Received: 19 August 2023 | Revised: 7 December 2023 | Accepted: 6 February 2024

DOI: 10.1002/for.3114

RESEARCH ARTICLE

WILEY

Forecasting of cryptocurrencies: Mapping trends, influential sources, and research themes

Tomas Pečiulis[1] | **Nisar Ahmad**[2] | **Angeliki N. Menegaki**[3,4] | **Aqsa Bibi**[5]

[1]Department of Economic Engineering, Vilnius Gediminas Technical University, Vilnius, Lithuania

[2]Department of Economics and Finance, College of Economics and Finance, Sultan Qaboos University, Muscat, Oman

[3]Department of Regional and Economic Development, Agricultural University of Athens-EU CONEXUS, Athens, Greece

[4]Department of Business Administration and Tourism, Hellenic Mediterranean University, Heraklion, Greece

[5]Saibaan Development Organization, Mansehra, Pakistan

Correspondence
Nisar Ahmad, Department of Economics and Finance, College of Economics and Finance, Sultan Qaboos University, Muscat, Oman.
Email: nisar@squ.edu.om

Abstract

This systematic literature review examines cryptocurrency forecasting trends, influential sources, and research themes. Following PRISMA guidelines, 168 articles from Q1 or A-tier journals in the Scopus database were analyzed using bibliometric techniques. The findings reveal a significant increase in cryptocurrency forecasting research output since 2017, particularly in 2021. "Finance Research Letters" emerges as the most productive journal, whereas "Economics Letters" receives the highest number of citations. Elie Bouri is identified as the most prolific author, and China is the top contributor country. Key research themes include bitcoin, cryptocurrency, volatility, forecasting, machine learning, investments, and blockchain. Future research directions involve utilizing internet search-based measures, time-varying mixture models, economic policy uncertainty, expert predictions, machine learning algorithms, and analyzing cryptocurrency risk. This review contributes unique insights into the field's growth, influential sources, and collaborative structures and offers a foundation for advancing methodology and enhancing cryptocurrency forecasting models.

KEYWORDS

bibliometric analysis, cryptocurrency forecasting, systematic literature review

1 | INTRODUCTION

Since the dawn of the blockchain-based cryptocurrencies in 2009, when a person named Satoshi Nakamoto or more of them publicly announced a white paper of the bitcoin entitled: Bitcoin: peer-to-peer Electronic Cash System (Nakamoto, 2008), more than a decade has passed. The conventional money exchange structure is fully dependent on the third-party centralized financial institutions, for example, banks, in order to implement and validate the financial transactions. Cryptocurrencies eliminate the involvement of centralized third-party institutions (banking system) and all the inadequacies that pertain therein. Each transaction has to be validated by each peer using suitable consensus algorithm, for example, proof of work (PoW) or proof of stack (PoS), to name a few, but there are many more. These consensus algorithms use timestamps and the transaction hash for the confirmation of the transaction. It requires miners (see below) to solve a complex mathematical problem (complexity adapts according to the computing power) to add a block in the existing chain. The process of solving the problem is called mining, and peers who solve these problems are called miners. They are rewarded for the work they have done through a new crypto currency, which is mined and increases the money supply of that particular cryptocurrency (Patel et al., 2022).

Funding: This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Cryptocurrencies use cryptography to transfer funds securely, regulate and control the supply of cryptocurrency, and make transactions secure (Garcia et al., 2014), hence the term cryptocurrency (Khedr et al., 2021) whereby "crypto" means secret or shadowy. Records or exchanges are secured through a protected hash set of secure hash algorithm-256 (SHA-256) and message digest 5 (MD5) calculations (Patel et al., 2022). The market of cryptocurrencies has significantly matured in 2021 and then the capitalization of the cryptocurrencies has reached the amount of USD 2000 billion in circulation (Coinmarketcap, FRED) and has become a tantamount entity in global finance. While the significance of block chain-based cryptocurrencies has become more prominent, the interest of the scientific community in this market has also risen sharply.

The scientific literature on bitcoin and cryptocurrencies in general has proposed different aspects that are possibly paramount in the estimation of cryptocurrencies value (Liu & Tsyvinski, 2021). The first strand of research affirms the network effect of cryptocurrency enactment (Cong, He, & Li, 2021a; Pagnotta & Buraschi, 2018). The second strand of research centers on the production and mining part of the cryptocurrencies (Cong, Li, & Wang, 2021b; Sockin & Xiong, 2020). The third strand of research focuses on the fluctuation of cryptocurrency returns and volatility, attempting to estimate forecasting methods as well as trying to find the main elements that constitute the price of bitcoin and altcoins (Ciaian et al., 2016; Katsiampa, 2017; Sun et al., 2020). There is also a small strand of research on the empirical regularities of the bitcoin and other cryptocurrencies (Liu & Tsyvinski, 2021). As the dynamics of the price and volatility of cryptocurrencies is of prime interest for investors, portfolio managers, and economic policymakers (Karim et al., 2022), the papers on the fluctuation of cryptocurrency returns and volatility constitutes the lion's share of research papers sampled in this review.

Forecasting the price and volatility of cryptocurrencies poses a significant challenge due to the absence of a well-established theoretical foundation capable of elucidating the intricate behavior and dynamics inherent in these digital assets. These cryptocurrencies operate within an environment characterized by high levels of uncertainty, speculation, and manipulation, rendering them susceptible to extreme volatility and unpredictability. The applicability of conventional financial theories and models, such as the efficient market hypothesis (EMH), to the cryptocurrency markets remains ambiguous. The EMH asserts that financial asset prices reflect all available information, and market participants cannot consistently outperform the market by exploiting arbitrage opportunities. Nevertheless, empirical studies examining the EMH in cryptocurrency markets yield varied results, indicating efficiency discrepancies across different cryptocurrencies, timeframes, and methodologies (López-Martín et al., 2021; Souza & Carvalho, 2023). Factors influencing market efficiency encompass liquidity levels, information accessibility and quality, regulatory measures, market frictions, and the diversity of investor expectations and preferences. This article endeavors to conduct a thorough literature review on cryptocurrency price and volatility forecasting, elucidating prevalent trends, influential sources, and research themes within this burgeoning field. Additionally, we explore the implications and constraints of existing approaches while proposing directions for future research.

There are thousands of papers devoted to the prediction and forecasting techniques of cryptocurrencies' price and volatility, but to the best of our knowledge, there are only two literature reviews. The first one is by Olvera-Juarez and Huerta-Manzanilla (2019). There are several very important differences that distinguish this paper from the aforementioned vast mass. Foremost, its authors give some hints about the systematic literature review (SLR) methodology, but they are silent about the selection keywords, and the information about the article selection process is inadequate. Thus, it does not have the necessary attributes to be characterized as a SLR, but instead it can be regarded as a traditional narrative style literature review. Moreover, Olvera-Juarez and Huerta-Manzanilla (2019) focus only on the prediction of prices using autoregressive integrated moving average (ARIMA) family models, so the scope of the review is very narrow. Finally, the analyzed period in the latter is from 2015 to 2018, which is also very short. The second survey is by Khedr et al. (2021). Similarly, to Olvera-Juarez and Huerta-Manzanilla (2019), authors state that it is a SLR and that it even provides some keywords such as "cryptocurrency price prediction," "ML techniques (and) cryptocurrency price prediction," "cryptocurrency price prediction using ML techniques," and "DL (and) cryptocurrency price prediction," but still all other information and prerequisites that are required to be fulfilled in a SLR are missing. There is no information about (i) the databases authors have used, (ii) articles selection process, and (iii) inclusion and exclusion criteria. That review also lacks comprehensive information about the framework, which was used to perform the analysis, so that paper too falls under the umbrella of a traditional narrative style review.

Generally, there are two broad categories of literature reviews: the traditional literature review (TLR) and the SLR (Ahmad, Aghdam, et al., 2020). TLR is the most common approach in every field of research. TLRs

explore and explain fundamental ideas that have been declared by other scientists (Wakefield, 2014). This type of review could be performed in a completely descriptive and/or entirely qualitative manner. There are no specific rules for performing a TLR; thus, the article selection process or the concept applied for analyzing and classifying the articles completely depends on the person performing the TLR; namely, it may suffer from bias and not be reproducible. Therefore, each researcher may implement a TLR in various ways, and the selection of the papers may be completely subjective based on researchers' individual experience (Asatullaeva et al., 2021). On the other hand, in an SLR, the process is clearly defined and can be reproduced with transparency. First, the strategy of the article search process is developed in order to assure that no relevant articles will be missing. Second, a set of rigorous exclusion and inclusion criteria is incorporated. Finally, a template for data entry, using well-defined categories and coding schemes with a view to produce an unbiased outcome, is developed (Ahmad, Menegaki, & Al-Muharrami, 2020). SLR differs from TLRs also by applying a replicable, transparent, and scientific rigorous process, which will generate unbiased results (Tranfield et al., 2003). SLRs are considerably more objective than TLRs, as their working process is open, transparent, and replicable by others. Moreover, SLRs are less prone to selectivity bias or reporting bias, which refers to the selective publication or inclusion of studies based on the significance or direction of their results, leading to an incomplete or distorted representation of the available evidence (Bennett et al., 2005). The unbiased results imply that scientists are using equitable means to generate inferences and draw conclusions rather than stating their own subjective judgments.

There are various studies that emphasize the superiority of SLR over TLR for performing reviews in numerous fields (Kowalczyk & Trukuck, 2013; Lock & Seele, 2015). SLR has recently become a benchmark in many disciplines. Quite a few studies use nowadays the SLR methodology, and these reviews have been published in top tier journals. These disciplines include Management (Colicchia & Strozzi, 2012; Adams et al., 2017; Durach et al., 2017; Hussain et al. (2023)), Marketing (Coombes & Nicholson, 2013; Dangelico & Vocalelli, 2017; Nill & Schibrowsky, 2016), Human Resources (Hohenstein et al., 2014; Macke & Genari, 2019; Nolan & Garavan, 2016) Information Systems (Bandara et al., 2011; Collins et al., 2021; Tummers et al., 2019), Operations (Thomé et al., 2016; Ntabe et al., 2015; Glock et al., 2019), Tourism (Ahmad, Naveed, et al., 2020; Mariani et al., 2018; Yang et al., 2017; Yung & Khoo-Lattimore, 2017) General Business (Gast et al., 2017; Morioka & de Carvalho, 2016; Reim et al., 2015), Energy (Ahmad, Aghdam, et al., 2020), Environment (Menegaki et al., 2021), and Economics (Alkhudary et al., 2020; Fiaz et al., 2023; Gregorio et al., 2018; Jámbor & Török, 2019).

The scope of our paper is also broader from the existing studies, and this occurs from a thematic point of view, because it includes the prediction of both volatility and prices, whereas the study by Khedr et al. (2021) only reviews papers in price forecasting. Last, the analyzed period in the study by Khedr et al. (2021) is from 2010 to 2020. It is worth mentioning that scientific production of cryptocurrency prediction and forecasting has increased in 2021 and 2022. Furthermore, more advanced prediction and forecasting techniques have been implemented during this period. Moreover, none of the previous studies has provided bibliographic information about the topic. This study addresses the aforementioned issues and fills in the necessary gaps. The analyzed period of our review ranges from 2009 to 2022. We provide bibliographic information and detailed content analysis of the 50 most influential articles (the influence of the article has been measured by its annualized citation count). In this study, we provide a very comprehensive list of keywords (based on expert views and previous literature) that were used to search for relevant papers, information about databases that were used, and article selection processes as well as articles inclusion and exclusion criteria. The current study provides detailed citation analysis of 168 peer-reviewed Scopus indexed papers on forecasting of cryptocurrencies price and volatility.

Overall, the goal of the current paper is to review and summarize the literature relevant to the field of the forecasting of cryptocurrencies, using the bibliometric data of scientific papers in Scopus database. Our objective is to determine the trends of publications, as well as the most influential journals, authors, and articles in this field of research and to identify gaps in the research and discover potential areas for new contributions. The specific research questions of the study can be formulated as follows:

1. How has the concept of crypto currency evolved over the years or what the publication trends on cryptocurrency are? The answer to this question will unveil the gaps and possible publication niches in literature.
2. What are the major contributions, the most influential authors, journals, conceptual structure keywords, and themes in forecasting on cryptocurrencies? The answer to this question will lead new researchers to must-read publications and will provide an outline of the research structure up to date with major literature strands. Thus, it groups literature and makes it more convenient accessing that in brief.

