A Scientometrics Review Of Option Pricing Research: Insights Into The Black-Scholes Model And Its Variants

Tsegenet Mengistu Abebe[1] , Dr. Prafulla Kumar Swain[2] , Dr. Anita Sahoo[3]
Dr. Pallavi Mishra[4] , Dr. Rabinarayan Patnaik[5]

[1]Research Scholar, Faculty of Management Sciences, IBCS, Siksha'O'Anusandhan (SOA) Deemed to be University, Bhubaneswar, Odisha, India
[2]Professor, Faculty of Management Sciences, IBCS, Siksha 'O' Anusandhan (SOA) Deemed to be University, Bhubaneswar, Odisha, India
[3]Associate Professor, Faculty of Management Sciences, IBCS, Siksha 'O' Anusandhan (SOA) Deemed to be University, Bhubaneswar, Odisha, India
[4]Assistant Professor, Faculty of Management Sciences, IBCS, Siksha 'O' Anusandhan (SOA) Deemed to be University, Bhubaneswar, Odisha, India
[5]Corresponding author and Associate Professor, Faculty of Management Sciences, IBCS, Siksha 'O' Anusandhan (SOA) Deemed to be University, Bhubaneswar, Odisha, India, Email: patnaik.rabinarayan@gmail.com

Abstract

The pricing of options is a key concept in finance, and the Black-Scholes model, which was introduced in 1973, is one of the most important contributions to quantitative finance. This model provides a solid base for the valuation purposes of European options under some assumptions like the log-normality of asset prices and the constancy of volatility of the underlying asset. This paper makes a comprehensive study of the area of option pricing, with a particular focus on the development of the Black-Scholes model and its associated modifications. This paper adopts a scientometric review to bring together the growing body of literature on option pricing models and their variations. This paper finds yearly dissemination of publications, top research outlets, co-occurrence network of keywords, cluster analysis, collaboration network of authors in option pricing, co-authorship Patterns in Option Pricing Research, network analysis of article citation, most cited research articles in OP, influential Countries in Option Prices Research, Subject Area distribution in Option Pricing Research, and key Trends in Option Pricing Research. To the best of our knowledge, no previous research has tried to analyse the papers published in the Black-Scholes model. This paper contributes by conducting a scientometric analysis of Black-Scholes option pricing models. The research identified many themes, and it provides future research direction in this area of study.

Keywords: Option pricing models, Risk management, Option pricing variants, Black-Scholes Model, Financial Modelling

1. Introduction

Option Pricing models are mathematical models which provide us a fair value of an option. If the price (value of premium) of an option is not fair, both the option holder and option writer are in dilemma. As two important models, i.e. Binomial Option Pricing Model (BOPM) and Black-Scholes Model (BSM) are used in derivative contracts, but BSM is universally accepted as an appropriate model for determination of fair value of an option. Using specific assumptions, such as constant volatility and lognormal asset price distribution, it provides a robust framework for pricing European options (Black & Scholes, 1973). Although it is popular, critics scrutinise the assumptions of the model since they cannot fully capture real-world markets (Thompson, 2016; Sinha et al., 2018; Saedi and Tularam, 2018; Weatherall, 2018; and Sheybano and Buygi, 2021). Researchers, such as Hoa& Yin (2022) and Morales-Bañuelos et al. (2022), have developed new models that more accurately reflect market functioning. They include stochastic volatility and jump processes (Heston, 1993; Bates, 1996). The ongoing development of these models emphasises the critical role that option pricing research plays in both academic and practical discourse, emphasising the importance of a thorough examination of the field's intellectual structure.

Scientific analysis is essential to get an understanding of how the research has been progressed and where it stands today, but sifting through mountains of varied literature remains daunting. Blazun et al. The Lancet (2015) outlines a consistent way of assessing trends, progress and constraints within particular areas. We perform a scientometric review on the expanding literature on Option pricing models and its extensions in this paper. Computational techniques, Monte Carlo, finite difference methods (Broadie &Glasserman, 1997), machine learning technique Li,(2022) -- have significantly broadened the field over the past four decades along with substantial theoretical developments However, to date there is no systematic review of the intellectual structure and main contributions in this field of research. By analyzing ultimate research in option pricing with a particular emphasis on the usual Black-Scholes model and its variations (since 2024) the curriculum of this report is intended to fill such hole. A review of the literature maps such studies, revealing existing trends, seminal works and evolving areas in this field with a thorough view available to both academia and practice (Cavalcante et al., 2016; Kurani et al., 2021; Thakkar & Chaudhari, 2021a).Based on this information, this paper is organised as follows: The science mapping and scientometric techniques are the primary focus of Section 2, which delineates the research methods. Section 2 describes the use of software tools to describe data sources, including database selection, bibliometric data extraction, and analysis. Section 3 summarises the scientific mapping exercise's findings, which include general patterns in publications, the distribution of influential research outlets, and keyword co-occurrence networks. Section 4 discusses cluster analysis, which includes co-authorship networks, citation networks, influential countries, subject-area distribution, and major research areas in option pricing. Section 5 presents the results, with a focus on new developments in option pricing. Section 6 identifies some existing knowledge gaps and suggests future research topics.

