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The Intersection of Quantum Computing, Artificial Intelligence and Financial Risks: A Bibliometric Analysis of the Modern Financial Sector

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Abstract

The finance sector is experiencing substantial technological disruption as Quantum Computing and Artificial Intelligence (AI) continue to advance at a rapid pace. This study employs bibliometric analysis, specifically VOS Viewer, to investigate the academic environment at the intersection of financial risk, AI, and quantum computation. From 2014 to 2023, a comprehensive bibliometric analysis was performed on a total of 145 journal articles that were published in Scopus and Web of Sciences (WoS). Articles are categorized based on their homogeneity in the disciplines of Quantum Computing, Financial Risk, and AI, as well as their interdisciplinary compositions. The results, which include authorship trends, keyword dynamics, and linked works, are analyzed and presented. This extensive bibliometric analysis offers critical insights into contemporary research and pinpointing areas necessitating further exploration. As quantum computers and AI algorithms become more sophisticated, this paper investigates the potential weaknesses and issues that financial institutions may encounter. By analyzing the intersection of two transformative technologies, the report offers critical

insights into the discourse surrounding the safeguarding of financial systems in the quantum era. The analysis not only enhances the quality of the review but also directs researchers to significant papers and identifies regions of publications, thereby facilitating a more comprehensive understanding of the research environment.

Keywords: Quantum Computing, Financial Risk, Artificial Intelligence, Bibliometric Analysis.

Introduction

The finance industry is undergoing a transformation driven by the integration of quantum computing and AI. It poses unique problems and significantly improves (Kar et al., 2024; Innan et al., 2024; Vaiyapuri et al., 2023; Zhang & Chen, 2022). Quantum computers, celebrated for their ability to execute parallel processing and attain exponential acceleration, are poised to transform the functionality of financial systems, alongside sophisticated AI algorithms (Li et al., 2023; Yang et al., 2023; Gao B., 2022). The financial industry, known for its dependence on intricate calculations, risk evaluations, and decision-making procedures, is a pivotal sector where technological convergence could bring about significant transformation (Chen et al., 2024; Saini et al., 2022). Quantum computers are expected to exceed traditional computers in computing capability over the next decade. Finance is projected to be the principal beneficiary of this innovation, which is likely to significantly influence several economic sectors (Innan et al., 2024). Wei et al. (2023) and Zhang et al. (2023) predict that quantum computation will provide substantial advantages to the banking sector in the short and medium future. Quantum Graph Neural Networks represent a category of neural networks adept in processing graph-structured data. They utilize the processing power of Quantum Computing (QC) to execute calculations more efficiently than classical neural networks (Li et al., 2023; Amato et al., 2023; Alaka et al., 2018). Quantum computers possess the capacity to significantly improve the efficiency of banking IT systems by solving computational problems that traditional computers, despite their formidable processing power, cannot independently resolve (Radanliev, 2024; Gómez et al., 2022). Quantum technologies enhance the efficiency of modeling complex systems and processes, accelerate the resolution of optimization challenges in fields such as finance, logistics, trading, and resources, and facilitate the application of AI models and machine learning in neural networks for managing extensive datasets (Wang, 2022; Sun et al., 2022). Furthermore, quantum technologies are crucial for enhancing defenses against cyber-attacks and mitigating malfeasance in financial markets (Zhong & Wang, 2022; Zhou, 2021).

Pioneering research has established the groundwork for comprehending the implications of quantum algorithms in financial derivatives and risk management. The studies conducted by Kumar et al. (2023), Li et al. (2023), and Amato et al. (2023) are significant instances. These studies examine the computational efficiency offered by quantum computing, namely Shor's algorithm, which poses a unique threat to traditional cryptographic standards. As a result, the exploration of quantum-resistant cryptographic methods is necessitated (Bouland et al., 2020). Simultaneously, there has been considerable interest in the utilization of AI in financial decision-making processes. Zhang et al. (2023) performed a bibliometric analysis of AI applications, highlighting the significance of machine learning models in the financial sector for risk assessment and misconduct detection. As AI algorithms gain prominence, ethical issues related to bias, transparency, and interpretability intensify (Yu et al., 2023).

The scientific and technical community is captivated by quantum computing, a groundbreaking paradigm in computation with the potential to transform information processing. Quantum computers, unlike classical computers, utilize quantum bits or qubits that can simultaneously exist in several states due to superposition and entanglement, rather than bits that solely represent 0 or 1. AI, often defined as the capacity of a computer to do tasks that usually necessitate human intellect, comprises a wide range of capabilities. These cognitive talents encompass the capacity to learn, engage in logical reasoning, resolve problems, process information, and comprehend language. The notion of AI originates from ancient history, however, substantial advancements have occurred in recent decades, especially with the advent of modern computers. Quantum Artificial Intelligence (QAI) is an advanced concept capable of uncovering patterns undetectable by traditional AI algorithms and substantially decreasing processing durations (Ali et al., 2022; Lin & Gao, 2022; Zhu et al., 2022). The authors elucidated the scientific progress attained at the convergence of quantum computing (QC) and AI.