3. How is the countries research collaboration structure in the field of forecasting cryptocurrencies? The answer to this question might unveil possible underlying parameters that support research collaborations.
4. What are the future directions for the cryptocurrencies in business management, finance, and economics? The answer to this question is linked to all the above questions and is valuable for both current and future researchers for the evolution of the topic and its more efficient and fruitful development.

Citation analysis is a useful and comparably cost-efficient tool to measure the scientific performance of articles, journals, and authors (Chatha et al., 2015; Guerras-Martín et al., 2014; Jeung et al., 2011; Liu et al., 2013). The online databases such as Scopus, Google Scholar, or WoS enabled citation analysis. Citation count is used to assess the professional achievements and peer acknowledgment of the authors and to assess his/her contributions to the entire scientific community, because citations have been considered to be a scholar link between current work and the previous research work. The more cited articles are typically assumed to be of higher importance than those that are less frequently cited. When a piece of research is cited by another research article, this commonly indicates that the research has findings that are influential for subsequent publications (Jeung et al., 2011).

Citation analysis has shown that the *Journal Finance Research Letters* is the leading journal in terms of the number of publications and citations. Elie Bouri has been identified as the most productive author based on the number of publications and the H-index. The most cited author is Yukun Liu. Moreover, we also provide the full author's ranking based on the following criteria: H-index, G-index, M-index, the number of publications, and the number of citations. The most cited paper is entitled as "Speculative bubbles in Bitcoin markets? An empirical investigation into the fundamental value of Bitcoin" by Eng-Tuck Cheah and Fry (2015). The annual scientific production analysis results show that the number of publications in this research area has been growing substantially after the rapid growth of bitcoin prices in 2017.

The paper is organized as follows. Section 2 provides a detailed presentation of the methodology that is included in the SLR approach, article selection criteria, final data set, and the techniques used for analysis. Section 3 presents the results based on bibliometric analysis. Section 4 presents the content analysis of the 50 most influential papers, and Section 5 concludes the paper, highlighting its limitations and proposing future research areas.

2 | METHODOLOGY

The main objective of this research is to perform a SLR applying bibliometric analysis and the PRISMA guidelines as a research method. The SLR employed in this study involves three phases: planning the review, conducting the review, and reporting the review findings. Planning consists of the formulation of research questions together with the inclusion and exclusion criteria. Conducting the review includes the selection of research studies, a quality assessment, data the extraction, and data synthesis.

Scopus was selected as the database for searching articles in this review, because it captures a more comprehensive range of articles with complete metadata including reference sets, author/institution, keywords, and more (Corbet et al., 2019). There are a couple of other scientific databases available that provide similar data, particularly the Web of Science (WoS) and Google Scholar. These databases have their own advantages and disadvantages. For example, Google Scholar includes the citation counts from conference proceedings and from working papers, following a generic approach that hinders the quality of research (Harzing & Alakangas, 2016; Harzing & Van Der Wal, 2009). On the contrary, the WoS database is considered to be an ideal standard for constituting a scientific database, but it takes the strictest approach regarding the citation count, potentially excluding relevant citations from conference proceedings and working papers that could contribute valuable research insights, thereby limiting the comprehensiveness and inclusiveness of the database content. Scopus seems to be the best choice because it can be positioned between the two extremes regarding the citation count, and it tends to be more accurate in measuring the citation count if compared with the WoS or Google Scholar as documented by several researchers (Falagas et al., 2008; Franceschini et al., 2016; Garousi & Mäntylä, 2016).

The sample search for the current review was performed on January 5, 2023, with the adoption of the research strategy shown in Figure 1, based on PRISMA guidelines. The search string was forecast* OR predict* AND "digital currency*" OR crypto* OR bitcoin OR ether* OR blockchain AND NOT cryptography in the title, abstract, and keywords. To ensure the relevance and focus of our study, the term "cryptography" was deliberately excluded from the search strategy in order to omit any potentially extraneous or unrelated findings. The time period for the search string was 2013 up to date. This query produced 17,574 results. In the second step, the subject area was restricted to Economics, Econometrics, and Finance, Business, Management, and Decision science articles on English language only, and this

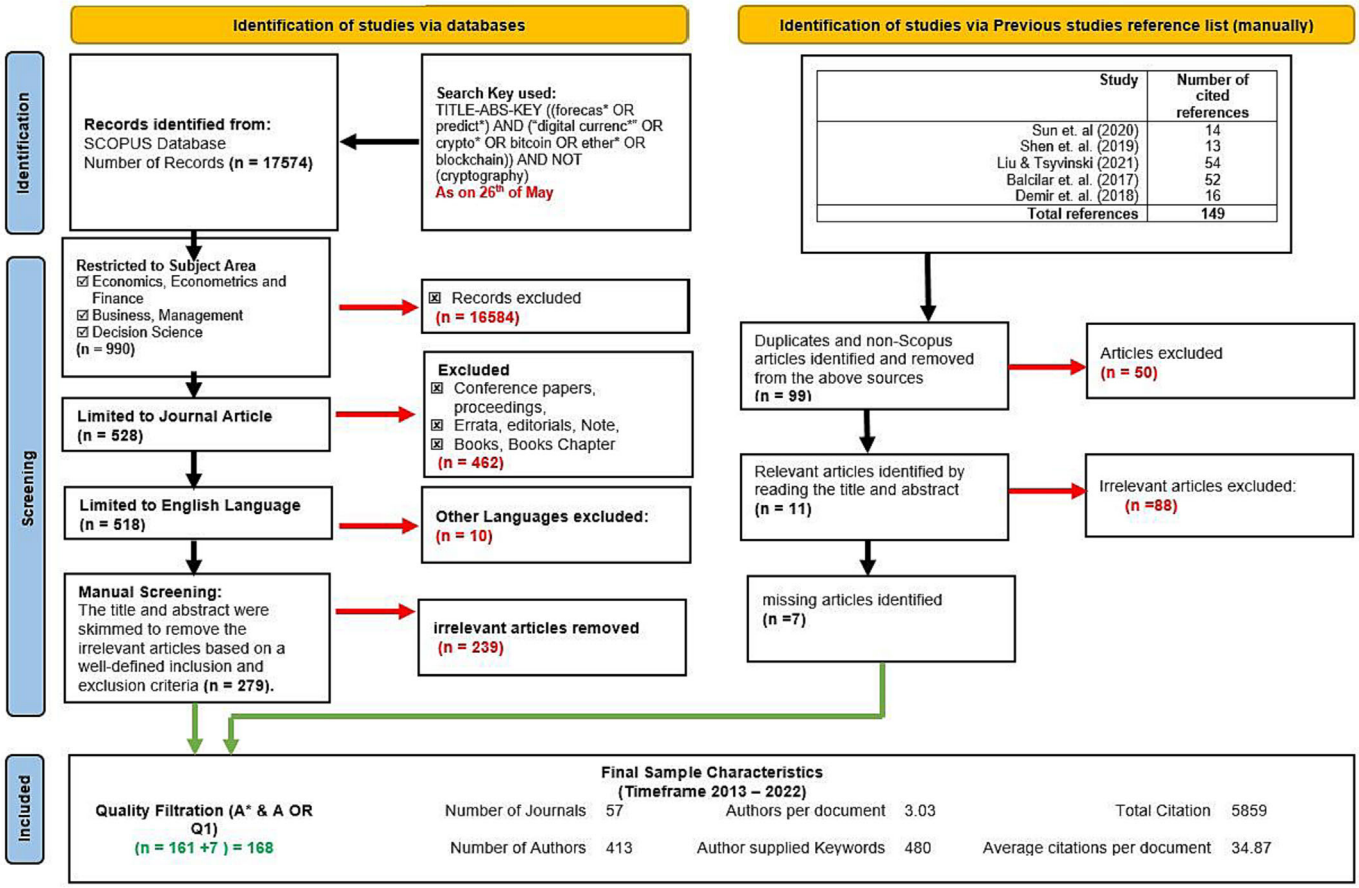


FIGURE 1 Article selection flowchart (PRISMA).

further reduced results to 990 documents. For quality purposes, we excluded proceedings, conference papers, editorials, errata, books, notes, and book chapters resulting in 518 articles. In the next step, the title and abstract of the selected articles were manually checked by the expert to remove irrelevant articles, and this left us with 279 relevant articles. For quality assessment purposes, only those articles were included that are published in A* and A or Q1. Finally, the reference lists of the 5 most cited articles (Balcilar et al., 2017; Demir et al., 2018; Liu & Tsyvinski, 2021; Shen et al., 2019; Sun et al., 2020) were used to check for any missing relevant article. During this process, 7 articles were added. The final sample for this study was 168 articles converted into BibTex format, which is readable in R-Studio software for Bibliometrix analysis.

Bibliometrix (Biblioshiny) is an open source R-tool for comprehensive quantitative research and scientific mapping, and it encompasses statistical algorithms, mathematical functionality, and visualization capabilities for analysis through tables and graphs (Aria & Cuccurullo, 2017). This tool is preferred to other counterparts that it helps to analyze bibliographic coupling and performs co-citation analysis of authors and articles as well as the extent of collaboration among authors, countries, and institutions. Last but not least, Bibliometrix is compatible with both Scopus and WoS databases.

3 | DATA ANALYSIS AND DISCUSSION

3.1 | Descriptive statistics

The selected articles for this study are 168 published in 57 outlets during 2013–2022. The publication time period of the articles starts from 2013, as the first paper published on the investigated topic was in 2013. There are 413 authors in total, showing that most of the articles are written by more than one authors, averaging 3.03 authors per articles. There are only 20 single-authored documents in the sample. The average age of the document is 1.73 years. These characteristic reveals that it is a nascent topic with ascending academic interest, which requires additional research. The annual growth rate is almost 46%. This rapid growth rate shows that it is an

emerging topic with an impetus, which is gaining huge attention in the scientific world despite its recent origin.

3.2 | Annual publication trends

This section examines the publication trends within the field, aiming to provide an overview of the patterns and changes observed in scholarly publications over the researched time period.

Figure 2 shows the growing trends of publications with 45.92% annual growth rate. Notably, the year 2013 is highlighted for the first publication in the field with a single article. Since then, the trend has showed a smaller number of publications, but from 2017 and afterwards, publications have increased drastically due to the bitcoin price bubble in 2017 and the second price bubble in 2021 as marked in Figure 2. Before 2017, the average publication of articles per year was 1.4, whereas after 2017, it has reached 33 articles per year. This phenomenon has been driven by bitcoin bubbles and is also linked to the growing interest of the scientific community, investors, and economic policymakers in the topic. It could also indicate the growth of crypto-currencies industry.

So far, 2021 has been declared as the most productive year, with 61 publications, which constitute 36% of the total production of research work. Average citations per year are shown in Figure 3. The citations of topic have fluctuated over the years. In 2017 was recorded the highest citation, at 7000, because many scholars referred to

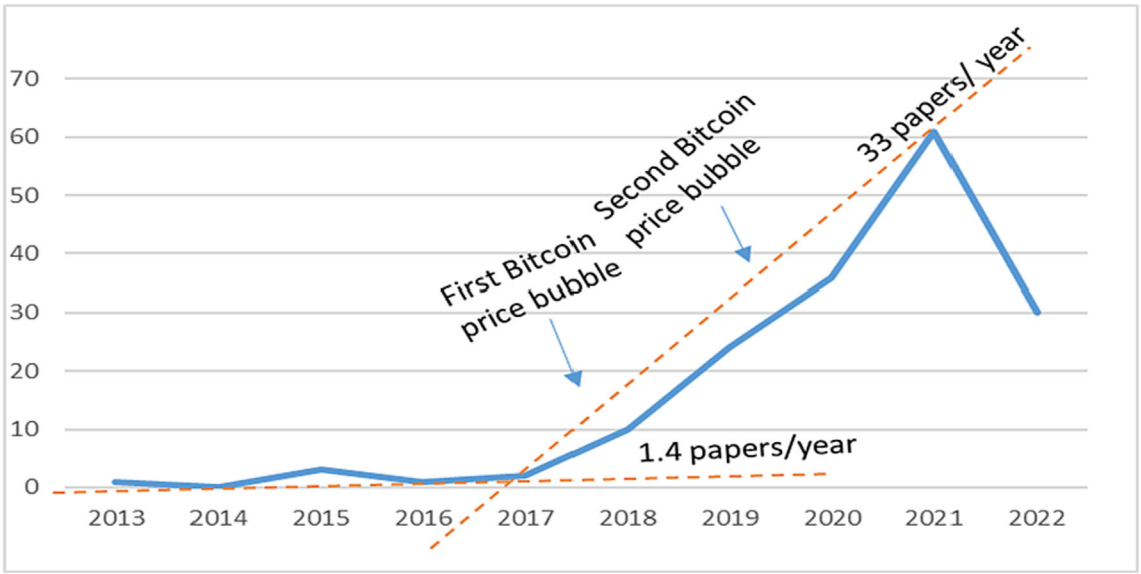


FIGURE 2 Annual publication trends.