2. Research Methods

Scientometrics is a niche field that studies the quantitative analysis of scientific literature as well as communication about it (Blümel and Schniedermann, 2020). As Tague-Sutcliffe (1992) has defined it, scientometrics is the study of the quantitative aspects of science as both an academic and an economic venture. With direct relations to the sociology of science, scientometrics has immense impacts on science policy formation in general (Dorta-González et al., 2024). It is closely related to bibliometrics and informatics, all of which analyse the dynamics within scientific disciplines through the lens of literature production. The Russian term "naukometriya," which Nalimov coined in 1969, serves as the historical foundation of scientometrics. Initially, this concept remained relatively obscure in the West, even after being translated into English.It was in 1978 when the journal Scientometrics came to be to signify the actual impetus for the field to progress and achieve more excellence in its academic status. According to Macias-Chapula, scientific community indicators were developed for use as very crucial tools of measurement. Scientometrics is a yardstick in checking advanced developments within a particular research area, quantifies scientific productivity, and detects trends in cooperation (Dikusar, &Cujba, 2024). These are the

signs of the quality of inputs into the development, organization, and productivity of this field of research, especially those now obscured from view within the literature of option pricing research.

2.1. Science Mapping and Scientific Techniques

Science mapping and scientific techniques for analysing bibliographic data can effectively illustrate scholarly contributions and the networks associated with research domain science mapping. Using a statistical tool, metrics, and indicators would highlight the most significant trends and patterns while opening up gaps for further research (Chen et al., 2023). The main objective of science mapping is to provide transparent information on the inter-linkages between publications, authors, affiliations, and keywords (Cobo et al., 2011; van Raan, 2021), which may help in identifying the most relevant research areas and key contributors to the area of option pricing research. Hence, scientific mapping helps identify, describe, visualize, and analyze earlier research articles with specific goals (Tijssen& Van Raan, 1994). This simplifies manual reviews, often laborious and time-consuming, by defining the connections between keywords, authors, journals, and institutions within option pricing (González et al., 2022). However, science mapping implies a bottom-up approach that answers fundamental questions such as "What are the leading research domains in option pricing?" What is the correlation between these domains? What is the correlation between these domains? "What are the temporal publication trends?" "Who are the principal actors in terms of authors, their affiliations, and venues?" The answers to those questions are critical for the purpose of understanding the maturing of the field and setting directions for future research. Science mapping further reveals the strength of connections and linkages among words, authors, their affiliations, and the participating countries in the option pricing work. The present study selected scientometry due to its ability to offer a comprehensive understanding of the progression and evolution of option pricing research. Although the K.O. system incorporates science mapping, it adds traditional schemes rather than substituting them (Mazzocchi, 2018). This paper applies a quantitative science mapping technique by Cobo et al. (2011) to the networks, patterns, and trends identified in a vast dataset of bibliometric records related to option pricing. The methodology guarantees enough information regarding the evolution in the domain and presents new trends and some significant contributions.