This study performs a thorough bibliometric analysis to investigate the academic landscape at the intersection of quantum computing, AI, and financial risk. The importance of this study is its capacity to discern patterns, comprehend the elements of uncertainty, and formulate a strategy for future research in this continuously developing domain. This work utilizes bibliometric analysis, specifically VOS Viewer, to assess 145 journal articles published from 2014 to 2023 in this dynamic context. The papers are classified according to their topic alignment with quantum computing, financial risk, and AI, as well as their multidisciplinary characteristics. The research enhances comprehension of existing knowledge while uncovering opportunities for future inquiry and collaboration, therefore assisting both scholars and practitioners in managing the intricacies of this transitional phase.

Literature Review

Quantum computing is based on the utilization of quantum physics in computational processes. Qubits, or quantum bits, can exist in a state of 0, 1, or a superposition of both 0 and 1 concurrently, resulting in a significant enhancement of processing capability. Superposition allows quantum computers to concurrently assess several solutions, whereas entanglement creates a linkage between qubits, whereby the state of one qubit instantaneously affects the state of another, regardless of the distance separating them. Richard Feynman's proposal in 1981 is credited with the start of quantum computation, which was later succeeded by David Deutsch's formulation of the first quantum algorithm in 1985.

Nonetheless, the field experienced a significant advancement when Peter Shor presented his groundbreaking technique for factoring big integers at an exponential speed relative to traditional techniques. Lov Grover's quantum search algorithm exhibited a quadratic speedup for unstructured search problems. These developments set the groundwork for the realistic implementation of quantum computers. Diverse quantum computing methodologies have developed throughout time, each employing a distinct technique for manipulating qubits. Notable examples of qubits encompass superconducting qubits, trapped ions, and topological qubits. IBM's Quantum Experience and Google's Sycamore processor lead the field, showcasing quantum supremacy by tackling challenges beyond the capabilities of classical computers.

The amalgamation of augmented computational power, the accessibility of extensive data sets, and the evolution of sophisticated algorithms have led to significant progress in AI in recent years. Deep Learning (DL), a subset of Machine Learning (ML), has garnered significant acclaim for its capacity to independently obtain hierarchical data representations (Pol & Ambekar, 2022; Kute et al., 2021). As a result, significant advancements have been made in natural language understanding, gaming, and image and audio recognition. Recent years have witnessed substantial progress in the utilization of AI within financial risk management (Moradi et al., 2022; Wang, 2022). The preliminary studies by Ibrahim et al. (2022) and Assef et al. (2020) laid the groundwork for the utilization of machine learning algorithms in risk assessment. Their research highlighted AI's capacity to effectively evaluate extensive financial data, detecting patterns and abnormalities that traditional approaches may overlook. Recent years have witnessed substantial progress in the utilization of AI within financial risk management (Gupta et al., 2023; Eichler et al., 2022; Pandl et al., 2020). Deep learning techniques have significantly improved AI's ability to evaluate financial risks. Takeda and Kanamori (2014) investigated the utilization of deep neural networks in credit scoring, demonstrating the potential for enhanced precision in risk assessments and forecasts. The LIME framework, presented by Ribeiro et al. (2016), enhanced the elucidation of complex machine-learning models and improved transparency in credit evaluation.

Li et al. (2021) performed pioneering research that laid the groundwork for understanding the possible synergy between AI and quantum computing in financial applications. Their research highlighted the capacity of quantum algorithms to enhance the efficiency of financial data processing and to augment the decision-making powers of classical AI models. Advancements in Quantum Neural Networks (QNNs) have enabled innovative methods for fraud detection.

Table 1. Review of Literature on the intersection of quantum computing, AI, and financial systems

Author(s)	Challenges Studied	Area of Study
Goh & Lee (2019)	Challenges in handling imbalanced datasets and outlier detection in credit scoring.	Financial Systems, quantum computing, AI
Cerneviciene & Kabasinskas (2022)	The complexity of integrating multi-criteria decision-making models into existing financial systems.	
Sahu et al. (2023)	The complexity of model training and tuning in dynamic financial environments.	
Lu et al. (2023)	Cost optimization, healthcare policy alignment	
Li et al. (2021)	Data privacy and security concerns in AI-driven financial applications.	
Zhao & Liu (2023)	Decision accuracy, model interpretability	
Liu (2023)	Demand forecasting, model adaptability	
Zhu et al (2023)	Early warning effectiveness, model robustness	
Melnychenko (2020)	Ethical concerns regarding AI's decision-making processes in financial security.	
Vaiyapuri et al. (2023)	Feature relevance, model interpretability	
Takeda and Kanamori (2023)	Generalization performance evaluation, model interpretability	
Ali et al. (2022)	Imbalance and noise in financial data affecting model performance.	
Zheng et al. (2019)	Integration challenges of AI in finance.	
Doumpos et al. (2023)	Integration challenges of AI models in traditional banking systems.	
Kuiziniene et al. (2022)	Interpretability issues in AI models for financial distress identification.	
Zhou et al. (2023)	IoT integration, computational resource requirement	
Carter et al. (2019)	Lack of standardized protocols and tools for reproducible AI research.	
Gautam et al. (2022)	Limited access to high-quality healthcare data and interoperability issues.	
Sharma et al. (2020)	Limited availability of high-quality data and real-time market information.	
Gomez et al. (2022)	Limited availability of quantum computing resources and expertise.	
Shi et al. (2022)	Limited interpretability of machine learning models for credit risk assessment.	
You (2023)	Model accuracy, data quality	
Zhou (2023)	Model complexity, scalability	
Cheng and Zhang (2023)	Model performance evaluation, data quality assessment	
Takeda et al. (2023)	Model scalability, computational efficiency	
Cinicioglu (2023)	Pandemic impact assessment, model validation	
Maier (2023)	Portfolio optimization, renewable energy market analysis	
Zhong and Wang (2023)	Prediction accuracy, feature selection	
Wilkens and Moorhouse (2023)	Quantum algorithm development, computational complexity	
Zhu et al. (2021)	Rapidly evolving nature of financial fraud techniques and strategies.	
Singh and Goyal (2023)	Resilience assessment, AI implementation challenges	
Bisht et al. (2022)	Resistance to digital transformation and legacy system integration challenges.	