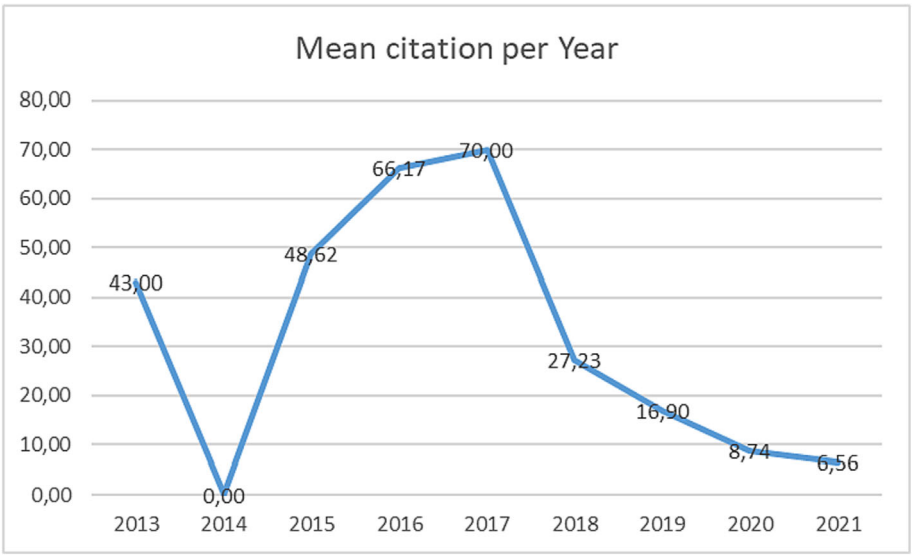


FIGURE 3 Average citations per year.

previous studies as references for their publications on cryptocurrency. The lowest citations number occurred in 2014 as no publication was recorded in this year. However, citations are expected to increase over time.

3.3 | The most productive journals

Table 1 represents the top 10 most influential journals in the in the field of cryptocurrency price and volatility forecasting, ranked according to the number of publications. There are 100 articles published in the top 10 journals, accounting for 59.52% among all publications. The "Finance Research Letters" has published the highest number of articles, 32 publications, which is almost three times higher than the second and third ranked journals, "Economics letters" and "Research in International Business and Finance," which have published 12 articles each. The number of citations for each journal, publication year, and impact factor is computed in Table 1, along with the H-index. "Economics Letters" has ranked first in terms of citations received with 1511 citations, which is 41% of the total number citations of the top five journals, followed by "Finance Research Letters" (1009 citations) and "Applied Economics" (409 citations). It should be noted that the journal "Economics Letters" has received more citations although it has published fewer articles than the "Finance Research Letters" that ranked first in terms of the number of articles produced. This can be explained by the fact that "Economics Letters" have begun publishing articles in 2015, whereas "Finance research letters" have started publishing in 2018.

Impact factor wise, "Finance Research Letters" have reported the highest impact factor, 9.848. The journal with the second-highest impact factor is the *International Review of Financial Analysis* (8.235), followed by the *International Journal of Forecasting* (7.022). Apart from that, the H-index for the publication on forecasting cryptocurrencies is also presented in Table 1. The H-index is defined as the maximum h value where the journal has published at least an h number of papers and each has been cited at least h times. Therefore, the higher the h-index, the higher the influence of a journal. *Finance Research Letters* has ranked first in terms of the h-index (15) followed by *Economics Letters* (10), *Research in International Business and Finance* (7), and *International Review of Financial Analysis* (7).

The dynamic growing trend of the journals is presented in Figure 4 to provide an insight on the topic.

A growing trend in each journal's publications has been observed since the first paper of publication in the field, namely, 2013. Initially all top 5 journals have recorded slow but steady growth in their number of articles on the cryptocurrencies research domain; however, the most cited articles are published during the period 2013–2018. The most prominent articles of this time period are "Bitcoin meets Google Trends and Wikipedia: Quantifying the relationship between phenomena of the Internet era" published in the journal "Scientific Reports" (Kristoufek, 2013), "Speculative bubbles in Bitcoin markets? An empirical investigation into the fundamental value of Bitcoin" published in the journal "Economics letters" (Cheah & Fry, 2015), and "Volatility estimation for Bitcoin: A comparison of GARCH models" published in the journal "Economics Letters" (Katsiampa, 2017). A more noticeable pattern is the exponential growth in the publication trend of *Finance Research Letters* during the relatively short period from 2018 to 2021. The most influential articles (as shown in Table 3) on the topic of cryptocurrenices were published in top tier journals and had received a lot of recognition.

TABLE 1 Most influential journals.

Rank	Journals	PS	TP	TC	IF	H-index
1	*Finance Research Letter*	2018	32	1009	9.848	15
2	*Economics Letters*	2015	12	1511	1.469	10
3	*Research in International Business and Finance*	2018	12	319	6.143	7
4	*International Review of Financial Analysis*	2019	11	187	8.235	7
5	*Financial Innovation*	2019	8	88	6.793	3
6	*Journal of Forecasting*	2018	7	33	2.627	2
7	*Annals of Operation Research*	2021	5	52	4.82	3
8	*International Journal of Forecasting*	2019	5	112	7.022	3
9	*Applied Economics*	2016	4	409	1.916	3
10	*Economic Modelling*	2017	4	356	3.875	3

Abbreviation: IF, impact factor; PS, publication year; TC, total citation; TP, total publications.

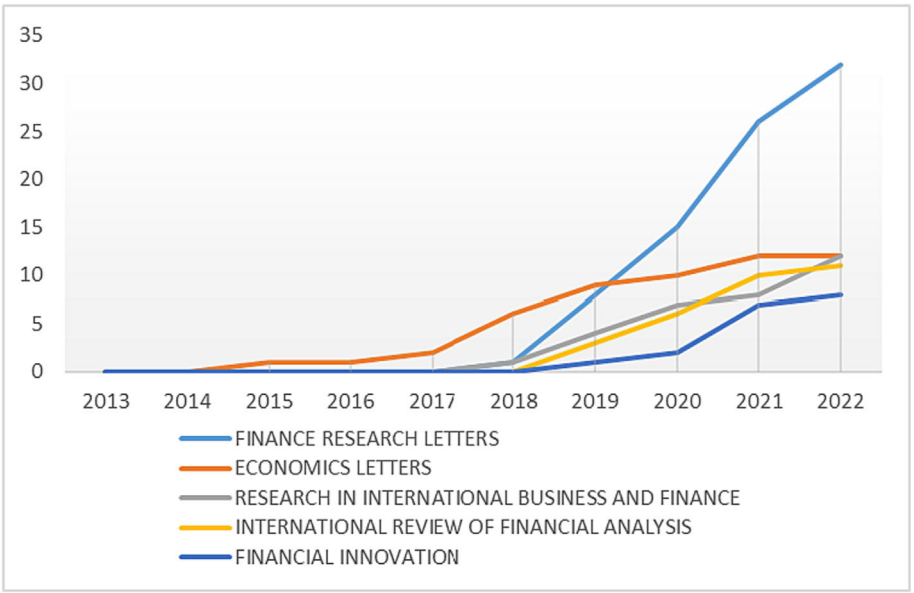


FIGURE 4 Publication trend growth by the top 5 journals in the field.

3.4 | The most prolific authors

Top 10 most prolific authors can be observed in Figure 5 based on their number of publications. The author who has the highest number of articles is Elie Bouri and has contributed 9 papers on the topic of cryptocurrency price and volatility forecasting. However, his final contribution is 2.53 papers, which means that this author did not write papers alone but with $9/2.53 = 3.56$ coauthors. This would mean in most of his/her publications, the papers were coauthored by 3 or 4 authors, and the work credit is divided analogously If we take the 10 most prolific authors, their total number of articles is 51, but their individual contribution is only 14.69, which would mean that these authors write articles with $(51/14.69 = 3.47)$ two or three coauthors. The second most productive is Marco Lau Chi Keung with 7 articles and a contribution of 1.78 to these 3 articles. Rangan Guptab produced 6 articles and appeared third at rank.

Table 2 depicts the most influential authors based on total citation, G-index, H-index, and M-index. G, H, and M-indices are metrics used to evaluate the impact and productivity of researchers, particularly in the field of academic publishing. This table shows a slightly different ranking overview of the authors, than the one depicted in Figure 5. Due to the calculation of indices, it is worth noting that the top five authors of Figure 5 and Table 2 are identical. For example, Elie Bouri is ranked first in each of the metrics either in the number of citations, or the number of articles produced, or H-index, G-index, and M-index followed by Marco Lau Chi Keung and Rangan Gupta. Hence, we understand that the first nine authors were the most impactful authors. It is also observed that Ender Demir has risen from the seventh rank in terms of productivity to the fifth rank in terms of citations along with indices. Moreover, Yuze Li, who was in the fourth place in terms of the number of articles published, is no longer in the top 10 list of Table 2. Thus, it is important to compare authors across a wide range of metrics and observe if the maintain their rank. The authors who maintain their rank are more resilient, and their ranking is the most undisputable.

3.5 | The most influential articles in the investigate field

Table 3 reveals the most influential articles in the field of cryptocurrency price and volatility forecasting in terms of the total number of citations. In order to make the comparison of articles more meaningful and fair, it is necessary to compare citations per year. This is so because articles that have been published at earlier times in the past have had more time allocated and more citation opportunities, if one compares them with articles that have been published at a later and more recent time. It is observed that the first most cited article is "Speculative bubbles in Bitcoin markets? An empirical investigation into the fundamental value of Bitcoin" (Cheah & Fry, 2015), and it has been cited 508 times with 56.44 citations per year. This article conducts economic and econometric modeling of bitcoin prices. As is the case for many other asset classes, the authors show that bitcoins are characterized by speculative bubbles. In addition, the authors find empirical evidence that the fundamental price of the Bitcoin is zero. Second most cited article is

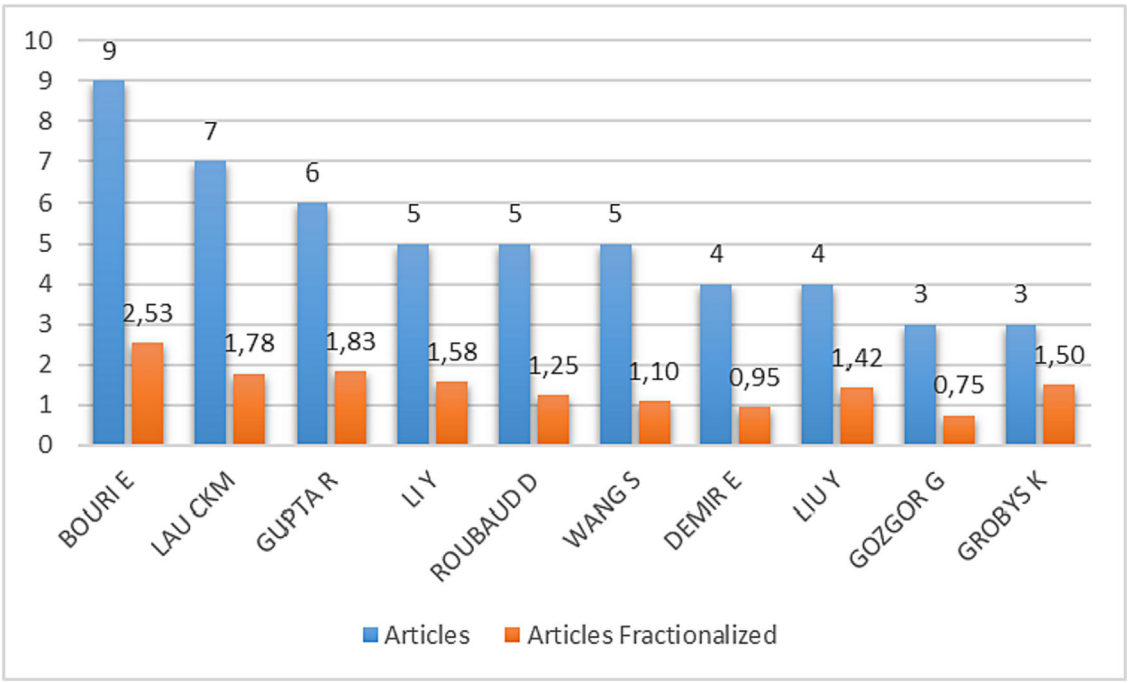


FIGURE 5 Most prolific authors based on number of publications.