2.2. Selection of Software in Scientometric Study

Scientific analyses of literature have relied solely on other software packages' interpretation and plotting of literature (Cobo et al., 2011). There still exist numerous free, web-based software packages accessible in various versions, depending upon the operating systems available. Determine what distinguishes the application tools and what difference these differences make: while some tools are superior in particular tasks, the other expand the scope of applicability of the tool. However, all of them are different tools with strengths and weaknesses; hence, it is highly important to choose the appropriate one according to the specific research objectives. Thus, with these tools, recognizing their features and weaknesses enhances the most appropriate selection of the tools. For example, some of the mostly used science mapping tools include IN-SPIRE, BibExcel, BiblioMaps, CiteSpace, Gephi, Biblioshiny, VOSviewer, Bibliometrix, CoPalRed, VantagePoint, CitNetExplorer, SciMAT, Leydesdorff's Software, Sci2 Tool, HistCite, and Network Workbench. We have selected the available tool, VOSViewer (v1.6.20), for the systematic mapping and visualization of the past forty years' developments in option pricing research. We selected it due to its proven track record of delivering reliable results and its user-friendly and robust GUI. According to Van Eck et al. (2010), open-source VOSviewer outperformed the MDS method. Many users in the academic community agree that it provides the credibility and adaptability needed for the purpose of science mapping. The three most frequently cited authors on VOSVIEWER are Ellegaard and Wallin (2020), Chen et al. (2022), and Ghasemzadeh and Jozi (2021). This paper used VOSViewer to analyze the complex structures of option pricing research in a more readable and analytically acceptable way.

2.3. Databank Selection

According to Amin & Mabe (2022), excellent database selection is the most important factor because it determines the comprehensiveness and accuracy of the information retrieved. Databases differ concerning coverage and levels of specialization; these are factors that have a great influence on the output of biblio-

metric analyses (Zhang et al., 2021). While conducting this literature evaluation on option pricing, we discovered that Scopus and Web of Science, which index financial models and option pricing, are two of the most essential and frequently visited databases relevant to the research issue. Previous assessments in finance and economics (Jin& Guo, 2023; Patel et al., 2022; Zhao et al., 2022) demonstrated that the two databases are adequate stores of bibliometric data. We choose the Scopus database over the Web of Science due to its broader coverage and more current updates, as indicated by Meho & Rogers, 2021. We endorse Scopus for its outstanding indexing capabilities and its extensive collection of scholarly documents, as highlighted by Garcia & Wang, 2023; Liu et al., 2022. Despices, Google Scholar, and Scopus provide a more carefully curated and reliable collection of scientific literature. Secondly, selecting a singular source like Scopus mitigates the potential confounding difficulties arising from data duplication and redundancy. This study determined that the VOSviewer software exhibits significant compatibility with Scopus, facilitating the direct input of bibliometric data in CSV format. Consequently, the program guarantees uniformity and facilitates analysis (Van Eck & Waltman, 2022).

2.4. Data Extraction and Academic Journal Selection

The keyword selection for this research has been determined by Black and Scholes, 1973; Merton, 1973; Hull and White, 1990; and Constantinides, 2022 and Alexander, 2023. Keywords have been used for this literature review, so that every area is covered completely in this research field. For this reason, the excellent keywords used during the bibliometric data collection process of this search include: "option pricing" AND ("Black-Scholes model" OR "Black–Scholes–Merton" OR "BS Model").The preliminary search was done using a combination of these keywords, which sum up the query: Article, Title , Abstract, Keywords (“option pricing" AND ("Black-Scholes model" OR "Black–Scholes–Merton" OR "BS Model"). The preliminary search query generated 918 articles (as of 19th July 20224). The Inclusion criteria were applied to ensure the significance of the publications (de Andrés-Sánchez, J., 2023). The inclusion criteria were publications in the Publications written in the only English language were included (889) was found and the subject areas of Economics, Econometrics and Finance, Business Management and Accounting, Decision sciences, social sciences and multi-disciplinary fields. This resulted in 433 documents. The articles, conference papers, book chapters and reviews and were included, this resulted in 419 documents. The bibliometric data was received in CSV and RIS file format. The CSV file was recruited into VOSviewer for mapping analysis to gain meaningful insights into option pricing, black shole model trends, while the RIS file was imported into EndNote for bibliography management.

2.5. Procedure

Following data importation into science mapping software, analyses were carried out at distinct stages to ensure high process fidelity. A careful review was performed to rule out the possibility of error in the interpretation of the data. Proper scrutiny was provided to avoid any discrepancy in the analysis of collected data. At first, after the VOSviewer software was launched, the data type was set to “map-based bibliographic data," then the data source was checked to “bibliographic database file," proceeding to upload the “Scopus CSV file,” which helps in carrying out analysis and mapping activities like citation, co-citation, co-authorship, co-occurrence, and bibliographic coupling. Next, each option was further examined under the “Unit of Analysis” using indicators like documents, sources, authors, institutions, and countries. The subsequent section reports and demonstrates the result and various analyses conducted on the recruited data.