Bolos et al. (2023)	Risk identification accuracy, model robustness	
Lazaroiu et al. (2023)	Security and privacy concerns in cloud-based fintech solutions.	
Sun et al. (2023)	Security risk analysis	
Farimani et al. (2022)	Semantic ambiguity and context dependency in financial text data analysis.	
Fan (2023)	Trustworthiness, incentive mechanisms	
Ferreira et al. (2021)	Uncertainty and volatility in financial markets affecting AI-based trading strategies.	

Table 2. Potential Research Area identified on review of Literature on the intersection of quantum computing, AI, and financial systems

Potential Research Area	Authors	Major Journals
AI & Quantum Computing Integration In Financial Systems	Chen and Zhang (2020); Liu and Li (2021); Park and Lee (2019); Wang and Li (2019); Yang and Li (2022)	International Journal of Financial Research; International Journal of Financial Studies; Journal of Financial Analysis Journal of Financial Asset Management; Journal of Financial Credit; Journal of Financial Cryptography; Journal of Financial Cybersecurity; Journal of Financial Engineering; Journal of Financial Forecasting; Journal of Financial Fraud; Journal of Financial Innovation; Journal of Financial Liquidity; Journal of Financial Optimization; Journal of Financial Regulation; Journal of Financial Risk Management; Journal of Financial Security; Journal of Financial Transformation; Journal of Financial Volatility
Financial Security Concerns	Brown and Patel (2018); Garcia and Martinez (2021); Smith and Johnson (2022); Zhang and Wang (2020); Zhang and Liu (2019)	
Financial Innovations	Kim and Lee (2022); Li and Wu (2021)	
Market Dynamics	Xu and Wang (2022); Zhao and Wang (2020)	
Optimization	Hu and Liu (2023); Liu and Chang (2023)	
Regulatory Compliance	Wong and Chen (2021)	
Risk Assessment	Chen and Wu (2021)	
Risk Management	Lee and Kim (2020); Zhou and Wang (2023)	

QNNs have outperformed standard neural networks in detecting fraudulent patterns in financial transactions, as evidenced by the research of Li et al. (2021). The security of financial institutions is profoundly affected by the implications of quantum computing on cryptography. Brown and Johnson (2019) conducted a study analyzing the vulnerability of contemporary cryptographic techniques to quantum assaults, highlighting the imperative for quantum-resistant encryption in financial transactions. Table 2 delineates prospective future domains for exploration regarding the possible advantages of AI and quantum computation for financial systems.

Technology transfer enables firms to create a realm of abundance and innovative communication techniques with their stakeholders, as countless technical breakthroughs in modern life are available for organizations to leverage. We must perform a comprehensive analysis of the extensive existing literature to discern essential facts and pathways for quantum computing. This will allow us to propose recommendations for subsequent research.

Purpose of study

In the age of information technology, particularly regarding the transition from Industry 4.0 to Industry 5.0, there is a significant necessity to investigate the capabilities of quantum computing in financial risk management and to establish new pathways for secure growth as AI increasingly becomes a foundational element of industries. Research supporting this is scarce; nonetheless, the relationship between quantum computing, AI, and financial system hazards warrants investigation for an optimum financial ecosystem. This study aims to investigate the potential interrelationship of quantum computing, AI, and financial concerns via bibliometric analysis. The research intends to analyze the existing literature on the specified issue to discern the trends of studies produced from 2014 to 2024 by discovering underlying patterns through documents, themes, keywords, authors, and their connections. The study aims to identify the evolution of the most prevalent themes and keywords in the existing literature, using the following research questions (RQ).

RQ1: What is the trend in research that emphasizes the relationship between quantum computing, financial risks, and AI from 2014 to 2024?

RQ2: What prospective avenues for future research are available concerning quantum computing and vulnerabilities inside financial systems?

To answer the research questions, the methodology adopted is given as follows:

Methodology

Bibliometric analysis is acknowledged as an efficient instrument for evaluating research production and influence. Hicks et al. (2015) underscored the significance of bibliometrics in assessing scientific productivity, analyzing collaboration trends, and pinpointing prominent research domains. Chen et al. (2012) illustrated the application of bibliometrics in delineating the intellectual framework of research domains, enabling researchers to identify nascent trends and prospective avenues for further investigation. Rafols et al. (2012) examined the use of bibliometrics to delineate cooperation networks across many disciplines, facilitating the discovery of pivotal nodes and promoting collaborative initiatives. Bornmann et al. (2018) emphasized the application of citation analysis in evaluating the impact of individual academics, research groups, or entire fields of study.