TABLE 2 Most prolific authors.

Rank	Author	H-index	G-index	M-index	TC	NP	PY start
1.	Elie Bouri	8	9	1.143	791	9	2017
2	Marco Lau Chi Keung	6	7	1	457	7	2018
3	Rangan Gupta	5	6	0.714	628	6	2017
4	David Roubaud	5	5	0.714	620	5	2017
5	Ender Demir	3	4	0.5	356	4	2018
6	Giray Gozgor	3	3	0.5	353	3	2018
7	Andrew Urquhart	3	3	0.6	149	3	2019
8	Pengfei Wang	3	3	0.6	134	3	2019
9	David Y. Aharon	2	2	0.4	31	2	2019
10	Cüneyt Gürcan Akçora	2	2	0.333	34	2	2018

Abbreviation: NP, number of publications; PY, publication year; TC, total citation.

"Volatility estimation for Bitcoin: A comparison of GARCH models" (Katsiampa, 2017) with 408 citation published in *Economics Letters*. In this paper, the authors search for the optimal conditional heteroskedasticity model with respect to its fit to bitcoin price data.

The third ranked article is entitled as "The economics of Bitcoin price formation" (Ciaian et al., 2016) with 397 citations. It is worth noting that other influential articles come at fourth and fifth position entitled as "BitCoin meets Google Trends and Wikipedia: Quantifying the relationship between phenomena of the Internet era" (Kristoufek, 2013), and "What Are the Main Drivers of the Bitcoin Price? Evidence from Wavelet Coherence Analysis" (Kristoufek, 2015) with 393 and 387 citations, written by same author Ladislav Kristoufek, also ranked in the list of most prolific authors in Figure 5.

3.6 | Country wise article statistics

In terms of the geographic distribution of the literary works on forecasting cryptocurrency, a total of 49 countries have contributed, researchwise, in the field of forecasting cryptocurrencies.

TABLE 3 The most influential articles.

Rank	Article title	Journal	Reference	TC	TCY
1	Speculative bubbles in Bitcoin markets? An empirical investigation into the fundamental value of Bitcoin	*Economics Letters*	Cheah & Fry (2015)	508	56.44
2	Volatility estimation for Bitcoin: A comparison of GARCH models	*Economics Letters*	Katsiampa (2017)	408	58.29
3	The economics of Bitcoin price formation	*Applied Economics*	Ciaian et al. (2016)	397	49.63
4	What are the main drivers of the Bitcoin price? Evidence from Wavelet Coherence Analysis	*Plos One*	Kristoufek (2015)	393	43.67
5	Bitcoin meets Google trends and Wikipedia: Quantifying the relationship between phenomena of the Internet era	*Scientific Reports*	Kristoufek (2013)	387	35.18
6	Can volume predict Bitcoin returns and volatility? A quantiles-based approach	*Economic Modelling*	Balcilar et al. (2017)	292	41.71
7	Does economic policy uncertainty predict the Bitcoin returns? An empirical investigation	*Finance Research Letters*	Demir et al. (2018)	240	40.00
8	Liquidity and market efficiency in cryptocurrencies	*Economics Letters*	Wei (2018)	149	24.83
9	Price discovery of cryptocurrencies: Bitcoin and beyond	*Economics Letters*	Brauneis & Mestel (2018)	146	24.33
10	Persistence in the cryptocurrency market	*Research in International Business and Finance*	Caporale & Plastun (2019)	120	13.33

Abbreviations: TC, total citation; TCY, total citation per year.

China has become the top contributing country in the investigated field, in the world, followed by the UK with their total production of papers of 76 and 39, respectively. The other countries are USA, France, Turkey, Germany, Poland, India, South Africa, and Italy and are the top most producing countries as shown in Table 4. The country wise citation ranking is shown in Table 5. The UK and Lebanon received highest number of citations (1230 and 547, respectively). A most noteworthy point here is that China is the top contributing country to crypto currency research but has not received a considerable number of citations. Conversely, Spain, Cheque Republic, and Lebanon appear to receive the highest average article citation at 147.

3.7 | Network analysis (theme identification)

The network analysis approach is a quantitative method for analyzing scientific publications and has become progressively accepted within Bibliometric studies (Randhawa et al., 2016). Co-word analysis is used to map the conceptual structure of forecasting cryptocurrencies research. This analytical approach allows the creation of visualization with nodes to represent yield, the location of terminological subdomains, and their thematic development.

3.8 | Word cloud

According to Secundo et al. (2019), keywords are used to signal important themes in articles. Keyword analysis allows the analysis of a large amount of text without losing the focus on small amounts of material in considerable depth. Co-word analysis manages to trace the existence of scientific networks in a field (Callon et al., 1983; Ding et al., 2001) and visualizes the conceptual structure of the field by using the word co-occurrences in a bibliographic collection (Yang et al., 2012) and by highlighting the nexus of the main theme with the emerging subfields of the study (Köseoğlu & Parnell, 2020). The most frequently occurred author keywords in our sample are illustrated in the word cloud (Figure 6). Our analysis reveals 476 authors keywords in a total of 168 documents. The keyword *Bitcoin* has appeared the most, that is, 84 times (23% of total author keywords),

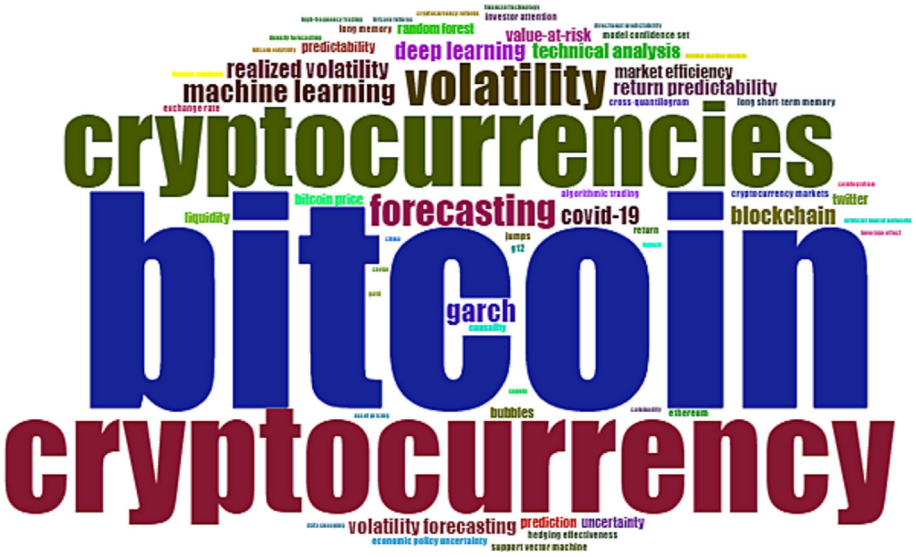
TABLE 4 Top contributing countries based the affiliation of all authors.

Country	Total production of research (in published papers)	Country	Total production of research (in published papers)
China	76	Lebanon	10
UK	39	South Africa	10
France	31	Switzerland	10
USA	30	Canada	9
Turkey	23	Greece	9
Germany	16	Pakistan	8
Poland	15	Netherlands	7
Czech republic	12	South Korea	7
India	10	Tunisia	7
Itlay	10	Denmark	6

TABLE 5 Most cited countries.

No.	Documents	Total citations	Average Articles Citation
	United Kingdom	1230	94.62
	Lebanon	547	109.40
	Spain	441	147.00
	Czech Republic	406	135.33
	China	246	10.25
	USA	164	18.22
	Austria	161	80.50
	Turkey	157	19.63
	Italy	139	34.75
	Switzerland	131	32.75

FIGURE 6 Word cloud allowing.



followed by *cryptocurrency* and *cryptocurrencies* with 43 and 14 times, respectively. These keyword frequencies indicate that bitcoin, cryptocurrency, cryptocurrencies, volatility, forecasting, and GARCH are the most trending themes this domain.

3.9 | Co-occurrence network

Figure 7 shows a keyword co-occurrence network that delineates the major themes in terms of seven clusters.

Minimum occurrence of the keywords investigated is three times. This result appears out of a total of 751 keywords, 57 have met the criteria. Cluster analysis has been applied in the co-occurrence network framework. Cluster 1 in red is entitled as "electronic money," cluster 2 in green is entitled as "machine learning," cluster 3 in blue as bitcoin, cluster 4 in yellow as cryptocurrencies, cluster 5 in purple as cryptocurrency, cluster 6 in sky-blue as investments, and cluster 7 in orange as forecasting. Table 6 shows a complementary summary description including the total occurrence (TO) of each keyword, Links of each keyword which shows the unique occurrence of each term with other terms, and total link strength (TLS) which shows the TO of each term with other terms in the entire topic (Donthu et al., 2021).

3.10 | Author co-citation network (ACA)

To analyze the network relation among different units of analysis, we have employed the VOSViewer developed by van Eck and Waltman (2010). VOS Viewer was selected due to its ability to create a map based on network data, bibliographic data, and text data and the flexibility to support all types of files. The file used for visualization purposes is in csv format, which contains bibliographic information of the articles.

ACA measures how often two authors, rather than two documents, are cited together by later published articles. ACA is effective in studying the knowledge base and the intellectual structures of research fields. ACA assumes that two authors are related if they both are related to a third paper in terms of the academic research work they do. It then follows that the more closely related two authors are to a third paper, the more closely they are related to each other too (Zhao & Strotmann, 2020). Analysis of co-citation patterns for authors was performed using the full counting method. Of the 7155 authors, 108 authors have met the threshold criteria of 20 minimum citations. Co-citation analysis of the cited authors resulted in the formation of four clusters depicted by four different colors in Figure 8. Additionally, Figure 8 shows the authors co-citation. Cluster 1 (in red color) depicts the work of 36 highly cited authors, and this is one of the largest clusters. Cluster 2 (in green) includes

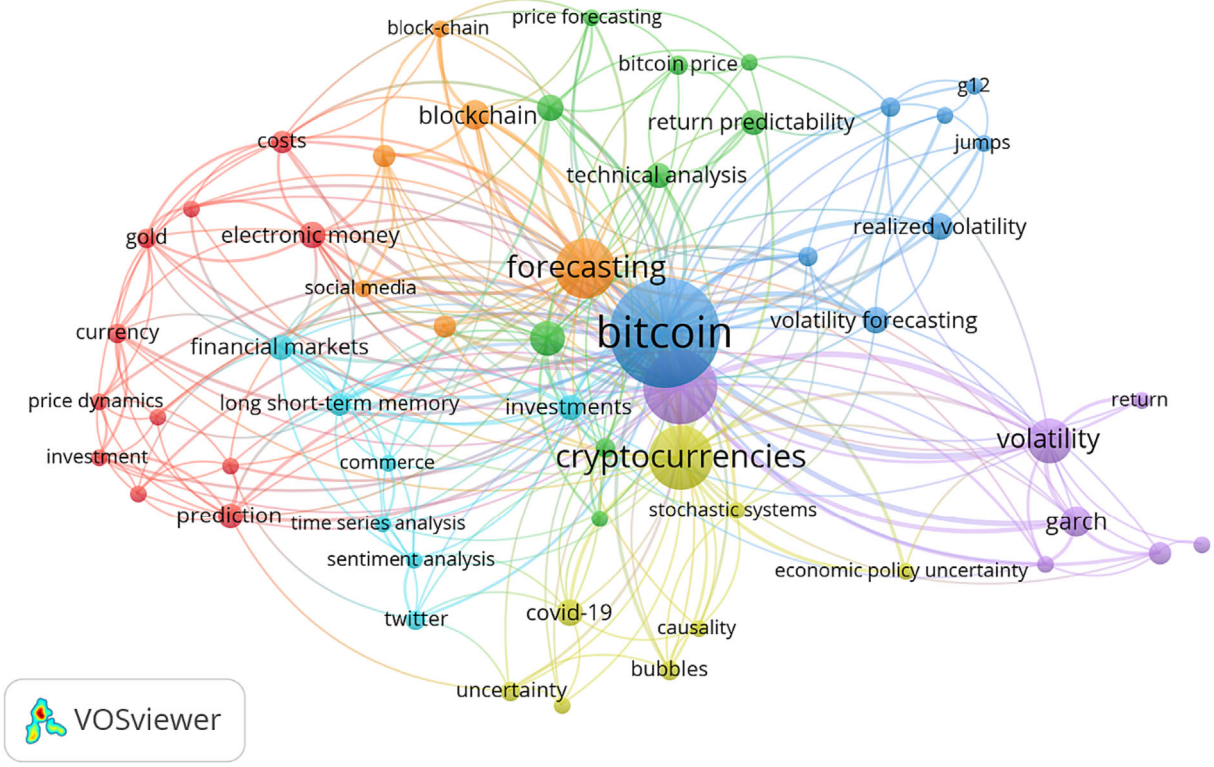


FIGURE 7 Keywords co-occurrence.

