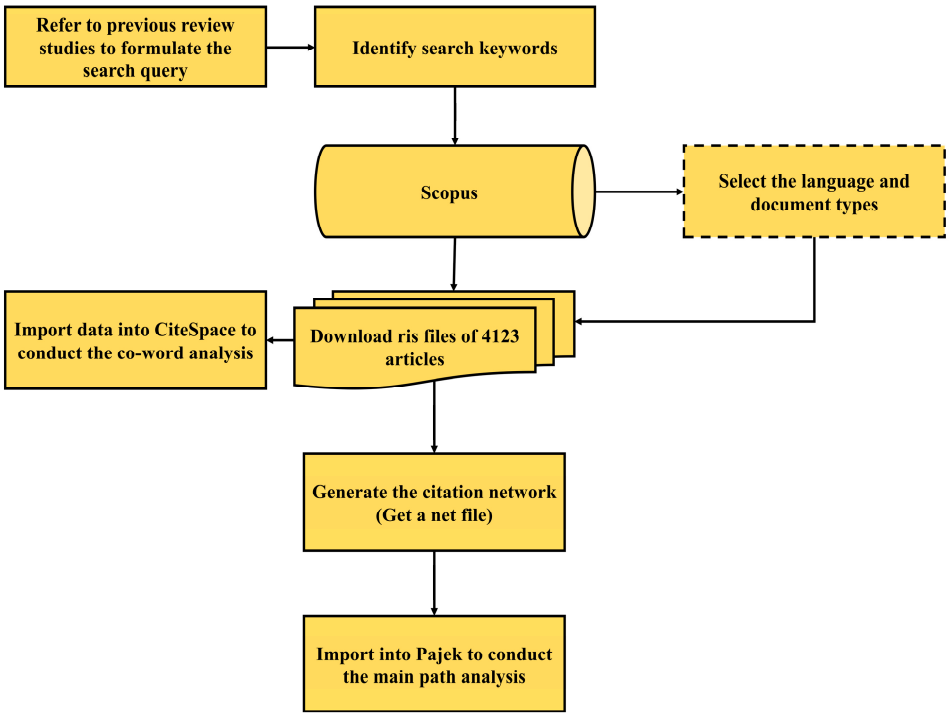

Figure 1. Review process.

The search protocol applied in this research consisted of the following parameters: Topic Search (TS) = (bitcoin). This review was undertaken using data obtained from the Scopus database, spanning from 2008, the inception of Bitcoin, to 2023. Data extraction was performed in April 2023. Only English-language journal articles were included in the final analysis. To ensure the reliability and accuracy of our work, the search string used to source the publications is provided in Appendix A. Post data collection, a manual examination of all article metadata was conducted to exclude publications that did not align with our research focus. This led to a final tally of 4123 relevant documents extracted from the database. These documents served as the foundation for the creation of a citation network. To perform the network analysis and visualization, we employed the Pajek software package. The choice of Pajek was motivated by several factors. First, its robust capacity to handle large datasets, which was crucial given the extensive number of articles we analyzed (Rejeb et al. 2023a). Second, Pajek's extensive features offer a comprehensive toolkit for network analysis, including various measures of network centrality and clustering algorithms. Finally, Pajek has been widely used and validated in the field of bibliometric studies, lending credibility to our analysis (Rejeb et al. 2022b; Yu and Sheng 2020).

2.2. Research Approach

CiteSpace 6.16 is a pioneering software tool employed in scientometric investigations to facilitate the unraveling of scholarly trajectories via co-word analysis (Mokhtarpour and Khasseh 2021). This method illuminates latent thematic structures and emerging tendencies throughout a corpus of scientific literature, elucidating the development of academic fields. The usage of co-word analysis has been widespread across numerous disciplines (Chen et al. 2016), predicated on the belief that chosen keywords effectively depict and encapsulate the primary substance of scientific papers. Consistent with earlier works (Jia and Harji 2023; Rejeb et al. 2023c), we applied co-word analysis to delve deeper into the research landscape pertaining to the knowledge domain of bitcoin.

Chen et al. (2019) underscore the prevalence of citation-based evaluations, such as bibliographic coupling analysis, co-citation analysis, and MPA, in outlining the intellectual structure and progression trajectories of a domain through the information embedded within citations. Typically, bibliographic coupling analysis examines the shared intellectual lineage of publications by investigating the common references amongst them. This technique postulates that a higher count of mutual references indicates a stronger shared scholarly foundation (Petrolo et al. 2023). On the other hand, co-citation analysis explores the dynamism, configuration, and paradigmatic transitions in a knowledge domain by analyzing the co-cited works and identifying the coherence of references and notions specific to the research field (Rejeb et al. 2022a). Papers with elevated co-citation frequency within a co-citation network underline widely explored notions and ideas within a specific scholarly field. To delineate the knowledge transmission among articles, Hummon and Dereian (Hummon and Dereian 1989) introduce MPA as a methodology reliant on direct citation relationships. MPA's effectiveness has facilitated its application in social network analysis and conflict resolution studies (Carley et al. 1993; Hummon and Carley 1993). Subsequently, Batagelj (2003) initiates the Search Path Count algorithm (SPC), and Liu and Lu (2012) propose various enhancements, including the key-route main path. Present main path methodologies encompass local main paths (forward and backward) and global main paths. In essence, the local main path aligns with the most frequently co-cited papers within a specific group, while the global main path aligns with the most highly cited papers across the entire network. Through scrutinizing these main paths, investigators can garner an understanding of the most impactful notions and concepts within a specific research arena (Rejeb et al. 2022c). In the present investigation, a citation network technique (Liu and Lu 2012) is utilized to devise the main path and allocate weights to the citation network.

Figure 2 serves as a visual representation of our method, illustrating a citation network composed of nodes and arrows, which signify academic articles and the circulation of intellectual material, respectively. This network consists of three distinct types of nodes: source nodes (depicted in blue), intermediate nodes (displayed in red), and sink nodes (indicated in green). Source nodes are only cited by others, sink nodes solely cite others, while intermediate nodes both cite and are cited. The SPC for each connection is determined by counting the frequency of the link's use in paths from source nodes to sink nodes. For example, the link H-K possesses an SPC of 4 as four unique paths traverse it, specifically A-H-K-M, A-D-F-H-K-M, A-D-C-F-H-K-M, and A-C-F-H-K-M. Upon attributing weights to each link in the citation network, subsequent steps involve algorithms for formulating main paths. The forward local main path initiates from sources and concludes at sinks, selecting the link from each node with the highest SPC. This generates a path encompassing several nodes, such as A-D-C-F-H-G-L-N, A-D-F-H-G-L-K-M, and A-D-F-H-G-L-M. Inversely, the backward local main path starts from sink nodes and progresses toward source nodes, opting for links with the highest SPC. This strategy also forms a distinct path like A-D-C-F-E-G-L-K-M and A-C-F-E-G-L-K-M. While local paths emphasize maximum values within smaller regions, the global main path uncovers the path with the top cumulative SPC value. Therefore, the global main path is identified as the one with the utmost overall SPC value, in this scenario, A-D-C-F-H-G-L-K-M. Nevertheless, these paths may not encompass all high-SPC links. To rectify this, the key-route main path method is suggested (Liu and Lu 2012). It initiates with the highest-SPC link as the main route and carries out searches from this route to source and sink nodes. This process can generate several paths with high SPC values, offering a granular understanding of the citation network. Collectively, local (forward and backward), global, and key-route main path analyses provide a holistic overview of the developmental trajectories within a research field. They assist in comprehending the evolution of research and pinpointing pivotal contributions across time.