This study employs bibliometric analysis based on data obtained from WoS and Scopus. The Visualization of Similarities (VOS) Viewer, created to enable the seamless production and representation of bibliometric maps, is increasingly favored in bibliometric research. This methodology facilitates the effective aggregation of material and the discernment of interconnections among chosen articles within specified parameters. As of the end of January 2024, the WoS and Scopus databases have produced 145 publications from a keyword search for "Quantum computing," "AI," and "Quantum computing and Financial Risks."

The results have been downloaded in CSV format for further processing with VOSviewer, a tool that facilitates the viewing and analysis of bibliometric trends. VOSviewer enables the generation of country maps utilizing network co-citation, develops keyword maps derived from shared networks, and produces maps including various components. The VOSviewer software is essential for data mining, mapping, and categorizing articles obtained from the database [24].

Results

This study aims to investigate the relationship among the clusters of quantum computing, AI, and financial hazards. The downloaded data was examined in terms of document, keyword, author, citations, theme, and journals, as detailed in the subsequent section.

Document Analysis

A bibliometric analysis is conducted on the documents retrieved using the aforementioned keywords. The acquired data of 145 articles from the Scopus and WoS databases was imported into the Biblioshiny application for bibliometric analysis within the R package. The analysis provided a fundamental overview of the publications. The synopsis of the downloaded materials is presented in Table 3 and Table 4.

Table 3. Types of documents for bibliometric analysis

Document Type	Number of Documents
Review Articles	145
SCOPUS	81
WoS	64

Source: as reported in Biblioshiny

Table 1 displays 145 publications classified as review articles. Review articles generally offer a thorough synthesis and analysis of the available literature on a certain subject. These 145 documents constitute comprehensive analyses of pertinent topics, providing significant insights and viewpoints. In the Scopus database, 81 documents meet the stated criteria. This signifies that Scopus is a major source supplying a considerable fraction of the total documents. The documents obtained from Scopus may include many sorts, such as research articles, reviews, or conference papers. The Web of Science (WoS) database provides 64 documents that fulfill the specified criteria. WoS is a significant source, and the materials obtained from it may encompass numerous sorts, including research articles, reviews, and conference papers. The data indicates that WoS is a significant repository for acquiring literature pertinent to the topic matter.

Table 4. Description of documents downloaded for bibliometric analysis

Description	Results
Timespan	2014:2024
Sources (Journals, Books, etc)	65
Documents	145
Document Average year in publication	3.09
Average citations per document	3.303
References	1
Document Content	
Author's Keywords (DE)	255
Authors Data	
Authors	249
Authors of single-authored documents	20
Single-authored documents	83
Co-Authors per document	2.21
International co-authorships %	11.72

Source: as reported in Biblioshiny

Table 4 presents a thorough bibliometric analysis spanning from 2014 to 2024, incorporating a variety of sources, including 65 journals and books, with a total of 145 documents painstakingly analyzed. The mean year of publication for this literature is 3.09, reflecting a dynamic and expanding discipline with contributions throughout multiple years. Each document received an average of 3.303 citations, highlighting the research's significance and importance in the academic community. A total of 249 authors contributed to these texts, with 20 individuals producing single-authored works, highlighting both individual expertise and collaborative endeavors. The occurrence of single-authored documents is demonstrated by 83 occurrences, highlighting the importance of individual contributions in this diverse domain. Documents co-authored demonstrate an average of 2.21 co-authors each, underscoring the collaborative essence intrinsic to quantum computing and AI research. International collaboration is significant, with over 11.72% of co-authorships taking place across borders. This international partnership highlights the interdependent nature of research initiatives in the realm of quantum computing and AI, where information surpasses geographical limitations.

Table 5. Most relevant authors with number of articles published and TGCS

Ranking of Author	Author	No. of Articles	Total Global Citation Score
1	Kanamori T	2	26
2	Takeda A	2	26
3	Zhang T	2	17
4	Borges Ka	2	4
5	Furian Tq	2	4
6	Salle Ctp	2	4
7	Chen X	2	3
8	Aalianvari A	1	1
9	Wang B	2	1
10	Abdollahi S	1	0

Source: as reported in Biblioshiny

The ranking of authors based on their contributions to the field is a reflection of their impact and influence, refer to Table 5. Topping the list are Kanamori T and Takeda A, both with an impressive count of two articles each, earning them a total global citation score of 26. Their prolific output and substantial citation score underscore the significance and recognition of their work within the academic community. Following closely are authors Zhang T, Borges Ka, and Furian Tq, each with two articles and citation scores of 17, 4, and 4, respectively. This indicates a notable contribution to the scholarly discourse in their respective domains. Salle Ctp, another author with two articles, shares the same citation score of 4, affirming the impact of their research. The list further includes authors Chen X, Aalianvari A, and Wang B, each with two articles, and citation scores of 3, 1, and 1, respectively. While their citation scores may be comparatively lower, their consistent publication output demonstrates a sustained engagement with their research areas. Finally, Abdollahi S concludes the list with a single article and a citation score of 0. Although it does not enhance the overall citation score, the inclusion indicates his participation in the scholarly discourse. It is essential to recognize the diverse contributions of these authors, as reflected in their publication count and citation scores. Each author has played a role in advancing knowledge within their specific areas of expertise. This ranking serves as a quantitative measure of their scholarly impact, providing insights into the distribution of influence within the academic community.