TABLE 6 Summary of each cluster.

Keyword	TO	Links	TLS	Keyword	TO	Links	TLS
Cluster 1: Electronic money				Cluster 2: Machine learning			
Electronic money	7	16	26	Machine learning	11	18	30
Prediction	6	12	18	Deep learning	7	13	22
Cost	5	13	21	Technical analysis	6	10	14
Currency	4	12	17	Return predictability	6	7	11
Gold	4	9	14	Random forest	4	8	12
Commodity	3	9	13	Bitcoin price	4	7	7
Price dynamics	3	9	12	Price forecasting	3	9	12
Exchange rate	3	9	12	Support vector machine	3	5	9
Investor attention	3	9	10				
Investment	3	8	12				
Cross contilogram	3	7	8				
Cluster 3: Bitcoin				Cluster 4: Cryptocurrencies			
Bitcoin	87	48	181	Cryptocurrencies	33	26	53
Volatility forecasting	7	9	18	Covid 19	7	9	11
Realized volatility	7	6	13	Bubbles	4	7	10
Ethereum	4	9	13	Uncertainty	4	7	8
Liquidity	4	8	9	Stochastic system	3	8	12
Jumps	3	6	8	Causality	3	6	7
Long memory	3	4	6	Hedging effectiveness	3	5	5
				Economic policy uncertainty	3	3	7
Cluster 5: Cryptocurrency				Cluster 6: Investment			
Cryptocurrency	43	40	99	Investment	6	17	27
Volatility	17	14	38	Financial markets	6	16	24
GARCH	9	9	27	Long term memory	5	14	19
Value at risk	5	7	11	Twitter	4	8	10
Model confidence set	3	7	12	Sentiment analysis	3	9	11
Return	3	3	6	Time series analysis	3	8	10
Cryptocurrency market	3	2	2	Commerce	3	7	9
Cluster 7: Forecasting							
Forecasting			29	32			90
Blockchain			8	11			23
Social networking (online)			5	10			17
Market efficiency			5	6			13
Social media			3	10			13
Bloch-chain			3	8			13

Abbreviations: TLS, total link strength; TO, total occurrence.

31 authors. Cluster 3 (in blue) includes 23 authors. Cluster 4 (in yellow) includes 18 authors. The most prominent authors in these clusters include Elie Bouri, David Roubaud, Andrew Urquhart, and Marco Lau Chi Keung, and they were also found in the most prolific authors list.

3.11 | Country collaboration

Figure 9 depicts the country collaboration map on crypto currencies research (based on all authors affiliation). It has illustrated that the collaborative works on crypto

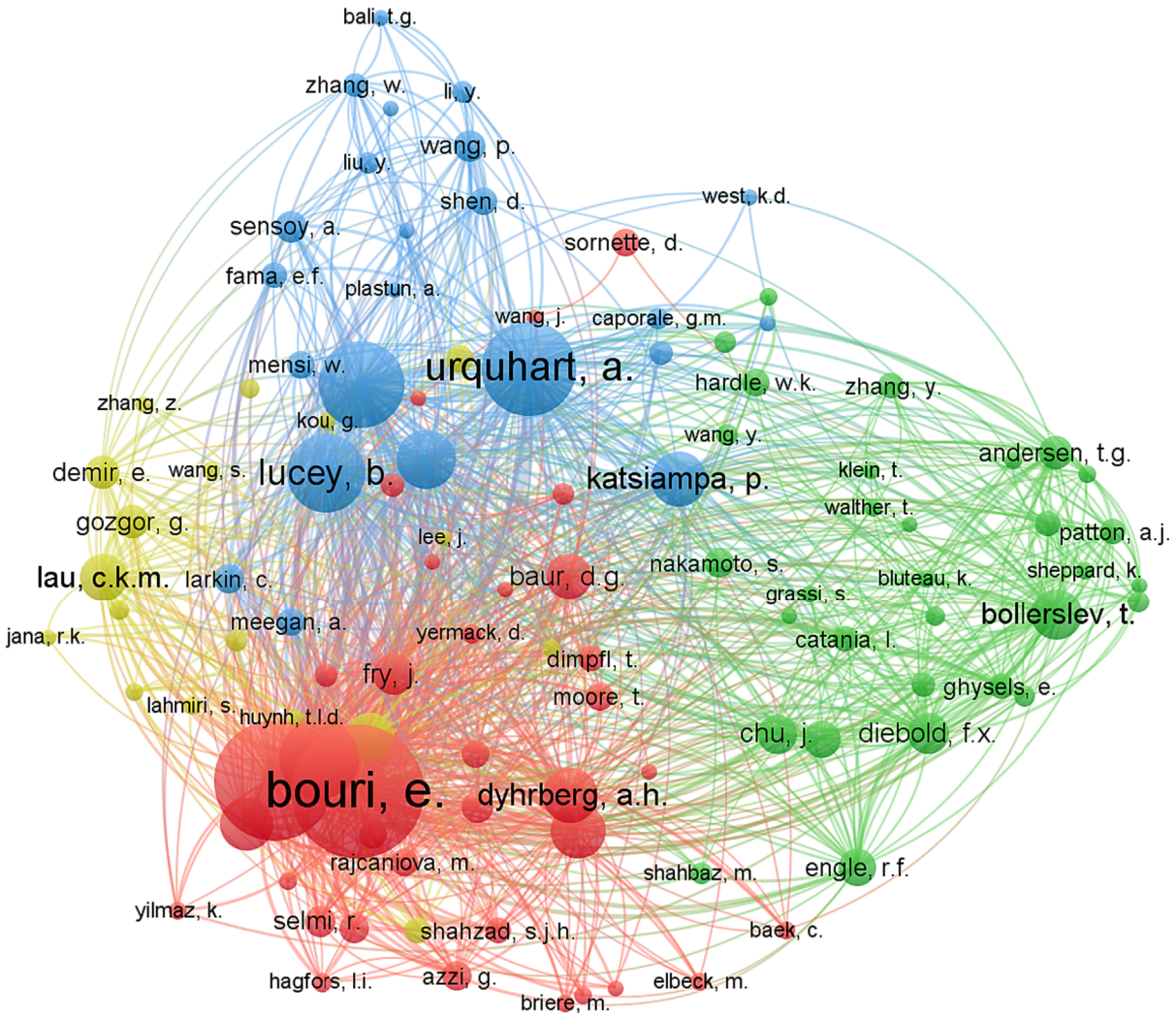


FIGURE 8 Author co-citation network.

currency research have been increased between China, UK, France, and Germany.

It is well observed that the UK and China have a high number of collaboration networks each with 16 participating countries and France with 9 countries. These are relatively high as compared with other countries across the globe in this research arena. Other countries with a remarkable collaborative network include Germany, Turkey, USA, and Poland. However, various countries across the globe are required to collaborate among themselves to enhance the awareness about forecasting cryptocurrencies and higher needs of necessary capital flow towards the developing countries.

3.12 | Thematic analysis

Figure 10 illustrates the thematic map in the field of forecasting cryptocurrency. The thematic map is implemented based on author keywords using biblioshiny, which is a web-based routine developed in bibliomatrix package built in R-language. The thematic map is composed of density (vertical axis) and centrality (horizontal axis). It has been segregated into four major quadrants (or referred as themes) based on their importance (Aria et al., 2017). The quadrant in the upper right side is referred to as "a motor theme" with high impact and high centrality. The name implies high moving or energy power. The keywords in this theme such as "bitcoin," "cryptocurrenacy," "cryptocurrencies," "machine learning," "covid 19," "technical analysis," "deep learning, "prediction," "uncertainty," "cointegration," "commodity," "gold," "twitter," "natural language processing," "sentiment analysis," and "bitcoin volatility" are highly developed and serve as a basic insight for forecasting cryptocurrencies. It highlights the importance of cryptocurrencies as they have paved the way for the development of decentralized applications and smart

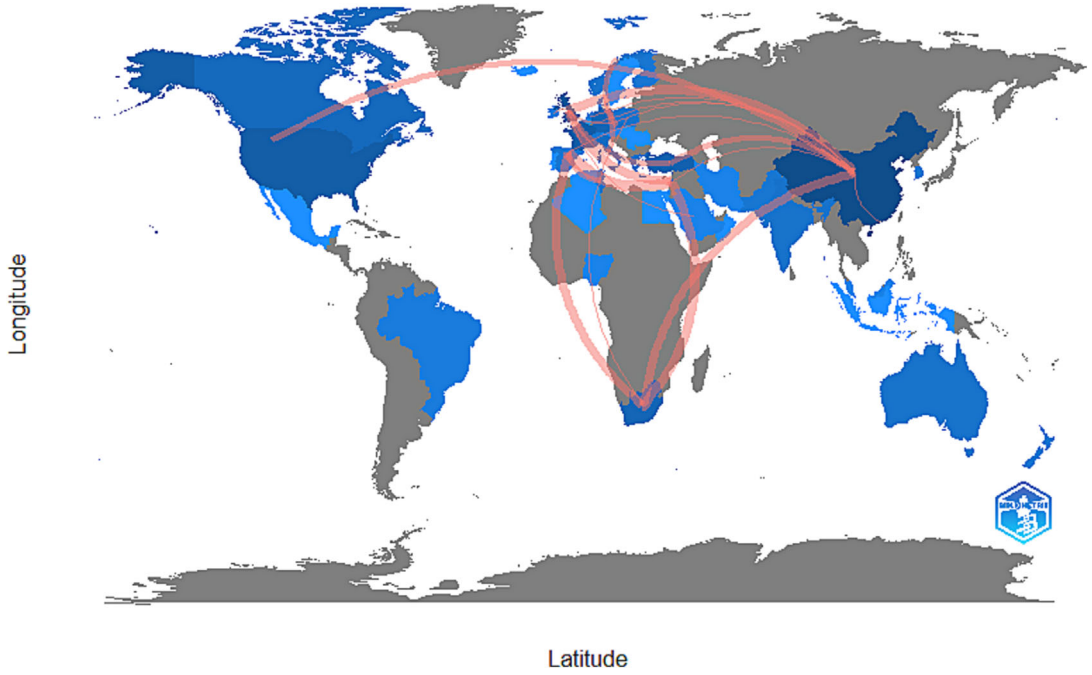


FIGURE 9 Countries collaboration map.

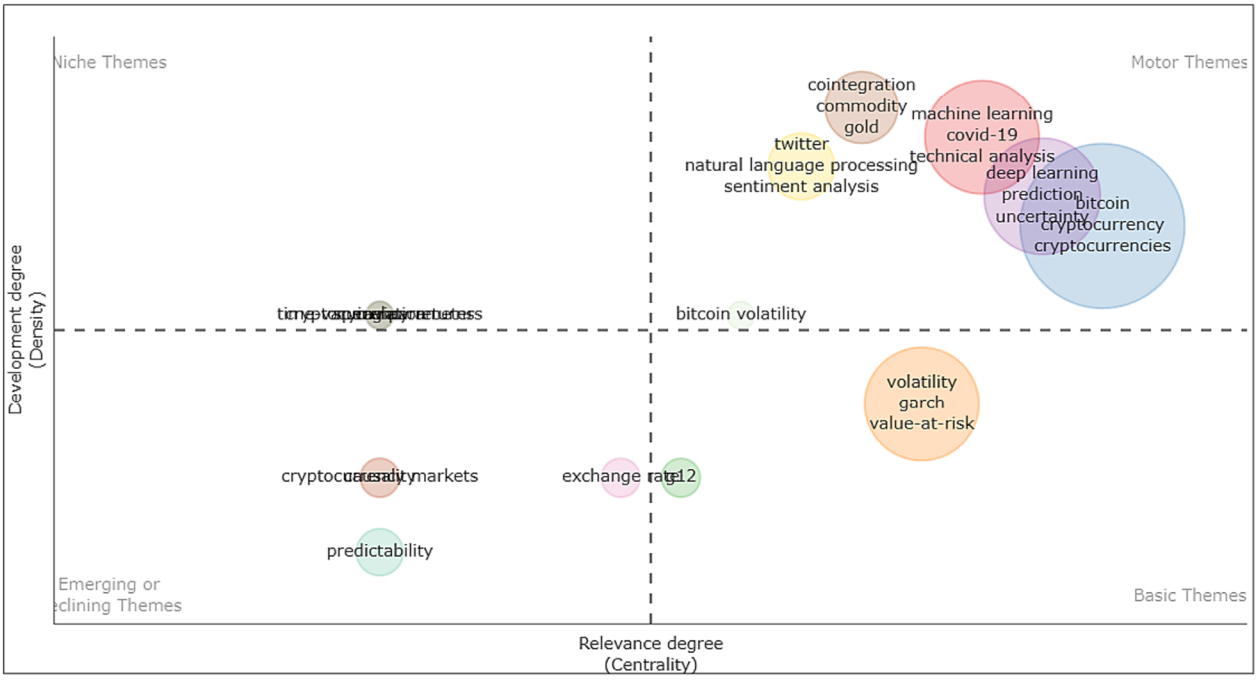


FIGURE 10 Thematic map.

contracts, which, in turn, can automate and streamline various processes. However, they also come with risks and challenges such as the regulatory uncertainty, the market volatility, and security concerns should be carefully considered when engaging with cryptocurrencies. To this end, it also emphasizes on the proper forecasting of finance in terms of investment with the effective usage of technology and the capital markets. It is likely noted here that future research could focus on new areas using these aspects across the different clusters, rather than relying on these few specific keywords.