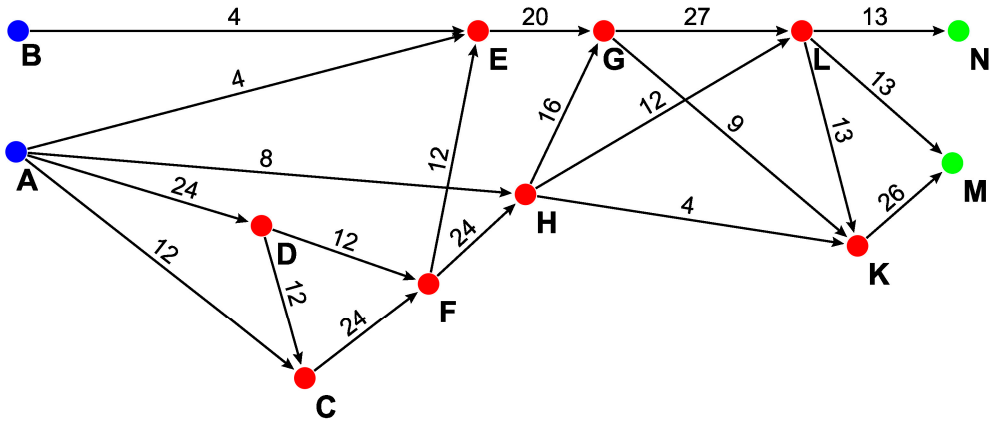

Figure 2. Exemplary citation network.

3. Findings from Co-Word Analysis

Keywords provide a concise overview of the content of research papers, and their analysis can assist in pinpointing the nascent research frontiers and popular topics within a discipline (Rejeb et al. 2020). In this investigation, we employ CiteSpace to examine the thematic progression of the bitcoin research domain (Chen 2006). The g-index is utilized as the criterion for visualizing keywords, resulting in a final network encompassing 713 nodes and 1615 links. The scaling factor 'k' plays a significant role in determining the granularity of the network analysis, impacting the size and detail of the resulting network visualization. In our study, we chose a value of 25 for 'k'. This choice was guided by prior research and our objective of striking a balance between detail and comprehensibility (Yu and Sheng 2021). Using CiteSpace's cluster function, we then established a cluster with a modularity value of 0.603. The high silhouette value, a measure for evaluating the quality of cluster analysis, is reported to be 0.80, thereby validating the reliability and coherence of the results. The labels for the clusters are produced using Latent Semantic Indexing (LSI) (Shen and Ho 2020), and the specifics of each cluster are detailed in Table 1.

In Figure 3, the timeline map presents a visual representation of the clusters' temporal trajectories, and it is clear that the largest cluster, labeled as Cluster #0, relates to 'safe haven'. This result indicates that the overlap between bitcoin and the safe haven concept has emerged as a significant focus within the bitcoin literature (Barbu et al. 2022; Barson et al. 2022). The idea of a safe haven, including factors such as gold, hedging, volatility spillover, and diversification, has become intricately intertwined with the broader bitcoin discourse as the need for financial security and hedging against traditional markets underlines the value of innovative financial instruments like bitcoin (Ammous 2015). Cluster #1, termed 'internet of things (IoT)', encapsulates a fascinating range of concepts, mainly highlighting the core facets of bitcoin—the intersection of finance, cryptography, and technology (Bhushan et al. 2021). The involvement with emerging technologies, whether through AI, cybersecurity, or payment systems, is a crucial factor in this context. Moreover, this cluster provides a unique aspect of the bitcoin conversation and offers insights into the complex dynamics and challenges intrinsic to bitcoin. The focus on trust reflects a fundamental issue in the bitcoin domain, which aims to establish and maintain trust in a decentralized, cryptographic system (Ali et al. 2023; Arli et al. 2021). The research represented by this cluster explores various facets of trust, with a specific emphasis on trust in the context of cryptocurrency markets, herding behavior, and the overall financial landscape (Ajaz and Kumar 2018; Almeida and Gonçalves 2022).

Table 1. Co-word clusters.

Cluster ID	Size	Silhouette	Mean (Year)	Label (LSI)	High-Frequency Keywords
0	100	0.785	2020	safe haven	COVID-19; gold; safe haven; hedge; EPU; cryptocurrency market; hedging; volatility spillover; granger causality; diversification
1	65	0.754	2017	internet of things	IoT; money; AI; cryptography; cybersecurity; trust; finance; herding; payment system
2	64	0.772	2019	proof of work	PoW; consensus; scalability; decentralization; consensus protocol; P2P network; consensus algorithm; proof of stake; hyperledger fabric; transaction; authentication
3	62	0.83	2019	market efficiency	LSTM; market efficiency; deep learning; ANN; bitcoin price; prediction; efficient market hypothesis; bitcoin future; price discovery; hurst exponent
4	55	0.703	2020	sentiment analysis	machine learning; sentiment analysis; VAR; twitter; liquidity; bibliometric analysis; anomaly detection; random forest; data mining; social media
5	53	0.76	2019	digital currency	digital currency; FinTech; financial market; altcoin; selfish mining; energy consumption; sustainability; contagion; industry 4.0; event study
6	52	0.824	2017	privacy	privacy; forecasting; anonymity; ICO; mining; lightning network; ransomware; PCN; de-anonymization; blockchain security

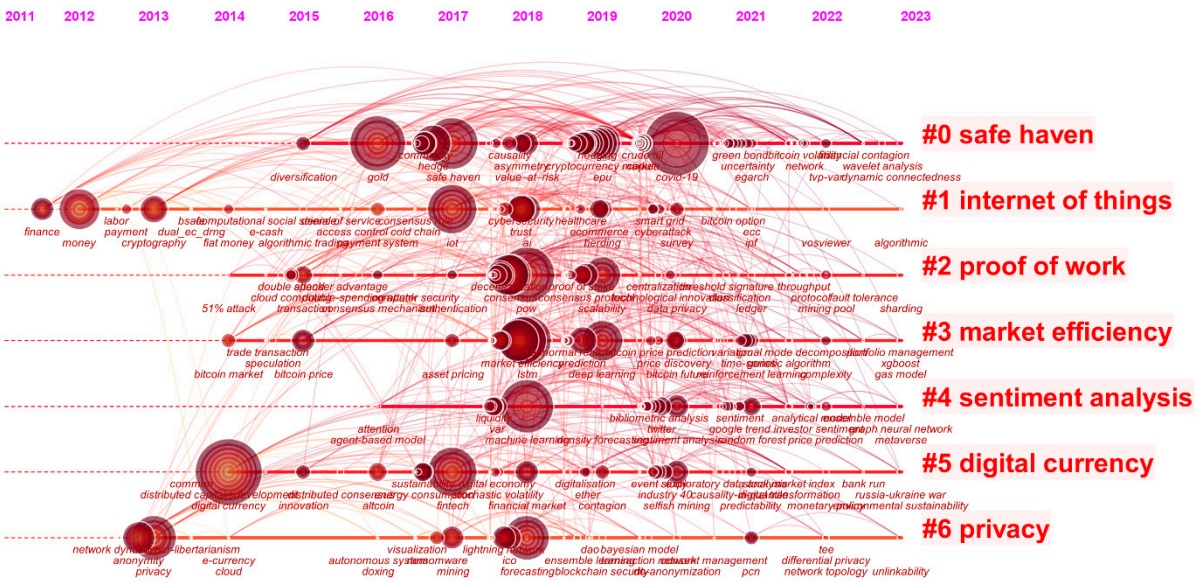

Figure 3. Co-word clusters.