Findings

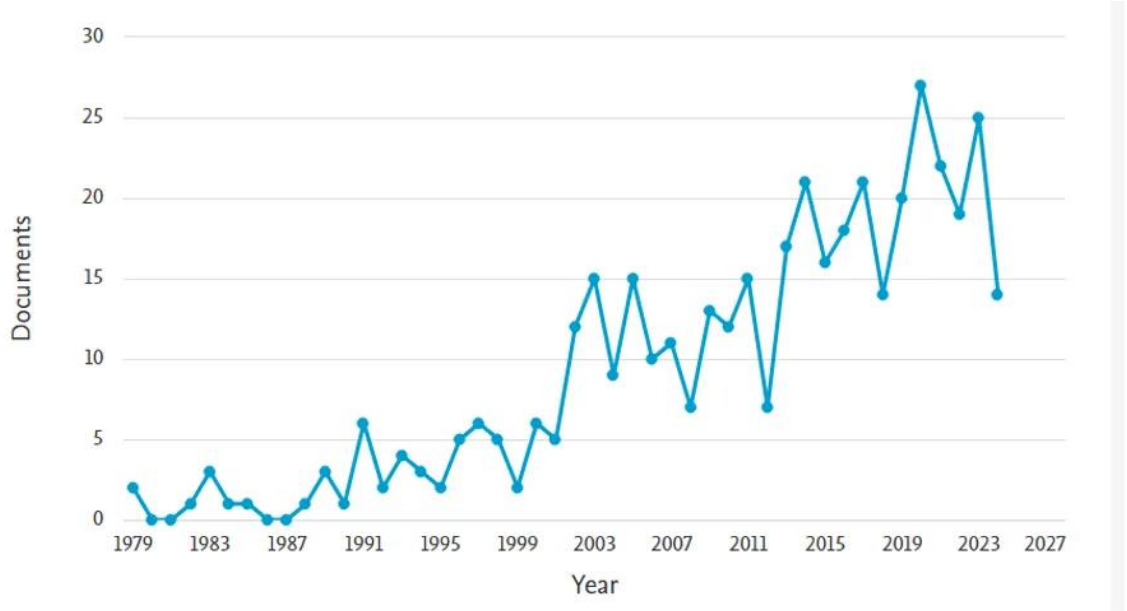
3.1. Yearly dissemination of publications

Even though research on option pricing evolved since the early 20th century when Bachelier (1900) came up, it seems that significant research on modern-day option pricing techniques started only in the 1970s. Our study addresses 419 documents published between 1979 and 2024. Despite not filtering the query to a specific date range, it is evident from our Scopus output that the earliest publication on option pricing appeared in 1979), in the Journal of Financial Economics (Cox et al., 1979), where Cox et al. (1979) introduced the

binomial options pricing model. Black and Scholes (1973) along with Merton 1973 were able to identify the Black-Scholes model which led to solving the problem of European options in closed form. From this output of the paper, came the financial revolution, which earned Merton and Scholes the Nobel Prize in Economic Sciences in 1997. Among the above directions of development is the Heston model from 1993, which introduced stochastic volatility, but there are also other classes of models that take, apart from geometric stochasticity, Lévy processes into account for describing the realization of market jumps. Now, thanks to the tools of number-based methods such as Monte Carlo simulations introduced by Boyle (1977), tree-based methods developed by Cox et al. (1975), and finite element methods introduced by Brenner and Scott (2008), we can carry out the task of pricing options in alignment with the needs of modern financial markets.

Figure 1 illustrates the percentage of studies that focus on examining changes in pricing strategies, which in turn explain price models, market conditions, and their fluctuations over time. Despite the initial lack of research on option pricing, the analysis of the Scopus database reveals a sharp increase in the number of published papers from 1979 to 2024. The information indicates a positive trend based on the starting points. From the year 1979 to 1999, the average annual articles published were very low and stood at about 1.86 articles per year. From 2000 to 2009, this figure increased to 11.3 articles per year, and it further increased to 14.1 articles per year between 2010 and 2019. In the latest period, that is, 2020 to 2024, a significant peak occurred with an average of 21.4 articles per year. The overall mean number of articles per year stands at approximately 8.93, the median stands around 9.5, and the mode is 15. The data shows a significant increase in recent years, indicating a growing focus on option pricing. More importantly, it indicates an orientation toward more quantitative, finance-focused research.

Figure 1: Annual Research Published in the given timeframe.