The "basic theme quadrant" (lower right-side) is with high centrality and low impact. It includes the topics "volatility," "GARCH," "value at risk," and "G12." The

niche theme quadrant (upper left-side) is with high impact but low centrality (lower left side). The keyword in this quadrant includes "speculation" only. Speculation involves a long-term approach focused on the underlying value and fundamental factors of an asset.

The emerging theme (lower left side) is with low centrality and low impact. It includes "cryptocurrency markets," "exchange," and "predictability" as major keywords curating future research areas with new and fresh ideas that would benefit the various actors and stakeholders. Due to the volatility and risk, the concept of cryptocurrency with its intent to promote innovation and technological advancement and financial inclusion, it becomes evident that the various forms of cryptocurrency have been deeply investigated with several names in different time horizons with their relative importance such as digital currency, block chain-based currency, coin, crypto, token, and altcoin. This corroborates the idea that the domain of cryptocurrencies has turned out to be an important field in the present era that needs to be expanded further. Thus, more research is imminent shortly and in the future.

4 | DIRECTIONS FOR FUTURE RESEARCH

4.1 | Future methodological advancements

As the field of cryptocurrency forecasting continues to evolve, there are several areas where future research can focus on methodological advancements. The following subsections outline some of the key suggestions provided in the abstracts, indicating potential avenues for improving forecasting techniques and methodologies.

Bouri and Gupta (2021) highlighted the statistical strength of internet-based economic uncertainty-related queries in predicting bitcoin returns. Future research can further explore the use of internet search-based measures, such as sentiment analysis derived from social media platforms like Twitter. Researchers can investigate optimal time intervals and explore the integration of sentiment and volume of tweets to not only predict the direction but also the magnitude of price changes. The use of neural network models, including recurrent nets and convolutional networks, can be explored for more reliable predictions (Critien et al., 2022). Jiang et al. (2022) proposed the time-varying mixture (TVM)-accelerating generalized autoregressive score (aGAS) model for forecasting the density of daily cryptocurrency returns and value at risk (VaR). Future research can expand on this approach by incorporating policy factors and exploring the impact of policy on cryptocurrency volatility. Additionally, combining the aGAS model with other models, such as copula functions, can be investigated to study the tail dependence of cryptocurrencies Further advancements can be made by exploring the use of TVM-aGAS models to predict cryptocurrency prices and study the associated risks. Xia et al. (2023) suggested the inclusion of high- and low-frequency exogenous data to build a powerful volatility forecasting model that combines economic policy uncertainty (EPU) and Cryptocurrency Uncertainty (UCRY) indices. Future research can focus on developing such models and investigating the impact of temporal lags in more detail (Xia et al., 2023). Exploring the spillover and connectedness between UCRY and the cryptocurrency market can provide valuable insights into the relationship between uncertainty and cryptocurrency trading behaviors (Xia et al., 2023). Gerritsen et al. (2022) analyzed the impact of expert predictions on bitcoin returns and found that bearish predictions are followed by negative abnormal returns, and bullish predictions do not significantly affect returns. Future research can delve deeper into understanding the factors influencing expert predictions and investigate the effect of different market regimes on expert predictions. Additionally, Wang et al. (2022) suggested exploring the development of models of informed trading suitable for the cryptocurrency market to improve price efficiency. Li et al. (2022) proposed a hybrid bidirectional deep-learning model for forecasting the daily price change in the bitcoin market. Future research can explore the inclusion of features from external financial environments to enhance the predictive power of the model. The integration of ensemble learning methods, such as random forest or gradient boosting, with volatility prediction frameworks can be investigated to improve forecast accuracy (Müller et al., 2022). Furthermore, Liu et al. (2023) recommended incorporating higher frequency data and exploring the predictive power of other features, such as order book data, in forecasting models. Bouri et al. (2022) emphasized the importance of analyzing cryptocurrency risk and tail dependence. Future research can conduct further analysis on the tail dependence structure between cryptocurrencies and traditional assets. Exploring alternative measures of tail dependence, such as the tail-risk spillover index, can provide a more comprehensive understanding of the dynamics in the cryptocurrency market.

Future methodological advancements in cryptocurrency forecasting can include the utilization of internet search-based measures and sentiment analysis, TVM models for VaR forecasting, incorporation of EPU, analysis of expert predictions and trading behavior, utilization of machine learning techniques and ensemble learning

models, and further analysis of cryptocurrency risk and tail dependence. These areas of research provide promising avenues for improving the accuracy and robustness of cryptocurrency forecasting models.

4.2 | Emerging research themes

As the field of cryptocurrency forecasting continues to evolve, several emerging research themes have gained prominence. These themes reflect the growing interest in understanding and improving the accuracy of cryptocurrency price and volatility predictions. This subchapter explores some of these emerging research themes.

Researchers, such as Bouri and Gupta (2021), have highlighted the predictive power of internet search-based measures of uncertainty in forecasting bitcoin returns. Further exploration of these measures, along with sentiment analysis of online content, can enhance our understanding of the relationship between investor sentiment, uncertainty, and cryptocurrency price movements. The introduction of the accelerating generalized autoregressive score (aGAS) technique into TVM models, as proposed by Jiang et al. (2022), shows promise in forecasting the volatility of cryptocurrencies. Investigating the effectiveness of these models in predicting VaR can provide valuable insights into risk management strategies in the cryptocurrency market. The role of EPU and UCRY indices in forecasting bitcoin volatility has been explored by Xia et al. (2023). Further investigation into the impact of these indices, including spillover and connectedness effects, can shed light on the relationship between policy factors, uncertainty, and cryptocurrency market dynamics. Analyzing expert predictions and trading behavior in the cryptocurrency market, as discussed by Gerritsen et al. (2022), offers valuable insights into the role of information intermediaries. Future research can delve deeper into the factors influencing expert predictions and explore the effects of different market regimes on expert performance. The application of machine learning algorithms for cryptocurrency return prediction has shown promise (Wang et al., 2022). Future research can explore the integration of ensemble learning methods, such as random forest or gradient boosting, to further enhance prediction accuracy and robustness (Müller et al., 2022). Additionally, incorporating alternative features and higher frequency data can improve the forecasting performance of machine learning models (Liu et al., 2023). Understanding cryptocurrency risk and tail dependence is crucial for effective risk management. Bouri et al. (2022) highlight the importance of analyzing tail dependence between cryptocurrencies and traditional assets. Future research can explore alternative measures of tail dependence and investigate the dynamics of tail-risk spillover in the cryptocurrency market.

These emerging research themes provide valuable directions for future studies in cryptocurrency forecasting. By addressing these themes, researchers can contribute to the advancement of knowledge in the field and improve the accuracy of cryptocurrency price and volatility predictions.

4.3 | Research questions based on the suggested future research

This sub-section explores research questions based on the suggested future research. The key research questions are derived from a comprehensive review of articles published in Q1 or A-tier journals in the Scopus database over the past 3 years. These questions have been carefully extracted to shed light on the emerging research themes in cryptocurrency forecasting. As shown in Table 7, research questions are divided into three groups, and each group focuses on specific aspects within the field. The first group, "Internet Search-Based Measures and Sentiment Analysis," examines the relationship between internet search-based measures, sentiment analysis, and cryptocurrency price movements. The second group, "Time-Varying Mixture Models and VaR Forecasting," investigates the effectiveness, advantages, and limitations of TVM models in forecasting VaR for cryptocurrencies. The third group, "Economic Policy Uncertainty and Expert Predictions," delves into the impact of EPU on cryptocurrency volatility, the influence of UCRY on price dynamics, and the accuracy of expert predictions in the cryptocurrency market. By framing the research questions based on recent publications in esteemed journals, this subchapter provides a solid foundation for future investigations in the field of cryptocurrency forecasting.

5 | CONCLUSION

This SLR aimed to analyze the evolution and publication trends of cryptocurrency forecasting; identifies influential authors, journals, and conceptual structure keywords; examines collaboration structures among countries; and explores future research directions in cryptocurrency forecasting within business management, finance, and economics. By employing a systematic approach and following PRISMA guidelines, a comprehensive analysis of 168 articles was conducted.

The findings of this study revealed several important insights into the field of cryptocurrency forecasting. First, the publication trends indicated a significant increase in

TABLE 7 Research questions for future cryptocurrencies forecasting studies.

Group name	Research questions
Group 1: Internet Search-Based Measures and Sentiment Analysis	1. What is the relationship between internet search-based measures of uncertainty and cryptocurrency price movements?
	2. How can sentiment analysis of online content contribute to the accuracy of cryptocurrency price predictions?
	3. Can combining internet search-based measures and sentiment analysis improve the forecasting performance of cryptocurrencies?
Group 2: Time-Varying Mixture Models and VaR Forecasting	1. How effective are time-varying mixture (TVM) models with accelerating generalized autoregressive score (aGAS) technique in forecasting VaR for cryptocurrencies?
	2. What are the advantages and limitations of TVM models compared to traditional models in cryptocurrency volatility prediction?
	3. How do different TVM model specifications and parameterizations affect the accuracy of VaR forecasts in the cryptocurrency market?
	4. Can TVM models capture tail-risk spillovers and extreme events in the cryptocurrency market more effectively than other models?
	5. How do TVM models perform in forecasting VaR for different cryptocurrencies and under various market conditions?
Group 3: Economic Policy Uncertainty and Expert Predictions	1. What is the impact of economic policy uncertainty (EPU) on the volatility of cryptocurrencies, and how does it differ across various policy contexts?
	2. How does Cryptocurrency Uncertainty (UCRY) influence the price dynamics and risk profiles of cryptocurrencies?
	3. What are the spillover effects and interconnections between economic policy uncertainty, Cryptocurrency Uncertainty, and other financial markets?
	4. How accurate are expert predictions in the cryptocurrency market, and what factors influence their performance?
	5. How does the accuracy of expert predictions vary under different market regimes and during periods of high uncertainty?

Abbreviation: VaR, value at risk.

research output from 2017 onwards, coinciding with the bitcoin price bubbles and the growing interest from the scientific community, investors, and economic policymakers. The year 2021 emerged as the most productive year, with a notable rise in publications.

The analysis of influential journals identified "Finance Research Letters" as the most productive outlet, followed by "Economics Letters" and "Research in International Business and Finance." Whereas "Economics Letters" received the highest number of citations, "Finance Research Letters" demonstrated the highest impact factor and H-index, indicating its significant influence in the field.

Regarding prolific authors, Elie Bouri emerged as the most prolific author, followed by Marco Lau Chi Keung and Rangan Gupta. These authors, along with other highly productive researchers, collectively contributed to the advancement of knowledge in cryptocurrency price and volatility forecasting. The collaborative nature of research in this field was evident, with most articles being co-authored by multiple authors.

In terms of country contributions, China emerged as the top contributor in the field, followed by the UK. However, when considering citation impact, the UK received the highest number of citations, indicating the influence of research originating from this country. Collaborative works were observed between countries such as China, the UK, France, and Germany, suggesting an international collaboration network in cryptocurrency research.

The network analysis, employing co-word and co-citation analysis, revealed prominent themes and author relationships within the field. The major themes identified included bitcoin, cryptocurrency, volatility, forecasting, machine learning, investments, and blockchain. These themes reflect the focus on understanding the dynamics of cryptocurrencies, exploring predictive models, and investigating the potential of blockchain technology.