Cluster #2 in bitcoin research revolves around 'proof of work' (PoW). This sphere of study illuminates the intricate dynamics associated with the PoW protocol, which is a cornerstone of bitcoin and similar cryptocurrencies (Bala and Manoharan 2020). It stresses the pivotal role of achieving and maintaining consensus within a decentralized network, encapsulating various facets of consensus protocols. Notable topics within this cluster include scalability, decentralization, and authentication, and each offers unique insights into the complex workings of PoW systems. Moving on, Cluster #3, termed 'market

efficiency', unravels a niche of study focused on the performance and predictability of the bitcoin market. The exploration within this cluster leverages advanced techniques like deep learning and Long Short-Term Memory (LSTM) networks to predict bitcoin prices (Al-Nefaie and Aldhyani 2022; Jakubik et al. 2023). Researchers in this realm touch on the efficient market hypothesis, price discovery, and future trends, forming a comprehensive picture of market efficiency in the context of bitcoin.

Cluster #4, 'sentiment analysis', underscores the practical use of machine learning and data mining for understanding the public's sentiment towards bitcoin. This cluster takes us into a world where social media platforms like Twitter become the pulse of cryptocurrency markets, reflecting public sentiment and its impacts on liquidity and market anomalies (Almeida and Gonçalves 2022). On the other hand, Cluster #5, defined as 'digital currency', presents an intriguing cross-section of bitcoin within the wider scope of FinTech and sustainability. This cluster navigates through topics like 'altcoin', 'selfish mining', 'energy consumption', and 'Industry 4.0' (Akgul et al. 2022; Chicarino et al. 2020; Corbet et al. 2020b). It is a fascinating exploration that connects bitcoin with broader digital economy trends and sustainability concerns, forming a comprehensive understanding of bitcoin's role and implications in the global financial ecosystem. Finally, Cluster #6, centered on 'privacy', delves into the intellectual labyrinth of privacy issues within the bitcoin ecosystem. It accentuates the importance and implications of maintaining privacy and anonymity in cryptocurrency transactions (Ansah and Adu-Gyamfi 2020; Conti et al. 2018). From exploring 'blockchain security' to 'ICO', this cluster illustrates an ongoing discourse on how privacy considerations shape the landscape of the cryptocurrency world. As a result, Cluster #6 is a rich tapestry that underscores the significance of privacy within the ever-evolving cryptocurrency ecosystem.

4. Findings from Main Path Analysis

This portion of the analysis undertakes a multi-dimensional investigation of the main channels in the network, incorporating local (both local and forward), global, and key-route perspectives. Each node in the path traditionally denotes a scholarly article labeled with the primary author's name and the publication year. The direction of the arrow signifies the course of knowledge transmission, and its thickness indicates the volume of this transmission. The entire citation network, shown in Figure 4, is assembled from the chosen articles for this study. This network incorporates 4123 nodes and 34,336 links. The first cluster of nodes in this figure includes the 3587 nodes that shape the largest weakly connected component. This sizable subnetwork captures the most important citation links among articles, thus constituting the main channels being examined. The second cluster includes nodes with fewer citations and is connected to only a small number of articles within the network. These nodes are mostly found on the periphery of the network. Lastly, the third group of nodes are those that are completely separate from the rest of the network, indicating their relative isolation within the overall structure.

4.1. Local Main Path

Both the local forward and the backward local main paths contain significant articles, with 23 and 26 papers, respectively, though they share only one article in common. This suggests a vibrant and diverse range of research areas within the field, with each path representing a different direction of academic exploration.

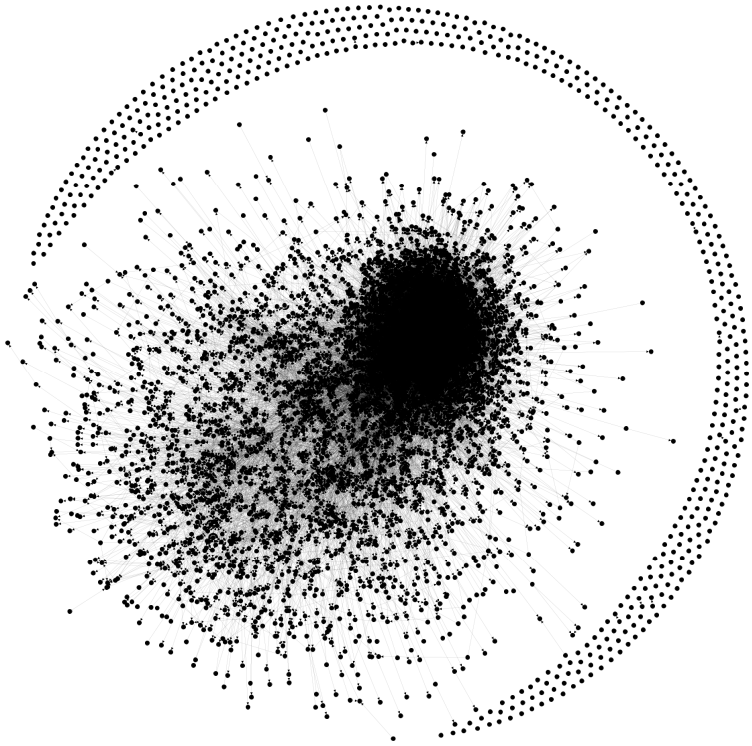

Figure 4. The entire citation network of bitcoin research.