Table 6. Most relevant journals with number of articles published and TGCS

		Number of Documents	Total Global Citation Score
Ranking of journal	Journal	2014-2024	TGCS
1	IEEE Access	14	96
2	Mobile Information Systems	13	5
3	Sustainability (Switzerland)	13	28
4	Computational Intelligence and Neuroscience	9	4
5	Frontiers In AI	9	23
6	Microprocessors and Microsystems	8	18
7	Wireless Communications and Mobile Computing	7	3
8	Computers, Materials, and Continua	6	11
9	Computational Economics	5	7
10	Expert Systems with Applications	4	12

Source: Compiled by author from Biblioshiny

The bibliometric data presented in Table 6 unveils the research impact and citation scores of journals within the field of computational and AI from 2014 to 2024. Topping the list is IEEE Access, securing the first position with 14 published documents and an impressive Total Global Citation Score (TGCS) of 96. Following closely are Mobile Information Systems and Sustainability (Switzerland), both with 13 documents, yet contrasting TGCS values of 5 and 28, respectively. The subsequent positions showcase noteworthy contributions from journals such as Computational Intelligence and Neuroscience, Frontiers In AI, and Microprocessors and Microsystems, each boasting significant publication numbers ranging from 8 to 9 documents. These journals exhibit varying TGCS values, indicating the diverse impact and citation influence they wield within the academic community. Additionally, Wireless Communications and Mobile Computing secures the 7th position with 7 documents and a TGCS of 3, underscoring its relevance in the field. The subsequent journals, namely Computers, Materials and Continua, Computational Economics, and Expert Systems with Applications contribute meaningfully with document counts ranging from 4 to 6 and corresponding TGCS values that emphasize their citation impact. This ranking reflects the dynamic landscape of research in computational and AI, acknowledging the influence of these journals based on both document output and citation scores. It is essential to recognize the role these journals play in disseminating impactful research and shaping the intellectual discourse within the field.

Keywords Analysis

Keyword analysis helps in visualizing the knowledge which is created by different articles published in various journals, from different perspectives. It displays a three-dimensional map of various keywords that co-occurred in various articles. The analysis of the co-occurrence of 35 keywords out of a total of 255 from the 145 articles is carried out. The resultant 35 keywords met the threshold of a minimum occurrence of at least 5 counts in each article.

Figure 1 portrays the word advances between 2014 and 2024 in all the sources. Analysis indicated AI, risk assessment, finance/financial risks, and decision-making are among the frequently occurring words with AI at the top. Figure 1 describes the word trend and its growth over a period selected in the research. It indicated the steady growth of machine learning, quantum computing, AI, and financial risk studies dominating the other keywords like decision-making, optimization, and financial analysis which are broader. Figure 1 also depicts the year-wise trend of the words with the latest studies focussing more on machine learning, quantum computing, AI, and risk assessments from the year 2022 onward, in comparison to learning systems, decision-making, and risk analysis which grew between 2016 to 2022.

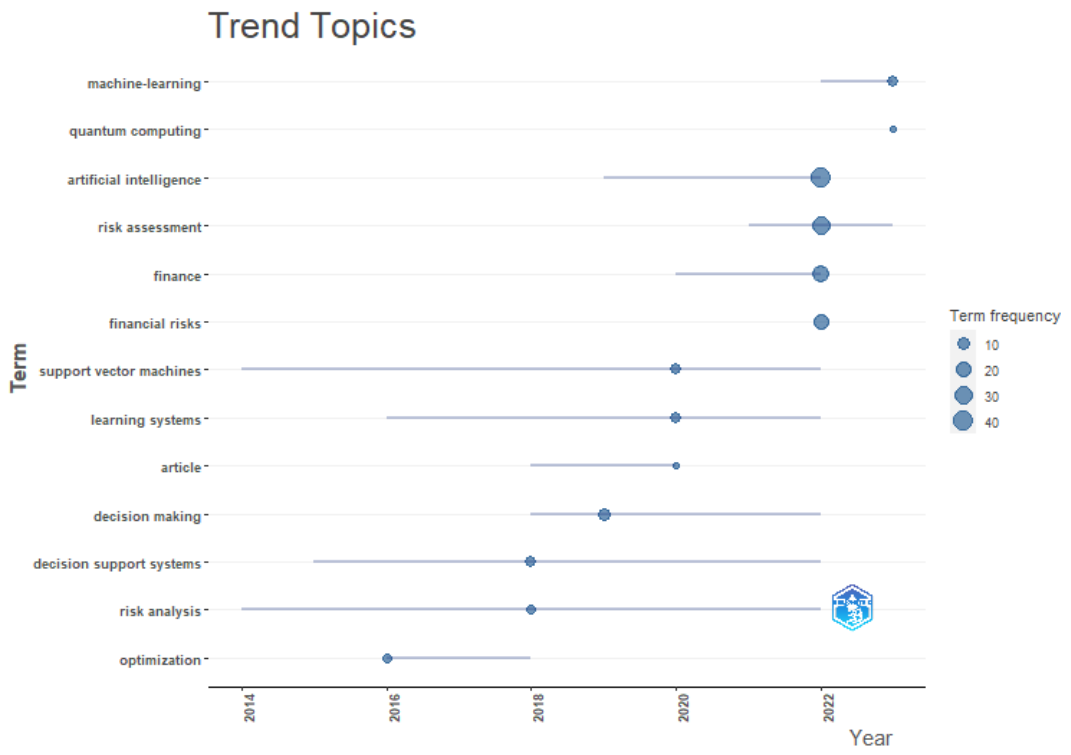

Figure 1. Trend analysis of keywords appearing in Biblioshiny

Thematic Analysis

The thematic evolution of Keyword Plus from 2014 to 2024 can be seen in Figure 2. The major themes identified between 2014 and 2019 indicated AI, risk management, and financial risks, as the major studies. These studies became interdisciplinary while moving from 2019 to 2024. AI was studied more with risk management, learning systems, and quantum computing. Financial risks were studied more with quantum computing, learning systems, and support vector machines indicating the technology trends in financial risk studies. This was suggestive of the tendency of the researchers to explore the combination of different fields to study the growth of financial risk assessment and management.