The study also highlighted several directions for future research in cryptocurrency forecasting. Methodological advancements were suggested, such as the

utilization of internet search-based measures and sentiment analysis, exploration of TVM models for VaR forecasting, incorporation of EPU, analysis of expert predictions and trading behavior, utilization of machine learning techniques, and further analysis of cryptocurrency risk and tail dependence.

Emerging research themes identified included the predictive power of internet search-based measures, the application of TVM models, the role of EPU and UCRY, analysis of expert predictions, and the use of machine learning algorithms for cryptocurrency return prediction. These themes present exciting opportunities for researchers to contribute to the field and improve the accuracy of cryptocurrency price and volatility predictions.

ACKNOWLEDGMENTS

We would like to thank the anonymous reviewers for their insightful comments, which significantly raised the paper's quality.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

ORCID

Tomas Pečiulis https://orcid.org/0009-0006-8837-6580
Nisar Ahmad https://orcid.org/0000-0001-7285-0627

REFERENCES

Adams, R. J., Smart, P., & Huff, A. S. (2017). Shades of grey: Guidelines for working with the grey literature in systematic reviews for management and organizational studies. *International Journal of Management Reviews*, *19*(4), 432–454. https://doi.org/10.1111/IJMR.12102

Ahmad, N., Aghdam, R. F. Z., Butt, I., & Naveed, A. (2020). Citation-based systematic literature review of energy-growth nexus: An overview of the field and content analysis of the top 50 influential papers. *Energy Economics*, *86*, 104642. https://doi.org/10.1016/j.eneco.2019.104642

Ahmad, N., Menegaki, A. N., & Al-Muharrami, S. (2020). Systematic literature review of tourism growth nexus: An overview of the literature and a content analysis of 100 most influential papers. *Journal of Economic Surveys*, *34*(5), 1068–1110. https://doi.org/10.1111/joes.12386

Ahmad, N., Naveed, A., Ahmad, S., & Butt, I. (2020). Banking sector performance, profitability, and efficiency: A citation-based systematic literature review. *Journal of Economic Surveys*, *34*(1), 185–218. https://doi.org/10.1111/joes.12346

Alkhudary, R., Brusset, X., & Fenies, P. (2020). Blockchain in general management and economics: A systematic literature review. *European Business Review*, *32*(4), 765–783. https://doi.org/10.1108/EBR-11-2019-0297/FULL/PDF

Aria, M., & Cuccurullo, C. (2017). bibliometrix: An R-tool for comprehensive science mapping analysis. *Journal of informetrics*, *11*(4), 959–975.

Asatullaeva, Z., Aghdam, R. F. Z., Ahmad, N., & Tashpulatova, L. (2021). The impact of foreign aid on economic development: A systematic literature review and content analysis of the top 50 most influential papers. *Journal of International Development*, *33*(4), 717–751. https://doi.org/10.1002/jid.3543

Balcilar, M., Bouri, E., Gupta, R., & Roubaud, D. (2017). Can volume predict Bitcoin returns and volatility? A quantiles-based approach. *Economic Modelling*, *64*, 74–81. https://doi.org/10.1016/J.ECONMOD.2017.03.019

Bandara, W., Miskon, S., & Fielt, E. (2011). A systematic, tool-supported method for conducting literature reviews in information systems. 19th European Conference on Information Systems, ECIS 2011.

Bennett, J., Lubben, F., Hogarth, S., & Campbell, B. (2005). Systematic reviews of research in science education: Rigour or rigidity? *International Journal of Science Education*, *27*(3), 387–406. https://doi.org/10.1080/0950069042000323719

Bouri, E., Christou, C., & Gupta, R. (2022). Forecasting returns of major cryptocurrencies: Evidence from regime-switching factor models. *Finance Research Letters*, *49*, 103193. https://doi.org/10.1016/J.FRL.2022.103193

Bouri, E., & Gupta, R. (2021). Predicting bitcoin returns: Comparing the roles of newspaper- and internet search-based measures of uncertainty. *Finance Research Letters*, *38*, 101398. https://doi.org/10.1016/J.FRL.2019.101398

Brauneis, A., & Mestel, R. (2018). Price discovery of cryptocurrencies: Bitcoin and beyond. *Economics Letters*, *165*, 58–61.

Callon, M., Courtial, J.-P., Turner, W. A., & Bauin, S. (1983). From translations to problematic networks: An introduction to co-word analysis. *Social Science Information*, *22*(2), 191–235.

Caporale, G. M., & Plastun, A. (2019). Price overreactions in the cryptocurrency market. *Journal of Economic Studies*, *46*(5), 1137–1155.

Chatha, K. A., Butt, I., & Tariq, A. (2015). Research methodologies and publication trends in manufacturing strategy a content analysis based literature review. *International Journal of Operations and Production Management*, *35*(4), 487–546. https://doi.org/10.1108/IJOPM-07-2012-0285/FULL/XML

Cheah, E. T., & Fry, J. (2015). Speculative bubbles in Bitcoin markets? An empirical investigation into the fundamental value of Bitcoin. *Economics Letters*, *130*, 32–36. https://doi.org/10.1016/J.ECONLET.2015.02.029

Ciaian, P., Rajcaniova, M., & Kancs, d.' A. (2016). The economics of BitCoin price formation. *Applied Economics*, *48*(19), 1799–1815. https://doi.org/10.1080/00036846.2015.1109038

Colicchia, C., & Strozzi, F. (2012). Supply chain risk management: A new methodology for a systematic literature review. *Supply Chain Management*, *17*(4), 403–418. https://doi.org/10.1108/13598541211246558/FULL/PDF

Collins, C., Dennehy, D., Conboy, K., & Mikalef, P. (2021). Artificial intelligence in information systems research: A systematic literature review and research agenda. *International Journal of Information Management*, *60*, 102383. https://doi.org/10.1016/J.IJINFOMGT.2021.102383

Cong, L. W., He, Z., & Li, J. (2021a). Decentralized mining in centralized pools. *The Review of Financial Studies*, *34*(3), 1191–1235. https://doi.org/10.1093/RFS/HHAA040

Cong, L. W., Li, Y., & Wang, N. (2021b). Tokenomics: Dynamic adoption and valuation. *The Review of Financial Studies*, *34*(3), 1105–1155. https://doi.org/10.1093/RFS/HHAA089

Coombes, P. H., & Nicholson, J. D. (2013). Business models and their relationship with marketing: A systematic literature review. *Industrial Marketing Management*, *42*(5), 656–664. https://doi.org/10.1016/J.INDMARMAN.2013.05.005

Corbet, S., Lucey, B., Urquhart, A., & Yarovaya, L. (2019). Cryptocurrencies as a financial asset: A systematic analysis. *International Review of Financial Analysis*, *62*, 182–199. https://doi.org/10.1016/J.IRFA.2018.09.003

Critien, J. V., Gatt, A., & Ellul, J. (2022). Bitcoin price change and trend prediction through twitter sentiment and data volume. *Financial Innovations*, *8*(1), 45. https://doi.org/10.1186/S40854-022-00352-7

Dangelico, R. M., & Vocalelli, D. (2017). "Green Marketing": An analysis of definitions, strategy steps, and tools through a systematic review of the literature. *Journal of Cleaner Production*, *165*, 1263–1279. https://doi.org/10.1016/J.JCLEPRO.2017.07.184

Demir, E., Gozgor, G., Lau, C. K. M., & Vigne, S. A. (2018). Does economic policy uncertainty predict the Bitcoin returns? An empirical investigation. *Finance Research Letters*, *26*, 145–149. https://doi.org/10.1016/J.FRL.2018.01.005

Ding, Y., Chowdhury, G. G., & Foo, S. (2001). Bibliometric cartography of information retrieval research by using co-word analysis. *Information Processing & Management*, *37*(6), 817–842.

Durach, C. F., Kembro, J., & Wieland, A. (2017). A new paradigm for systematic literature reviews in supply chain management. *Journal of Supply Chain Management*, *53*(4), 67–85. https://doi.org/10.1111/JSCM.12145

Falagas, M. E., Pitsouni, E. I., Malietzis, G. A., & Pappas, G. (2008). Comparison of PubMed, Scopus, Web of Science, and Google Scholar: Strengths and weaknesses. *The FASEB Journal*, *22*(2), 338–342. https://doi.org/10.1096/FJ.07-9492LSF

Fiaz, A., Ahmad, N., Al-Abri, A., Khurshid, N., & Menegaki, A. (2023). Exchange rate misalignment: A systematic literature review based on citation and content analysis. *OPEC Energy Review.*, *47*, 176–196. https://doi.org/10.1111/OPEC.12278

Franceschini, F., Maisano, D., & Mastrogiacomo, L. (2016). Empirical analysis and classification of database errors in Scopus and Web of Science. *Journal of Informetrics*, *10*(4), 933–953. https://doi.org/10.1016/J.JOI.2016.07.003

Garcia, D., Tessone, C. J., Mavrodiev, P., & Perony, N. (2014). The digital traces of bubbles: feedback cycles between socio-economic signals in the Bitcoin economy. *Journal of the Royal Society Interface*, *11*(99), 20140623. https://doi.org/10.1098/RSIF.2014.0623

Garousi, V., & Mäntylä, M. V. (2016). Citations, research topics and active countries in software engineering: A bibliometrics study. *Computer Science Review*, *19*, 56–77. https://doi.org/10.1016/J.COSREV.2015.12.002

Gast, J., Gundolf, K., & Cesinger, B. (2017). Doing business in a green way: A systematic review of the ecological sustainability entrepreneurship literature and future research directions. *Journal of Cleaner Production*, *147*, 44–56. https://doi.org/10.1016/J.JCLEPRO.2017.01.065

Gerritsen, D. F., Lugtigheid, R. A. C., & Walther, T. (2022). Can bitcoin investors profit from predictions by crypto experts? *Finance Research Letters*, *46*, 102266. https://doi.org/10.1016/J.FRL.2021.102266

Glock, C. H., Grosse, E. H., Jaber, M. Y., & Smunt, T. L. (2019). Applications of learning curves in production and operations management: A systematic literature review. *Computers & Industrial Engineering*, *131*, 422–441. https://doi.org/10.1016/J.CIE.2018.10.030

Gregorio, V. F., Pié, L., & Terceño, A. (2018). A systematic literature review of bio, green and circular economy trends in publications in the field of economics and business management. *Sustainability*, *10*(11), 4232. https://doi.org/10.3390/SU10114232

Guerras-Martín, L. Á., Madhok, A., & Montoro-Sánchez, Á. (2014). The evolution of strategic management research: Recent trends and current directions. *BRQ Business Research Quarterly*, *17*(2), 69–76. https://doi.org/10.1016/J.BRQ.2014.03.001/ASSET/IMAGES/LARGE

Harzing, A. W., & Alakangas, S. (2016). Google Scholar, Scopus and the Web of Science: A longitudinal and cross-disciplinary comparison. *Scientometrics*, *106*(2), 787–804. https://doi.org/10.1007/S11192-015-1798-9/TABLES/4

Harzing, A. W., & Van Der Wal, R. (2009). A Google Scholar h-index for journals: An alternative metric to measure journal impact in economics and business. *Journal of the American Society for Information Science and Technology*, *60*(1), 41–46. https://doi.org/10.1002/ASI.20953

Hohenstein, N. O., Feisel, E., & Hartmann, E. (2014). Human resource management issues in supply chain management research: A systematic literature review from 1998 to 2014. *International Journal of Physical Distribution and Logistics Management*, *44*(6), 434–463. https://doi.org/10.1108/IJPDLM-06-2013-0175/FULL/PDF

Hussain, S. M., Ahmad, N., & Ahmed, S. (2023). Applications of high-frequency data in finance: A bibliometric literature review. *International Review of Financial Analysis*, 102790. https://doi.org/10.1016/j.irfa.2023.102790

Jámbor, A., & Török, Á. (2019). The economics of Arundo donax—A systematic literature review. *Sustainability*, *11*(15), 4225. https://doi.org/10.3390/SU11154225

Jeung, C. W., Yoon, H. J., Park, S., & Jo, S. J. (2011). The contributions of human resource development research across disciplines: A citation and content analysis. *Human Resource Development Quarterly*, *22*(1), 87–109. https://doi.org/10.1002/HRDQ.20062

Jiang, K., Zeng, L., Song, J., & Liu, Y. (2022). Forecasting value-at-risk of cryptocurrencies using the time-varying mixture-accelerating generalized autoregressive score model. *Research in International Business and Finance*, *61*, 101634. https://doi.org/10.1016/J.RIBAF.2022.101634

Karim, S., Lucey, B. M., Naeem, M. A., & Uddin, G. S. (2022). Examining the interrelatedness of NFTs, DeFi tokens and cryptocurrencies. *Finance Research Letters*, *47*, 102696. https://doi.org/10.1016/J.FRL.2022.102696

Katsiampa, P. (2017). Volatility estimation for Bitcoin: A comparison of GARCH models. *Economics Letters*, *158*, 3–6. https://doi.org/10.1016/J.ECONLET.2017.06.023

Khedr, A. M., Arif, I., Pravija Raj, P. V., El-Bannany, M., Alhashmi, S. M., & Sreedharan, M. (2021). Cryptocurrency

price prediction using traditional statistical and machine-learning techniques: A survey. *Intelligent Systems in Accounting, Finance and Management*, *28*(1), 3–34. https://doi.org/10.1002/ISAF.1488

Kowalczyk, N., & Trukuck, C. (2013). Literature reviews and systematic reviews: What is the difference? *Radiologic Technology*, *85*(2), 219–222. http://www.radiologictechnology.org/content/85/2/219.extract

Kristoufek, L. (2013). BitCoin meets Google Trends and Wikipedia: Quantifying the relationship between phenomena of the Internet era. *Scientific Reports*, *3*(1), 3415. https://doi.org/10.1038/srep03415

Kristoufek, L. (2015). What are the main drivers of the Bitcoin price? Evidence from wavelet coherence analysis. *PLoS One*, *10*(4), e0123923.