4.1.1. Forward Local Main Path

In the forward local main path (see Figure 5), Ober et al.'s (2013) paper examines the structure and anonymity of the bitcoin transaction graph. Through a detailed analysis, the study reveals the balance between parameters that amplify and those that decrease anonymity in the network, indicating certain variables in the transaction graph have stabilized over a given period. Subsequently, Böhme et al. (2015) provide a comprehensive insight into the multifaceted world of bitcoin, incorporating aspects of economics, technology, and governance. The study underscores bitcoin's unique design elements that offer increased flexibility and privacy, in addition to posing less susceptibility to regulatory oversight. Dyhrberg's study (Dyhrberg 2016) in 2016 explores the financial asset capabilities of bitcoin through the use of GARCH models. The research parallels bitcoin with gold and the dollar, highlighting bitcoin's hedging capabilities and advantages as a medium of exchange. The first paper by Urquhart in 2016 (Urquhart 2016) delves into the market efficiency of bitcoin. Findings from this study reveal bitcoin's market inefficiency over the full sample, although some level of efficiency is seen in a later period. Katsiampa (2017) provides a comparison of GARCH models for estimating bitcoin's volatility. The research identifies the AR-CGARCH model as the most fitting due to its consideration of both short-run and long-run components of conditional variance. In another 2017 paper, Urquhart (2017) explores price clustering in bitcoin. The study notes significant evidence of clustering at round numbers and a positive correlation between price and volume at these points. Despite the observed clustering, there was no discernible pattern of returns after reaching round numbers. Each of these papers represents a unique and valuable contribution to our understanding of bitcoin, from its structure and use to its market efficiency and price volatility.

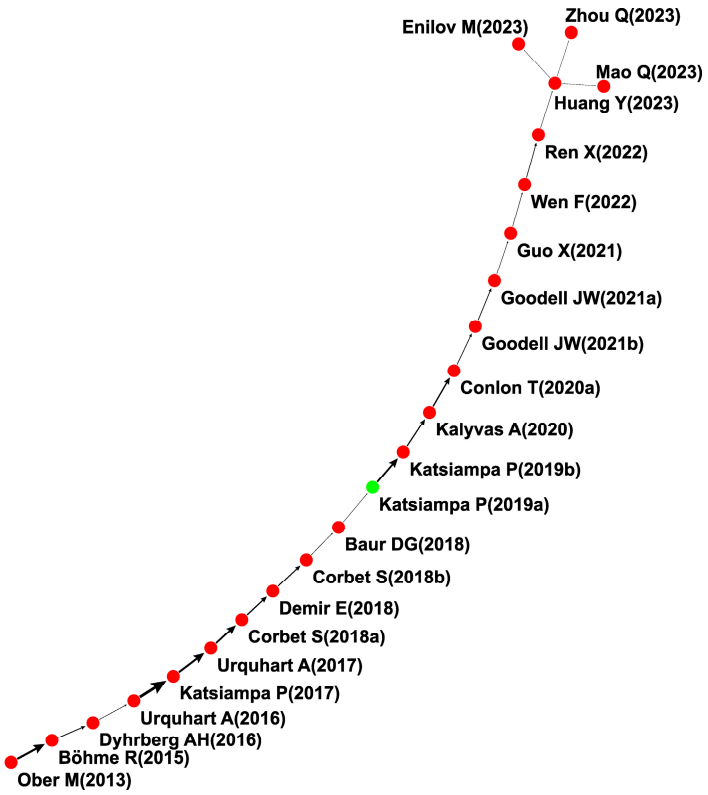

Figure 5. Forward local main path.

The forward local main path in the research field embraces an intriguing exploration of the volatility and market dynamics of cryptocurrencies. For instance, Corbet et al. (2018b) make a pivotal revelation about the bubble-like behavior in bitcoin and Ethereum, pointing towards an inherent instability. Simultaneously, Corbet et al. (2018c) delve into the world of bitcoin futures, asserting that despite their introduction, bitcoin continues to dwell in the realm of speculative assets rather than embracing the stability of a currency. Building upon the volatility narrative, Demir et al. (2018) take a unique angle by bringing economic policy uncertainty into the picture. The research elucidates that bitcoin returns are influenced by this uncertainty in a nuanced manner, painting bitcoin as a potential refuge in uncertain economic times. Lastly, Baur and Dimpfl (2018) broaden the horizon by examining the asymmetric volatility of the top 20 cryptocurrencies. The findings reveal an atypical pattern where positive shocks cause more turbulence than negative ones, hinting at the emotional trading behavior driven by the "fear of missing out". The tapestry of these studies narrates a tale of a dynamic cryptocurrency market characterized by volatility, influenced by external factors like economic policy, and steered by the trading behaviors of its participants.

As we delve deeper into the local main path, Katsiampa's studies in 2019 sit as a fulcrum, providing pivotal insights into the interplay of volatility among leading cryptocurrencies. The first study (Katsiampa et al. 2019b) establishes a nuanced understanding of volatility dynamics and shock transmission between bitcoin, Ether, and Litecoin. The second study (Katsiampa et al. 2019a), broadening the focus to eight cryptocurrencies, delineates their volatility co-movements and the significant asymmetric effects of positive and negative shocks in conditional volatility. This narrative of volatility and interlinkages smoothly leads us to the exploration of bitcoin's price crash risk, as examined by Kalyvas et al. (2020). The study asserts that bitcoin could potentially act as a hedge against economic uncertainty, intertwining behavioral factors and bitcoin crash risk in an intricate dance. Following this thread, the research progresses into the era of COVID-19, which represents a tumultuous period that tested bitcoin's character as an asset. In this regard, Conlon and McGee (2020) inject a dose of realism, arguing that bitcoin did not demonstrate the

much-hyped safe haven properties during the COVID-19 bear market. Simultaneously, Goodell and Goutte (2021) explore the co-movement of bitcoin prices with COVID-19 world deaths and other equity indices. The studies show how bitcoin's correlation with traditional markets intensified as the pandemic unfolded, challenging the notion of cryptocurrencies as a diversification benefit during downturns. Complementing this, Guo et al. (2021) provide empirical evidence of increased contagion between bitcoin and developed markets during the COVID-19 crisis. The authors suggest that bitcoin's safe haven, hedge, and diversification properties may wane during market turmoil. This viewpoint is further supported by the research of Wen et al. (2022), which positions gold as a more reliable safe haven than bitcoin during the pandemic. Ren et al. (2022) introduce another angle by comparing bitcoin's role as a shelter against oil market crashes with that of gold, especially during the heightened severity of the COVID-19 pandemic. The findings hint at a dynamic and asymmetric relationship between bitcoin, gold, and oil markets, further complexifying our understanding of bitcoin's performance in volatile times.

As the body of research progresses from Huang et al. (2023), the academic discourse diverges into three distinct yet interconnected areas. Huang et al.'s study lays the groundwork by identifying the evolving linkages between bitcoin and green assets during the COVID-19 pandemic and establishing bitcoin's enhanced investment sheltering role for green assets. Branching from this point, Enilov and Mishra (2023) broaden the scope to encompass a comprehensive set of active cryptocurrencies, assessing their effectiveness as safe havens against extreme oil price movements. The study creates a contrast between these digital currencies and gold and unveils new safe haven cryptocurrencies that have been largely overlooked in the academic literature. The introduction of the Cryptocurrency Tail Risk Index (CTRI) in this work adds an innovative metric for assessing the risk exposure of the entire cryptocurrency market. Enilov and Mishra's study culminates in the surprising revelation that investing in numerous cryptocurrencies may offer more extensive safe haven properties than investing in gold alone. Simultaneously, Zhou et al. (2023) delve into an exploration of the spillover effects of bitcoin's influence on carbon futures. The authors emphasize the vital role that bitcoin attention plays in causing variations in carbon futures. Notably, their study establishes an unprecedented link between bitcoin attention and the pricing of carbon futures, providing a fresh perspective on bitcoin's far-reaching impacts in the finance world. Lastly, in a parallel vein of research, Mao et al. (2023) unravel the impacts of blockchain technologies, represented by green and non-green cryptocurrency indices, on the performance of green bond indices. The authors identify an increased sensitivity of the green bond market to the gold index during the COVID-19 pandemic. Of particular significance is the finding that the green cryptocurrency index, notably Cardano, exerts a significantly stronger influence on green bonds during the pandemic period. This study accentuates the potential of green cryptocurrencies and the integration of cryptocurrencies in digital green financing, informing future research directions and policy-making considerations.