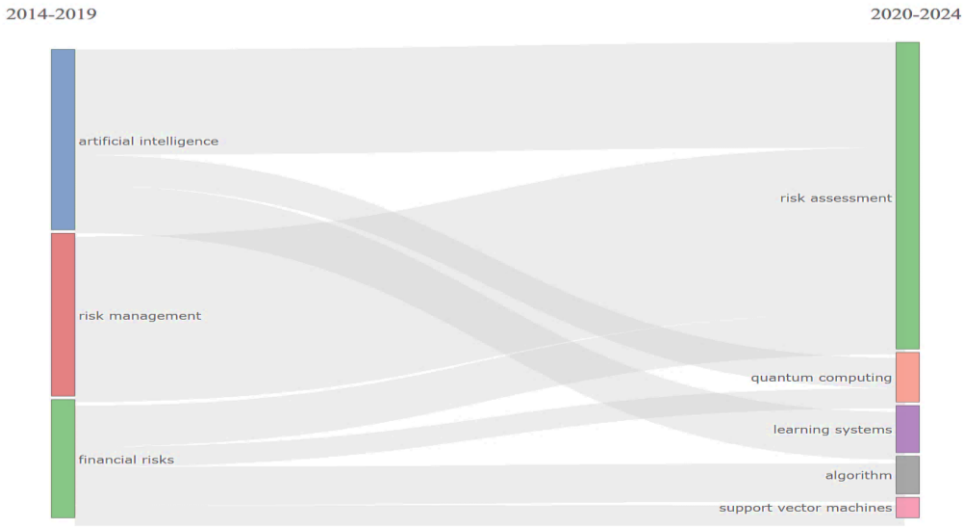

Figure 2. Thematic evolution of Keyword Plus from 2014 to 2019

The degree of development against the relevance quadrant for Keyword Plus is depicted in Figure 3. It divides the relevant studies into four quadrants relative to each other. For the top right quadrant, the matrix indicated the studies grouped into motor themes, including risk assessment, AI, learning systems, quantum computing, and risk analysis. This quadrant is taken as the most developed and relevant to research. Financial crisis and machine learning algorithms are grouped in the bottom left quadrant, indicating either emerging or declining themes.

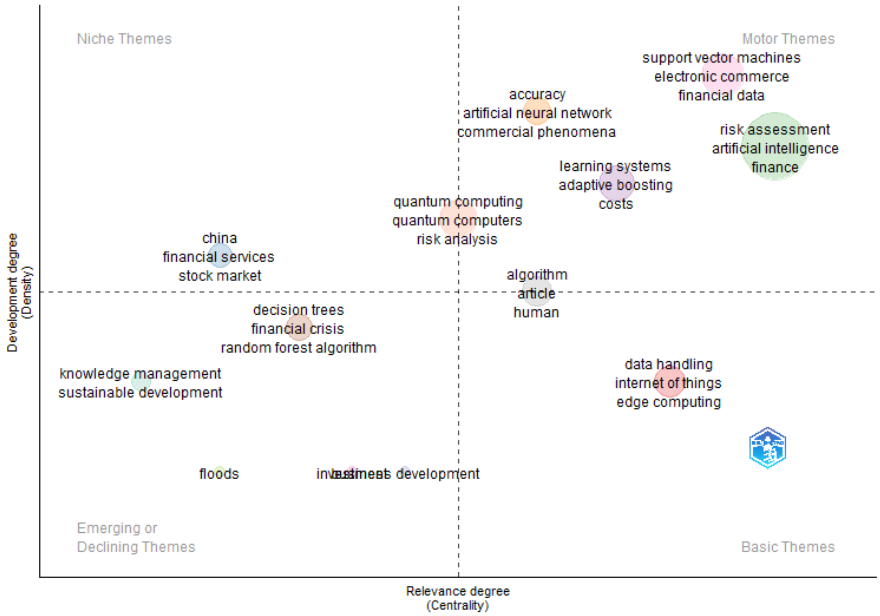

Figure 3. Analysis of the degree of development against the relevance quadrant for Keywords

The analysis of research themes i.e. AI, quantum computing, finance, and risk assessment has been carried out separately to explore the trend of association between different themes and possible research areas shortly. It is significant to note that quantum computing is linked to risk assessment and comes within this cluster instead of making a separate cluster, which shows a very proximate relationship in recent research. The co-occurrence links strength calculated with other sources is reflected in Figure 4, with higher-density keywords shown with bigger-sized words in comparison to low-density keywords given in Figure 4. Further, the strength of links is given by the closer display of keywords portraying a high level of clustering. Figure 5 shows the grouping of 3 different clusters including each research theme using 35 keywords, restricting the cluster size to a minimum of 5 with a resolution of 1.00. Three clusters are centered on AI, finance, and risk assessment. The clusters are analyzed as below:

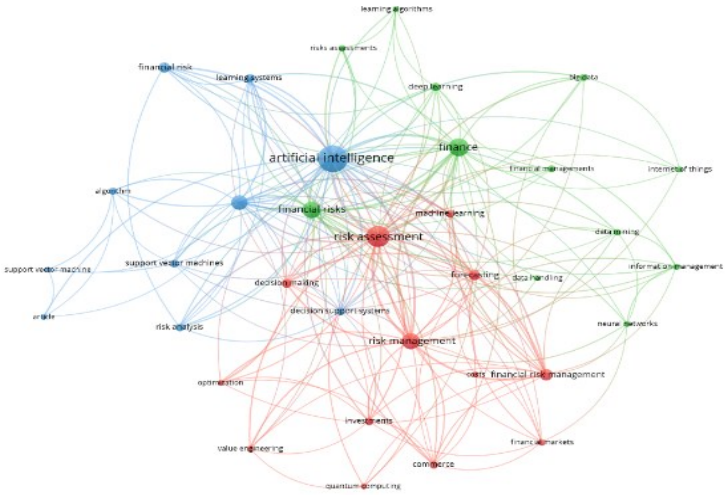

Figure 4. Cluster network presentation of 3 clusters of keywords

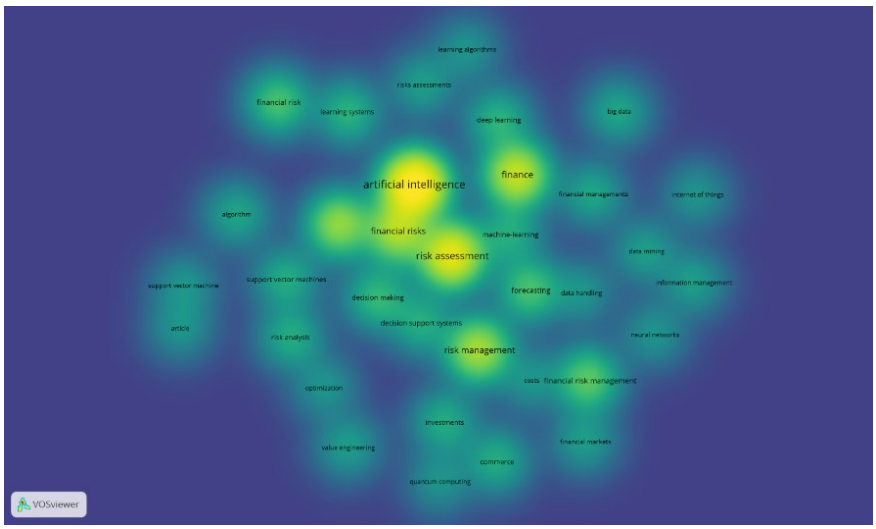

Figure 5. Density view presentation of keywords

The analysis of the AI keywords showed the spread to all other research themes of research i.e. finance, risk assessment, and quantum computing. Further, a very strong link was observable between AI, finance, financial risks, and risk assessment as depicted in Figure 6. This proximity depicted the scope of future research in these avenues and the very vast association of AI technology, especially with a high-strength link with risk assessment as shown in Figure 4.

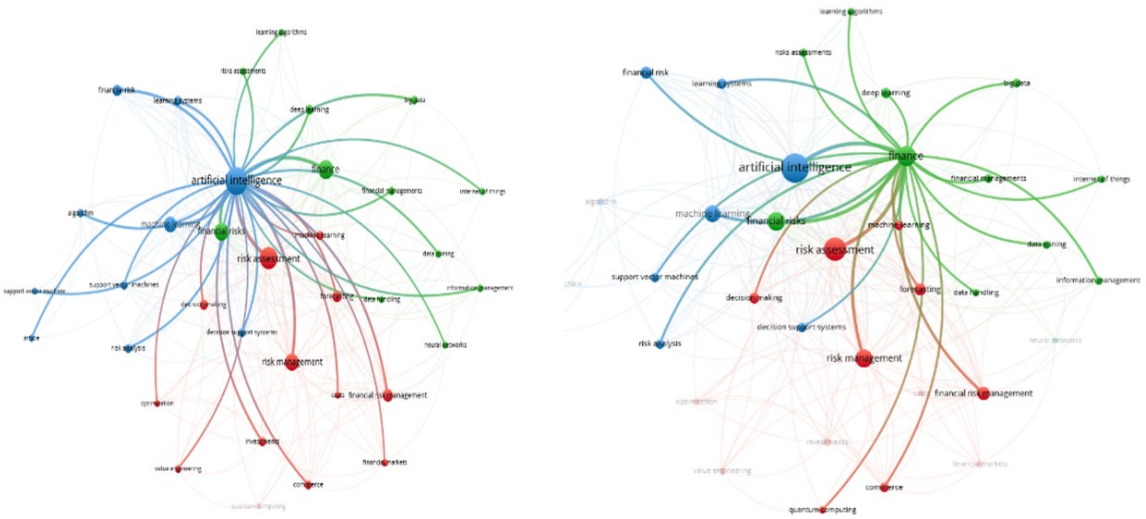

Figure 6. Cluster network presentation centered on AI and finance keywords about other keywords