Li, Y., Jiang, S., Li, X., & Wang, S. (2022). Hybrid data decomposition-based deep learning for Bitcoin prediction and algorithm trading. *Financial Innovations*, *8*(1), 31. https://doi.org/10.1186/S40854-022-00336-7

Liu, J. S., Lu, L. Y. Y., Lu, W. M., & Lin, B. J. Y. (2013). A survey of DEA applications. *Omega*, *41*(5), 893–902. https://doi.org/10.1016/J.OMEGA.2012.11.004

Liu, Y., Li, Z., Nekhili, R., & Sultan, J. (2023). Forecasting cryptocurrency returns with machine learning. *Research in International Business and Finance*, *64*, 101905. https://doi.org/10.1016/J.RIBAF.2023.101905

Liu, Y., & Tsyvinski, A. (2021). Risks and returns of cryptocurrency. *The Review of Financial Studies*, *34*(6), 2689–2727. https://doi.org/10.1093/RFS/HHAA113

Lock, I., & Seele, P. (2015). Quantitative content analysis as a method for business ethics research. *Business Ethics: A European Review*, *24*(S1), S24–S40. https://doi.org/10.1111/BEER.12095

López-Martín, C., Benito Muela, S., & Arguedas, R. (2021). Efficiency in cryptocurrency markets: New evidence. *Eurasian Economic Review*, *11*(3), 403–431. https://doi.org/10.1007/s40822-021-00182-5

Macke, J., & Genari, D. (2019). Systematic literature review on sustainable human resource management. *Journal of Cleaner Production*, *208*, 806–815. https://doi.org/10.1016/J.JCLEPRO.2018.10.091

Mariani, M., Baggio, R., Fuchs, M., & Höepken, W. (2018). Business intelligence and big data in hospitality and tourism: A systematic literature review. *International Journal of Contemporary Hospitality Management*, *30*(12), 3514–3554. https://doi.org/10.1108/IJCHM-07-2017-0461/FULL/XML

Menegaki, A. N., Ahmad, N., Aghdam, R. F. Z., & Naz, A. (2021). The convergence in various dimensions of energy-economy-environment linkages: A comprehensive citation-based systematic literature review. *Energy Economics*, *104*(October), 105653. https://doi.org/10.1016/j.eneco.2021.105653

Morioka, S. N., & de Carvalho, M. M. (2016). A systematic literature review towards a conceptual framework for integrating sustainability performance into business. *Journal of Cleaner Production*, *136*, 134–146. https://doi.org/10.1016/J.JCLEPRO.2016.01.104

Müller, F. M., Santos, S. S., Gössling, T. W., & Righi, M. B. (2022). Comparison of risk forecasts for cryptocurrencies: A focus on range value at risk. *Finance Research Letters*, *48*, 102916. https://doi.org/10.1016/J.FRL.2022.102916

Nakamoto, S. (2008). Bitcoin: A peer-to-peer electronic cash system. *Google Scholar*, *15*, 580–596. https://doi.org/10.1108/TG-06-2020-0114

Nill, A., & Schibrowsky, J. A. (2016). Research on Marketing Ethics: A Systematic Review of the Literature. *27*(3), 256–273. https://doi.org/10.1177/0276146707304733

Nolan, C. T., & Garavan, T. N. (2016). Human resource development in SMEs: A systematic review of the literature. *International Journal of Management Reviews*, *18*(1), 85–107. https://doi.org/10.1111/IJMR.12062

Ntabe, E. N., LeBel, L., Munson, A. D., & Santa-Eulalia, L. A. (2015). A systematic literature review of the supply chain operations reference (SCOR) model application with special attention to environmental issues. *International Journal of Production Economics*, *169*, 310–332. https://doi.org/10.1016/J.IJPE.2015.08.008

Olvera-Juarez, D., & Huerta-Manzanilla, E. (2019). Forecasting bitcoin pricing with hybrid models: A review of the literature. *International Journal of Advanced Engineering Research and Science*, *6*(9), 161–164. https://doi.org/10.22161/IJAERS.69.18

Pagnotta, E., & Buraschi, A. (2018). An equilibrium valuation of bitcoin and decentralized network assets. Available at SSRN 3142022.

Patel, N. P., Parekh, R., Thakkar, N., Gupta, R., Tanwar, S., Sharma, G., Davidson, I. E., & Sharma, R. (2022). Fusion in cryptocurrency price prediction: A decade survey on recent advancements, architecture, and potential future directions. *IEEE Access*, *10*, 34511–34538. https://doi.org/10.1109/ACCESS.2022.3163023

Reim, W., Parida, V., & Örtqvist, D. (2015). Product–service systems (PSS) business models and tactics—A systematic literature review. *Journal of Cleaner Production*, *97*, 61–75. https://doi.org/10.1016/J.JCLEPRO.2014.07.003

Secundo, G., Ndou, V., Del Vecchio, P., & De Pascale, G. (2019). Knowledge management in entrepreneurial universities: A structured literature review and avenue for future research agenda. *Management Decision*, *57*(12), 3226–3257.

Shen, D., Urquhart, A., & Wang, P. (2019). Does twitter predict Bitcoin? *Economics Letters*, *174*, 118–122. https://doi.org/10.1016/J.ECONLET.2018.11.007

Sockin, M., & Xiong, W. (2020). A model of cryptocurrencies. *Management Science*, *69*(11). https://doi.org/10.1287/mnsc.2023.4756

Souza, O. T., & Carvalho, J. V. F. (2023). Market efficiency assessment for multiple exchanges of cryptocurrencies. *Revista de Gestão*. https://doi.org/10.1108/REGE-05-2022-0070

Sun, X., Liu, M., & Sima, Z. (2020). A novel cryptocurrency price trend forecasting model based on LightGBM. *Finance Research Letters*, *32*, 101084. https://doi.org/10.1016/J.FRL.2018.12.032

Thomé, A. M. T., Scavarda, L. F., & Scavarda, A. J. (2016). Conducting systematic literature review in operations management. *Production Planning & Control*, *27*(5), 408–420. https://doi.org/10.1080/09537287.2015.1129464

Tranfield, D., Denyer, D., & Smart, P. (2003). Towards a methodology for developing evidence-informed management knowledge by means of systematic review. *British Journal of Management*, *14*(3), 207–222. https://doi.org/10.1111/1467-8551.00375

Tummers, J., Kassahun, A., & Tekinerdogan, B. (2019). Obstacles and features of farm management information systems: A systematic literature review. *Computers and Electronics in*

Agriculture, *157*, 189–204. https://doi.org/10.1016/J.COMPAG.2018.12.044

Van Eck, N., & Waltman, L. (2010). Software survey: VOSviewer, a computer program for bibliometric mapping. *Scientometrics*, *84* (2), 523–538.

Wakefield, A. (2014). Searching and critiquing the research literature. *Nursing Standard (Royal College of Nursing [Great Britain]: 1987)*, *28*(39), 49–57. https://doi.org/10.7748/NS.28.39.49.E8867

Wang, Y., Wang, C., Sensoy, A., Yao, S., & Cheng, F. (2022). Can investors' informed trading predict cryptocurrency returns? Evidence from machine learning. *Research in International Business and Finance*, *62*, 101683. https://doi.org/10.1016/J.RIBAF.2022.101683

Wei, W. C. (2018). The impact of Tether grants on Bitcoin. *Economics Letters*, *171*, 19–22.

Xia, Y., Sang, C., He, L., & Wang, Z. (2023). The role of uncertainty index in forecasting volatility of Bitcoin: Fresh evidence from GARCH-MIDAS approach. *Finance Research Letters*, *52*, 103391. https://doi.org/10.1016/J.FRL.2022.103391

Yang, E. C. L., Khoo-Lattimore, C., & Arcodia, C. (2017). A systematic literature review of risk and gender research in tourism. *Tourism Management*, *58*, 89–100. https://doi.org/10.1016/J.TOURMAN.2016.10.011

Yung, R., & Khoo-Lattimore, C. (2017). New realities: A systematic literature review on virtual reality and augmented reality in tourism research. *Current Issues in Tourism*, *22*(17), 2056–2081. https://doi.org/10.1080/13683500.2017.1417359

Zhao, D., & Strotmann, A. (2020). Telescopic and panoramic views of library and information science research 2011–2018: A comparison of four weighting schemes for author co-citation analysis. *Scientometrics*, *124*(1), 255–270.

AUTHOR BIOGRAPHIES

Tomas Pečiulis is an assistant professor at Vilnius Gediminas Technical University and a dedicated researcher in his fourth year of PhD studies. His expertise spans across cryptocurrencies, blockchain technology, the circular economy, and monetary policy, with a distinctive focus on forecasting techniques. Tomas has made significant strides in analyzing the nexus between monetary policy and cryptocurrency. Tomas aims to further explore the intersection of monetary policy and cryptocurrency, contributing to the understanding and application of blockchain technology in the global economy.

Nisar Ahmad earned his master's and PhD in Economics from Aarhus University in Denmark. He spent 5 years working as a postdoctoral researcher, assistant, and associate professor at the University of Southern Denmark. He is currently employed as an associate professor in the Department of Economics and Finance at Sultan Qaboos University. He has recently published articles in prestigious international journals such as the *Journal of Macroeconomics, International Migration, Energy Economics*, the *Journal of Economics Surveys*, and the *Journal of Labor Research*. He teaches econometrics, game theory, behavioral economics, and microeconomics.

Angeliki N. Menegaki is a full professor of Applied Economics in Environment, Energy, and Tourism in the Department of Regional and Economic Development in the Agricultural University of Athens-EU CONEXUS. She received her PhD from the University of Stirling UK and her masters' degree from the University of Leeds, UK. She holds two degrees: one in Economics from the University of Crete and one in Languages, Literature, and Culture of Black Sea Countries with the Specialization in Turkish Language. She has taught in various universities in Greece and abroad and has also worked both in the public and private sector. She has published more than 80 research papers in international journals with an impact factor and has also written or supervised the translation of 10 books in Greek or English, six of which in Tourism. Currently, she is deputy head in the Department of Regional and Economic Development and Director of Doctoral Studies. She is also the founder and editor in Chief of the *International Journal of the Energy-Growth Nexus* (Inderscience Publications), editor of the "Encyclopedia of Energy Economics" (Edward Elgar), and "New economics for Sustainability-Time for transformation (Elsevier).

Aqsa Bibi is a results-driven HR specialist with 8 years of experience in various aspects of Human Resource Management. She earned an MBA from Quaid I Azam University in Islamabad, Pakistan, and an MS in Human Resources from COMSATS University in Islamabad, Pakistan. She was a lecturer at the Jinnah School of Commerce and Management Sciences and a research associate at the COMSATS University in Islamabad. Her areas of interest include strategy, organizational behavior, responsible management, and digital transformation. She currently works as an HR Specialist for SAIBAAN Development Organization Pakistan.

How to cite this article: Pečiulis, T., Ahmad, N., Menegaki, A. N., & Bibi, A. (2024). Forecasting of cryptocurrencies: Mapping trends, influential sources, and research themes. *Journal of Forecasting*, 1–22. https://doi.org/10.1002/for.3114