4.1.2. Backward Local Main Path

The backward local main path begins with a diverse array of explorations into the early world of bitcoin and its implications (see Figure 6). Maurer et al. (2013) delve into the semiotics of bitcoin, arguing that the cryptocurrency offers a resolution to privacy, liberty, and value concerns through cryptographic protocols rather than traditional institutions or trust. This study highlights bitcoin's revolutionary promise and positions it as a response to the perceived shortcomings of traditional financial systems. Proceeding from this, Van Alstyne (2014) explores the intrinsic value of bitcoin, deriving it from the digital currency's innovative solution to the double spending problem and the non-governmental control of its supply. The paper underscores the groundbreaking aspect of bitcoin's design that limits its supply and assures users of its decentralization, thus preventing any central authority's interference. In the same vein, Dwyer (2015) examines the economics of bitcoin and similar digital currencies, demonstrating how their design facilitates unique peer-to-

peer transactions and prevents double-spending. The work highlights the equilibrium that can be achieved through these technologies and the limited production of digital currencies, which ultimately give bitcoin its value. Furthermore, Dwyer (2015) notes the advent of 24/7 computerized bitcoin markets and contrasts bitcoin's volatility against that of traditional assets.

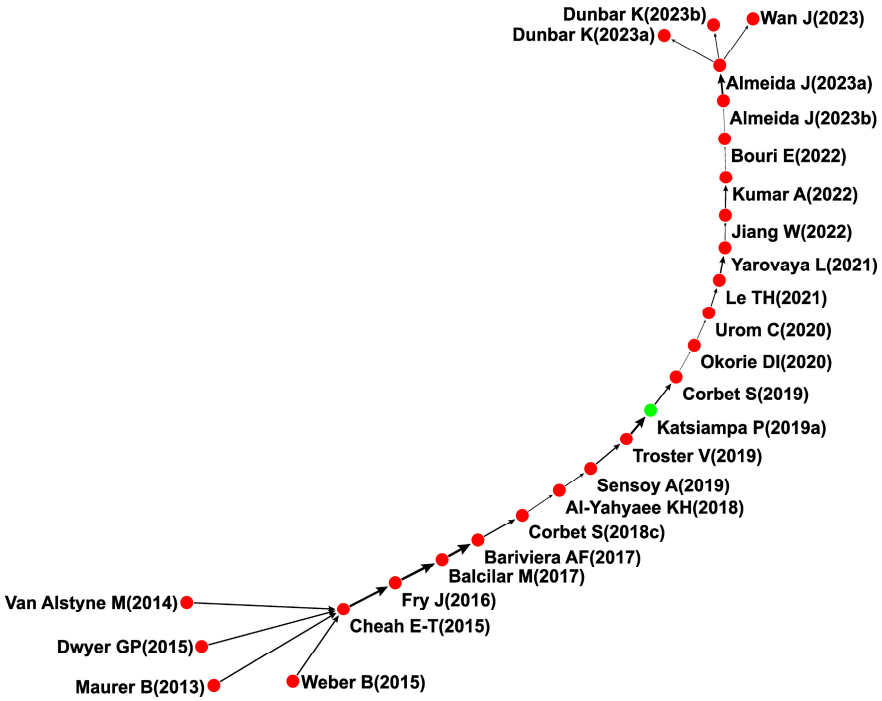

Figure 6. Backward local main path.

Weber (2015) shifts the discourse slightly by focusing on bitcoin's potential to disrupt the prevailing monetary and payment system that had been under a legitimacy crisis post the 2008 financial crisis. The study scrutinizes bitcoin's potential to create input and output legitimacy, thereby offering a new lens to view its societal and economic impacts. The four strands of academic discourse converge at Cheah and Fry (2015), where an empirical investigation is conducted to identify speculative bubbles in bitcoin markets. Despite the growing usage and popularity of bitcoin, the research startlingly concludes that the fundamental price of bitcoin is zero, indicating a dichotomy between its speculative and intrinsic values. This serves as a significant juncture in understanding bitcoin's market dynamics and potential risks, providing a crucial reference point for subsequent studies in the field.

Post Cheah and Fry (2015), the line of discourse on bitcoin and its market dynamics expands and deepens further. Fry and Cheah (2016) employ mathematical finance models analogous to those used in statistical physics to analyze financial bubbles and crashes, particularly focusing on bitcoin and Ripple, two of the largest cryptocurrencies. The study accentuates the intricacies of cryptocurrency markets and competition, adding a novel perspective to the ongoing debates about these digital assets. Then comes Balcilar et al. (2017), who propose a non-parametric approach to analyze the causal relation between bitcoin trading volume and returns. Unlike prior studies, the authors' paper explores the entire spectrum of their conditional distributions. The findings underscore the importance of modeling nonlinearity and accounting for extreme scenarios (or "tail behaviour"), particularly for understanding the causal relationships between bitcoin returns and trading volumes. At a similar time, Bariviera (2017) revisits the informational efficiency of the bitcoin market, exploring the time-varying behavior of long memory in bitcoin returns and

volatility. The study underscores different dynamics underpinning prices and volatility and sheds light on the complexity of the bitcoin market's informational efficiency.

Moving forward, Corbet et al. (2018a) examine the relationships between cryptocurrencies and other financial assets and discover that cryptocurrencies could offer diversification benefits for short-term investors due to their relative isolation from other financial and economic assets. These findings highlight the distinctive nature of cryptocurrencies as an asset class. Simultaneously, Al-Yahyaee et al. (2018) perform a comparative analysis of the efficiency of the bitcoin market against that of gold, stocks, and foreign exchange markets. This research suggests that bitcoin is less efficient due to its stronger long-memory feature and multifractality, implying greater complexity and unpredictability. Sensoy (2019) builds upon this line of inquiry with a high-frequency analysis of bitcoin prices. The study posits an increasing informational efficiency in bitcoin markets since 2016, adding an important nuance to the understanding of bitcoin's market efficiency. Lastly, Troster et al. (2019) employ general GARCH and GAS analysis for modeling and forecasting bitcoin returns and risk and provide essential insights for risk managers and investors. The paper argues for the effectiveness of heavy-tailed GAS models in forecasting bitcoin returns and risk, emphasizing the importance of accounting for bitcoin's excess volatility in risk management and investment strategies.