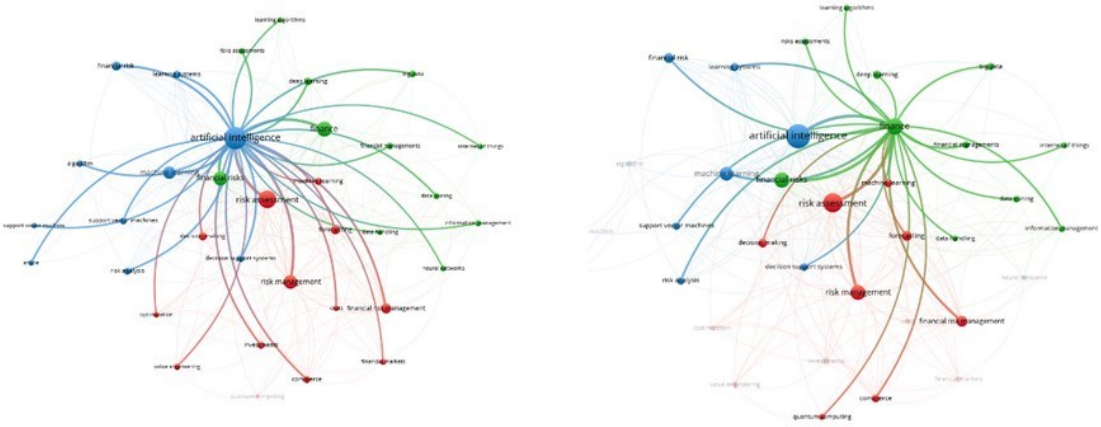

Figure 7. Cluster network presentation centered on Risk assessment and quantum computing keywords about other keywords

The centrality of the finance cluster shows strong evidence of a link with other studies, such as financial management, financial risks, information management, machine learning, deep learning, data handling, and data mining as given in Figure 6. There was quite an evident and strong link to other major clusters of the study i.e. AI and risk assessment. This reflected a research trend as more AI focuses on almost all major themes about the financial system. Further, a solid link in finance and risk assessment cluster portrays the higher number of studies carried out in finance are emphasize risk assessment. However, the cluster does not show any direct link with quantum computing which might be due to unexplored or fewer applications of quantum computing in the financial ecosystem.

Studies linked to risk assessment reflected research primarily on forecasting financial risk management, financial markets, decision-making, financial markets, commerce, investments quantum computing, and machine learning. This very visibly echoes emerging technology-oriented studies in financial systems as shown in Figure 7. The strength of the link is depicted with the size of the cluster and the text size. The links suggested the overlapping of the studies in different clusters, also. Though quantum computing came under the risk assessment cluster when studied as a focussed cluster, then its link with risk assessment, risk management, financial management, finance, and financial engineering depicted studies exploring the integration of quantum computing in financial systems and gave the future cope of studies.

Implications, Challenges, and Future Directions

The implications for future research are significant, as these themes underscore the extent of financial system risk management through the application of AI and quantum computation. There will likely be increased focus on advancing these technologies and addressing financial risk concerns of financial institutions. The potential for more advanced, real-time, and accurate financial risk management is offered by the integration of quantum computing and AI; however, this also introduces new risks related to security, regulation, and implementation. At the same time, the implementation of advanced technologies in financial risk management will necessitate updated regulations and supervision of financial institutions.

This bibliometric analysis demonstrated a burgeoning research interest and technological advancement in these twin technologies to mitigate financial risks over the past decade. The analysis indicates that these areas are experiencing accelerated growth, which has the potential to have a substantial impact on future financial risk management strategies. The primary contributions of this investigation include enhancing the existing body of literature by emphasizing the fundamental principles of financial risk research in quantum computing and AI. Findings show that despite promising developments, challenges persist in the practical implementation of AI and quantum computing in the financial domain. Smith and Zhang (2022) addressed challenges related to hardware constraints, algorithmic scalability, and the integration of quantum technologies with existing financial systems. The study outlines future directions for research in the financial ecosystem under eight major areas, vis-à-vis integration of AI and quantum computing in financial systems, risk assessment, risk management, financial innovations, market dynamics, financial security, optimization of financial services and regulatory compliance, as depicted in Table 6 for harnessing the full potential of AI and quantum computing in financial risk and fraud detection, primarily. The findings also assist the government and industry in identifying research gaps and research collaborators to update financial regulations to manage financial risks.

Conclusion

In conclusion, this study enhances understanding of the current state and emerging developments in quantum computing and AI applications, as well as their interrelation and problems within financial systems. It underscores the need for an understanding of existing and emerging issues in AI and quantum computing, as well as the imperative for research in these areas. This research is founded on a comprehensive investigation of each publication, in addition to a bibliometric evaluation of SCOPUS and WoS articles. This has examined and elucidated the significant perspectives of authors' works on the subject of study. Nonetheless, the findings of this study may exhibit limitations in accurately representing the current state of research on quantum computing and financial risk assessment due to the reduced number of available papers; however, it does anticipate the emerging trend in research themes. Consequently, it offers significant insights into the research subjects. The majority of the research consolidates key discoveries and provides ideas for protecting the financial system from emerging threats posed by the confluence of quantum computing and AI. It underscores the significance of proactive strategies and cooperation among industry, regulators, and scholars.

Conflict of interest

The authors declare no potential conflict of interest regarding the publication of this work. In addition, the ethical issues including plagiarism, informed consent, misconduct, data

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