Source: Scopus dataset

3.2. Leading publishing houses

The option pricing progress is based on the scientific output. For effective and smooth communication, metrics, such as impact factor for the journal publications must, therefore, be looked at. The present paper has visualized with the use of VOSviewer important journals that employ number of articles, total number of citations, mean citation per article, and normalized citation, among others, to estimate the ranking of these scientific papers. Table 1 shows in-depth insight into the activity of the publication and its influential strength. In relation to so many articles published and impacts from the publication, attention was made

towards the Table 2 regarding the Scientific Impact. As indicated on Table 2, varying degrees of influence exist since the quartile ranking as well as the H-index and SJR of this journal are quite different.

Table 1 displays the leading publications in the field of option pricing, demonstrating a remarkable difference between journals in terms of impact and academic work. The citations for mathematical finance include 982 for 9 articles, giving an average of 109.11 per article. The journal has become the flagship of the field due to its high citation rate and normalized citation score of 14.11. Similar circumstances apply to the Journal of Financial and Quantitative Analysis, which has garnered citations from 5 articles cited 388 times, with a slightly lower normalised citation score of 9.93 and an average citation rate of 77.6 times per article.

Table 1. Leading Research Outlets for Option Pricing.

Journal Name	No of Articles	Tot. Citations	Avg. citations	Tot. link strength	Norm. citations
Applied Mathematical Finance	9	98	10.8889	2	6.9304
Asia-pacific Financial Markets	6	42	7	0	5.3717
Computational Economics	12	42	3.5	1	19.6324
Journal of Banking and Finance	7	164	23.4286	1	14.3807
Journal of Derivatives	11	249	22.6364	3	20.0879
Journal of Financial and Quantitative Analysis	5	388	77.6	2	9.9278
Journal of Futures Markets	11	121	11	5	8.5537
Mathematical Finance	9	982	109.1111	9	14.1076
Quantitative finance	27	257	9.5185	4	28.4841
Review of Derivatives Research	8	67	8.375	1	7.0437

Source: **Authors**

Quantitative finance records the highest output, with 27 articles, an average citation rate of 9.52, and a significant normalized citation score of 28.48, signifying extensive and relevant research. The average scores of the Journal of Derivatives and the Journal of Banking and Finance, at 22.64 and 23.43, respectively, indicate a significant but lower ranking compared to the highly ranked journals. The influence of citation metrics is lower in computational economics and Asia-Pacific financial markets, indicating a higher level of specialization in these fields. This study identifies the primary sources of option pricing, highlighting their impact and level of expertise.

The use of research articles contributes to scientific advancement. Top research publications have a scientific influence on option pricing. The scholarly impact of research findings We obtained the information from scimagojr.com/journalrank.php on July 24, 2024, to understand the academic journal impact. This information includes a variety of journals, organized based on their scholarly importance and pertinence. It also gives researchers precise information on each journal's scientific ranks. Both mathematical finance and the Journal of Financial and Quantitative Analysis hold the top rankings. They both belong to the Q-1 quartile. Mathematical Finance has an impressive H-Index of 86 and SJR of 1.62. Its impact on both significance and prolific outputs in the domain is truly astounding, and its coverage spans from 1991 to 2023. Similarly, since its founding in 1966, the Journal of Financial and Quantitative Analysis has maintained a remarkable H-index of 147 and a robust SJR value of 3.98. On the other hand, the Journal of Banking and Finance stands under the top-quartile, holding the record with an H-Index value of 197, along with the SJR at 1.66,

which attests to the steady contribution the journal made in the sector for 1977–2023. Applied Mathematics Finance, Computational Economics, and the Journal of Futures Markets, among others, fall into the second-quartile categories. These esteemed journals exhibit lower H-index and SJR values compared to publications in the top quartile. For example, the journal Computational Economics has an H-index of 47 and an SJR of 0.5, indicating that its research period spans from 1993 to 2023.