The studies following Katsiampa et al. (2019b) on the path expand the breadth and depth of analysis in cryptocurrency markets, offering new insights into technical trading rules, market connectedness, and volatility, and the impacts of significant global events such as the COVID-19 pandemic. Corbet et al. (2019) focus on technical trading rules in the context of high-frequency bitcoin returns, finding significant support for moving average strategies. On a related note, Okorie and Lin (2020) examine the volatility connectedness between crude oil spot prices and cryptocurrencies, revealing bidirectional and unidirectional volatility spillover effects between these markets. The study by Urom et al. (2020) explores the volatility spillovers between bitcoin, develops equities, gold, and crude oil under different market conditions, and identifies bitcoin's potential as a hedge to certain assets during bearish markets. The onset of the COVID-19 pandemic in 2020 and its subsequent economic effects significantly shaped the direction of research. Le et al. (2021) demonstrate a frequency-based dependency on various financial assets under the extraordinary circumstance of the pandemic. Yarovaya et al. (2021) looked into the herding behavior in cryptocurrency markets during the pandemic and found that COVID-19 did not amplify this phenomenon.

Further expanding the understanding of market dynamics under extreme conditions, Jiang et al. (2022) study the tail risk spillover effects between cryptocurrencies and conventional assets, challenging conventional wisdom by providing evidence of these spillovers. Kumar et al. (2022) consider the connectedness among major cryptocurrencies during standard times and the COVID-19 outbreak, revealing a structural change in their connectedness in 2020 in reaction to unprecedented monetary injections to combat the economic standstill induced by the pandemic. In a more focused examination, Bouri et al. (2022) study the connection between S&P500 and bitcoin in higher-order moments, utilizing the time-scale perspective of the wavelet coherence analysis. Their study highlights the evolving dynamics of co-movement between the two markets. Finally, the path culminated in two systematic literature reviews (Almeida and Gonçalves 2023a, 2023b), which summarize the current state of knowledge regarding investor behavior in the cryptocurrency markets and the portfolio diversification, hedge, and safe-haven properties in cryptocurrency investments.

The three studies following Almeida and Gonçalves (2023a) further explore the influence of factors such as the COVID-19 pandemic, hedging, and trading behaviors on cryptocurrency returns. Wan et al. (2023) focus on the impacts of the COVID-19 pandemic on bitcoin and propose that pandemic attention, measured by Google search volume for the keyword "coronavirus", significantly influences bitcoin returns and volatility. The study suggests that heightened pandemic attention led to decreased bitcoin returns and increased

volatility and also improved the prediction of bitcoin returns and volatility. Dunbar and Owusu-Amoako (2023a, 2023b) both investigate the predictability of cryptocurrency returns, but each with a different perspective. Dunbar and Owusu-Amoako (2023a) show that the trading behavior of speculative retail traders, specifically net-short trading behavior, was a significant determinant of cryptocurrency returns, providing evidence that trading behaviors could predict crypto returns. In contrast, Dunbar and Owusu-Amoako (2023b) propose a new habit-based explanation for crypto return predictability and argue that risk-averse commercial traders' net positions in futures had a statistically significant and economically substantial impact on the predictability of crypto returns. This was particularly evident through its moderating effects on risk aversion and uncertainty channels, underscoring the role of hedging in predicting crypto returns. In essence, these studies emphasize the influence of external events such as pandemics, as well as internal market dynamics, including trading behaviors and hedging practices, on the predictability of cryptocurrency returns. They extend the understanding of factors shaping the behavior of the crypto market and its investors, as pointed out in Almeida and Gonçalves (2023a).

4.2. Global Main Path

The citation network analysis uncovers two local paths marked by influential connections, while the principal global path showcases the most impactful route within the sphere of bitcoin research. This path contains 28 crucial papers. The strongest connection is observed between Fry and Cheah (2016) and Urquhart (2016), followed by the link between Urquhart (2016) and Katsiampa (2017), and subsequently, the connection between Conlon et al. (2020) and Goodell and Goutte (2021) (see Figure 7). These works mainly delve into the analysis of bitcoin's price behavior, volatility, and its role as a potential safe haven asset, particularly in response to significant economic events such as the COVID-19 pandemic. These research papers examine various aspects, including the occurrence of financial bubbles and crash in cryptocurrency markets, the clustering of bitcoin prices, the estimation of bitcoin's price volatility, and the impact of global events on its price movement. Interestingly, the thickness of citation links is significantly pronounced at the commencement of the global main path. This indicates that earlier published studies have attracted more recognition and consideration within the field of bitcoin research. The location of these papers towards the beginning of the path incites contemplations about whether this accurately represents their relevance in the bitcoin domain, or if it is primarily motivated by the heightened initial interest in this burgeoning field. Consequently, with the introduction of new research in the bitcoin field, the importance of these earlier studies demands reassessment.

4.3. Key-Route Main Path

In an endeavor to deepen our understanding of the progression of bitcoin research, we generated the key-route main path using the local method. For a comprehensive assessment, we established that this key route comprised 53 studies, as depicted in Figure 8. The field of bitcoin exhibits cycles of knowledge diffusion that are both converging and diverging. Notably, all articles included in this path are also present in the local main paths. The key-route main path combines all the articles from local main paths, further integrating eight supplementary studies. Nadarajah and Chu (2017) address the efficient market hypothesis in relation to bitcoin and propose a power transformation of bitcoin returns that satisfies this hypothesis based on eight different tests. The findings challenge Urquhart's (2016) claim that bitcoin returns do not conform to the efficient market hypothesis. Following this, Akyildirim et al. (2020) investigate the bitcoin futures market and find that while they are dominated by bitcoin's price discovery relative to spot markets, CBOE futures lead in informational flow when compared to their CME equivalent. The analysis highlights the industry's pricing effects caused by fraudulent activity and regulatory uncertainty. Akhtaruzzaman et al. (2020) take a portfolio management perspective, utilizing a VARMA DCC-GARCH model to identify the benefits of bitcoin in global industry portfolios and

bond indexes. The study identifies a potential for hedging risks against industry portfolios and bonds and provides insights to investors about risk management. Next, Corbet et al. (2020a) explore the impact of the COVID-19 pandemic on bitcoin and gold and observe characteristics typical of a "flight to safety" during the analyzed period. The study provides evidence that bitcoin's dynamic correlations with the main Chinese stock markets changed during this period of financial stress. Mariana et al. (2021) further investigate the impact of COVID-19, considering bitcoin and Ethereum as potential short-term safe-havens for stocks. Their results support the idea that these cryptocurrencies can serve as safe havens during a crisis but also highlight their high volatility. Rehman et al. (2023) expand the focus beyond bitcoin and examine the extreme dependence and risk spillovers between bitcoin and the currencies of BRICS and G7 economies. Their results indicate significant time-varying dependencies and risk spillovers, especially notable during the COVID-19 pandemic. Then, Das et al. (2023) use a K-means clustering model to analyze the extreme value returns of bitcoin, categorizing the data into different clusters such as good, medium, and bad days. This analysis can prove highly useful for crypto investors and policymakers. Lastly, Kartal et al. (2023) explore the asymmetric effects of global factors on cryptocurrency returns, focusing on bitcoin, Ethereum, and Ripple. The study finds these effects to be generally positive and suggests that investors should consider these asymmetric effects for trading, investment, and hedging purposes.

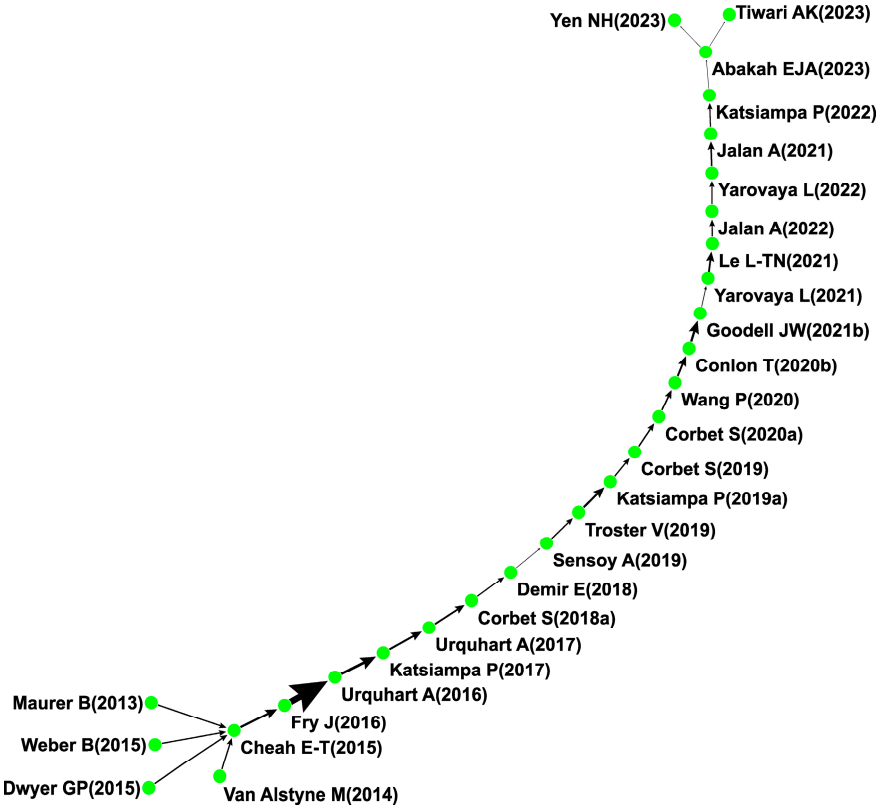

Figure 7. Global main path.

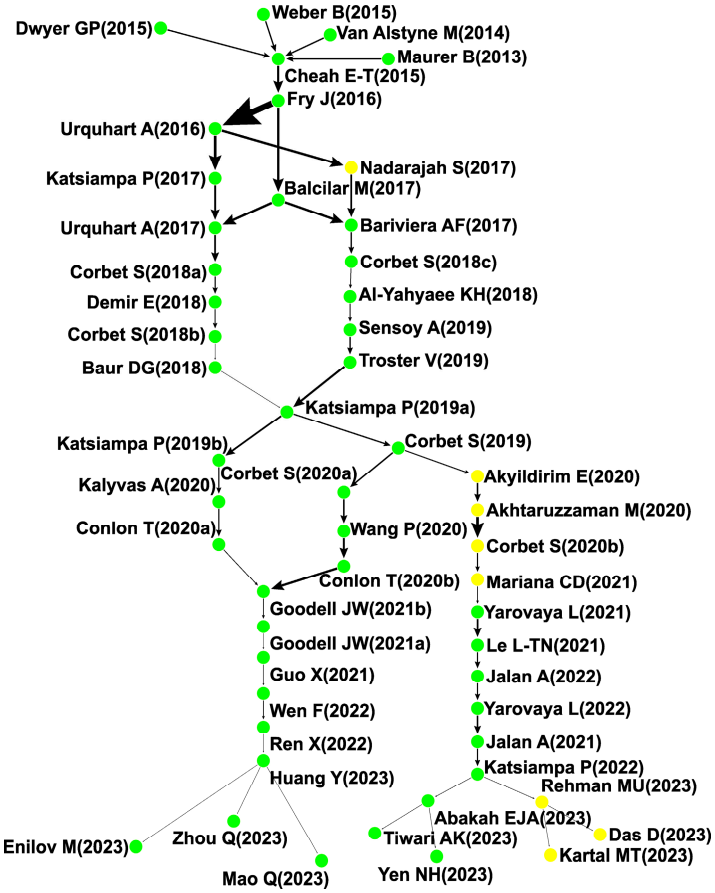

Figure 8. Key-route main path.

5. Discussion

The current study examines the co-word clusters and citation network of 4123 bitcoin-related articles, uncovering four significant paths of knowledge dissemination. This discussion, summarizing our findings from Figure 3, reveals key thematic clusters within bitcoin research, representing the field's core topics and developing areas.

A prominent cluster, #0, denotes a 'safe haven', highlighting bitcoin's growing association with financial security and risk hedging. The 'Internet of Things' (Cluster #1) represents the nexus between finance, cryptography, and technology, emphasizing emerging technologies and the essential role of trust in bitcoin's decentralized system.

Other crucial clusters include 'proof of work' (Cluster #2), underscoring the operational mechanics of PoW systems and the importance of consensus. 'Market efficiency' (Cluster #3) focuses on bitcoin market performance and predictability, while 'sentiment analysis' (Cluster #4) explores public opinion through machine learning and data mining. The 'digital currency' (Cluster #5) speaks to broader FinTech and sustainability discussions, and 'privacy' (Cluster #6) uncovers ongoing debates on privacy within the bitcoin ecosystem. Overall, these findings offer a dynamic view of bitcoin research, illuminating the multifaceted aspects of this growing field.

The evolution of cryptocurrency research, encompassing both the forward and backward local main paths, has been a journey of unfolding complexities and shifting perspectives. Initially, the forward path delved into the heart of bitcoin's innovation, dissecting its structure and anonymity and contrasting it against traditional financial assets. This led to an exploration of broader market dynamics, with a particular emphasis on the volatility and speculative nature of bitcoin and other cryptocurrencies, as well as their response to fluctuations in economic policy.

As the landscape shifted, so did the focus of research. The field started to probe into the resilience of bitcoin amidst economic turbulence. The pivotal moment was during the COVID-19 pandemic when bitcoin's role as a safe haven was put to the test. However, bitcoin did not entirely live up to its proposed function, thus challenging its potential as a portfolio diversifier. Most recently, research has pivoted to include an ecological perspective, examining the interplay between bitcoin and green assets and investigating the role of various cryptocurrencies as safe havens. The impact of blockchain technologies on green bond indices has also come under scrutiny, highlighting the increasing integration of cryptocurrencies in the realm of green financing. In parallel, the backward local main path of research has charted a similar, albeit distinct, trajectory. It started by scrutinizing bitcoin's radical potential as a decentralized, privacy-oriented currency that could disrupt traditional financial systems. Even though concerns about bitcoin's fundamental price being zero were raised, the conversation deepened to encompass more intricate facets of cryptocurrency markets, like financial bubbles, trading volumes, and risk management strategies. As the discourse matured, the impact of global events, such as the COVID-19 pandemic, on cryptocurrency market behavior was studied. This also coincided with a growing interest in the significance of investor behavior within these markets. Ultimately, the research lens zoomed in on the intersection of external events and internal market dynamics, examining their collective influence on the predictability of cryptocurrency returns. This twin-path analysis underlines the multifaceted narrative of cryptocurrency research, demonstrating its evolution from a singular focus on bitcoin's features to a comprehensive understanding of the dynamic cryptocurrency ecosystem.

The key-route main path analysis synthesized 53 studies, illustrating a complex, evolving narrative of bitcoin research. Early works challenged established ideas, like the non-conformity of bitcoin, to the efficient market hypothesis, while later studies delved into portfolio management, risk hedging, and price discovery dynamics. The impact of the COVID-19 pandemic was particularly noteworthy, shedding light on bitcoin's role as a safe haven and its interplay with global economies. Extremes in bitcoin value returns were examined, providing valuable insights for investors and policy makers. Finally, the asymmetrical effects of global factors on crypto returns were explored, stressing their importance for trading, investment, and hedging strategies. Incorporating these findings alongside the local main path analysis underlines the multifaceted journey of bitcoin research, from its decentralized beginnings to its role in global economics and green financing.

5.1. Theoretical Implications

Our examination of the bitcoin research landscape illuminates a wide range of themes that have been thoroughly explored, such as safety, the intersection with emerging technologies, consensus-building protocols, market efficiency, sentiment analysis, sustainable development, and privacy concerns. These themes reflect the intricate interplay of finance, cryptography, technology, economics, and social factors that are instrumental in shaping the growth and perception of bitcoin.

However, this comprehensive exploration also hints at areas where further research could be particularly fruitful. While these areas may have been touched upon within the existing body of literature, they have not yet been investigated in-depth. Future directions for research could involve delving deeper into understudied themes, such as the potential integration of bitcoin within novel financial ecosystems, the implications of bitcoin's interplay with AI and cybersecurity, and the environmental implications of extensive bitcoin and blockchain utilization.

Understanding and addressing these gaps will not only enrich the existing body of bitcoin research but also contribute to a more holistic understanding of the implications and potential of bitcoin and related technologies. Therefore, our study not only provides a synthesis of the state-of-the-art in bitcoin research but also outlines potential avenues for future investigations, further advancing our understanding of this multifaceted field.

Based on the progression of bitcoin research identified in our study, future directions for research could include:

- Bitcoin as a safe haven: Conduct an in-depth analysis of bitcoin's role and potential as a safe haven asset, especially during economic shocks and market volatility. Examine the factors that could affect its efficacy as a safe haven in different economic contexts.
- Intersection with emerging technologies: Investigate the interplay of bitcoin with emerging technologies such as IoT and AI. Analyze the impacts of these technologies on bitcoin's functionality, security, and environmental impact. Explore how these interactions could reshape the bitcoin and cryptocurrency ecosystem.
- Privacy and trust in bitcoin: Delve deeper into the issues of privacy and trust within the bitcoin ecosystem. Evaluate their implications on user adoption, regulatory responses, and the development of new blockchain technologies.
- Bitcoin and green financing: Research the potential role of bitcoin and blockchain technologies in promoting sustainable development and green financing. Assess the environmental costs associated with these technologies and explore potential strategies to mitigate these impacts.
- Market dynamics and predictability: Expand research on the market dynamics of bitcoin and other cryptocurrencies. Develop new models for predicting cryptocurrency price movements and volatility, incorporating factors such as investor behavior, global events, and technological advancements.

5.2. Practical Implications

The insights from this study provide practical implications for a range of stakeholders. Investors and financial advisors gain an improved understanding of bitcoin's market dynamics, enabling more informed investment and risk management strategies. Emphasizing bitcoin's potential as a safe haven could drive its inclusion in diversified portfolios, despite its demonstrated volatility. For technology firms and innovators, the highlighted intersections with emerging technologies such as AI and IoT suggest areas for innovation and development, while the focus on privacy emphasizes the necessity of robust security measures. Policymakers and regulators can glean insights into the challenges and opportunities presented by bitcoin and other cryptocurrencies, informing more nuanced and effective regulatory responses. Lastly, the emphasis on green financing underlines the need for sustainability in blockchain technology's implementation, encouraging companies to consider environmental impacts in their operations and potentially paving the way for greener practices within the industry.

6. Conclusions

Bitcoin research has experienced a notable evolution, drawing attention from a wide range of scholars, professionals, and investors. Our study has employed a comprehensive collection of 4123 scholarly articles, using co-word analysis and MPA to unveil the principal themes and influential works that have dictated the progression of bitcoin research. The study has identified several key clusters, including safe haven, internet of things (IoT), proof of work (PoW), market efficiency, sentiment analysis, digital currency, and privacy, giving a detailed understanding of the mainstays of bitcoin research. This research distinctively merges co-word analysis and MPA to delve into the intricate channels of knowledge diffusion within the vast landscape of bitcoin research. The amalgamation of these methodologies offers a comprehensive view of the bitcoin research field, transcending conventional review methods and bibliometrics and revealing the central contributions and complete knowledge diffusion pathways.

Despite these breakthroughs, the study has limitations. The research only includes articles from Scopus. Thus, it only captures a section of all published bitcoin research. Future inquiries could supplement these findings by using other databases like Web of Science and incorporating other types of publications, such as conference proceedings or book chapters. Artificial intelligence (AI) and machine learning have been instrumental

in numerous fields for their capacity to detect patterns and trends within large, complex datasets (Moro et al. 2015). When applied to literature analysis, these tools can assist in uncovering areas that have received less attention or 'low signals' (Rejeb et al. 2023b). In the context of our study, the use of AI could help identify new or under-explored themes in bitcoin research. For example, Natural Language Processing (NLP), a subfield of AI, could be used to conduct more nuanced semantic and sentiment analyses on the literature corpus. By processing large amounts of text data, NLP algorithms can provide insights into latent topics or trends in the literature that may not be readily apparent through manual analysis. Moreover, machine learning models such as topic modeling can automatically cluster similar topics together, which may help discover novel areas of research or unexpected connections between existing ones (Rejeb et al. 2023b). Additionally, our research considers all cited and citing articles as equally important, possibly overlooking variations in their impact or relevance. Future studies could consider the significance or influence of articles within the citation network to refine this aspect. Nevertheless, the study presents multiple pathways for future research, assisting researchers in expanding their scope of investigation in this vibrant field. To conclude, this research adds significant insights to the bitcoin research field, highlights its dynamic progression, and stimulates further explorations.

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Appendix A

TITLE-ABS-KEY ("bitcoin") AND (LIMIT-TO (SRCTYPE, "j")) AND (LIMIT-TO (DOCTYPE, "ar") OR LIMIT-TO (DOCTYPE, "re")) AND (LIMIT-TO (LANGUAGE, "English")).

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