Table 2. Application of research articles on scientific development

Journal Name	Q-Index	H-Index	SJR	COVERAGE	PUBLISHER
Applied Mathematical Finance	Q-2	36	0.47	1994-1997, 1999-2023	Routledge
Asia-Pacific Financial Markets	Q-3	25	0.34	1996-2023	Springer New York
Computational Economics	Q-2	47	0.5	1993-2023	Springer Netherlands
Journal Of Banking And Finance	Q-1	197	1.66	1977-2023	Elsevier B.V.
Journal Of Derivatives	Q-3	50	0.25	1996-2023	Portfolio Management Research
Journal Of Financial And Quantitative Analysis	Q-1	147	3.98	1966-2023	Cambridge University Press
Journal Of Futures Markets	Q-2	65	0.67	1981-2023	Wiley-Liss Inc .
Mathematical Finance	Q-1	86	1.62	1991-2023	Wiley-Blackwell Publishing Ltd
Quantitative Finance	Q-1	82	0.71	2001-2023	Taylor and Francis Ltd.
Review Of Derivatives Research	Q-2	28	0.28	1996, 1998-2000, 2002-2023	Springer New York

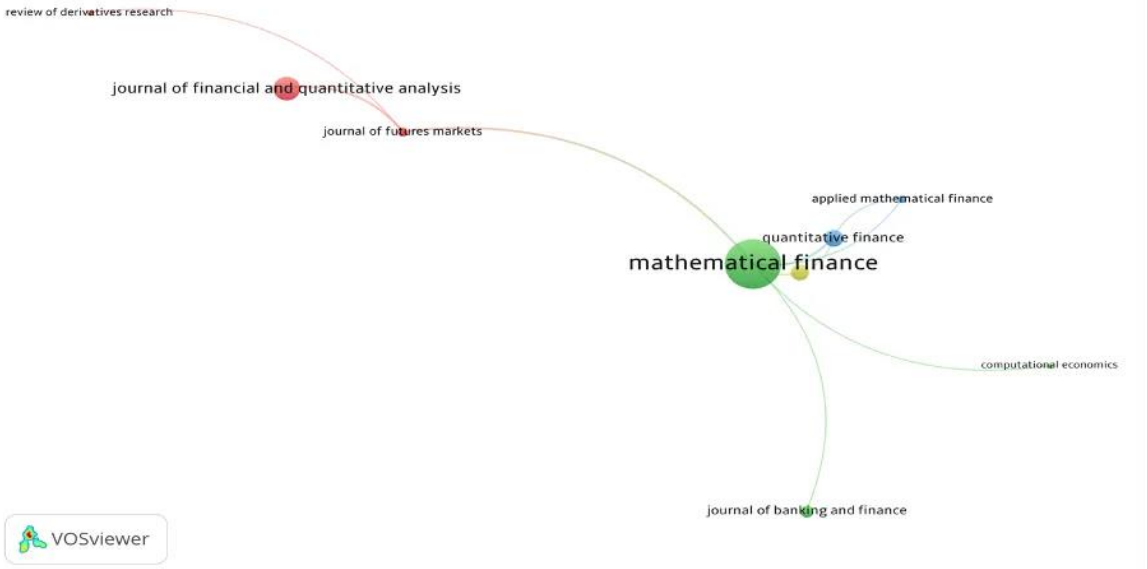
Source: **Authors**

The H-index for the journal, Applied Mathematical Finance, has scored 36, while its SJR is equal to 0.47, and the period under study stands to be 1994-2023. Similarly, the journals Asia-Pacific Financial Markets and Journal of Derivatives rank in the third quartile, or Q-3. Asia-Pacific Financial Markets have an H-Index of 25 and an SJR of 0.34, covering 1996 to 2023. The Journal of Derivatives has an H-index of 50 and an SJR of 0.25, indicating a more specialized but lesser position in the field. Conversely, Review of Derivatives Research, dated Q-2, has the lowest H index with a value of 28, and yet the SJR value stands at 0.28, indicating an even more niche but still relatively minor contribution in general research. Thus, the top-tier journals exhibit a marked variance in the degree of influence and impact, highlighting this divide and widening the gap between top-ranking sources and the general body of literature on option price calculation.

Figure 2 displays networks and information flows among the different journals and the significant contributors in the field. We created the source citation network using VOSviewer, and Figure 2 illustrates the diverse relationships among various types of financial research literature. An indication of the influence of leading journals is provided by a node citation count in Figure 2, which illustrates the relationship between nodes and clusters and the most important financial research literature. Our study shows that "Mathematical Finance" is the most important network node with 982 citations and 6 connections. This shows the journal's

importance for finance research. Four thematic clusters were also found in the network. Cluster 1 included journals like the Journal of Financial and Quantitative Analysis, Journal of Futures Markets, and Review of Derivatives Research with a high financial and quantitative analysis theme. Cluster 2 encompassed computational economics and the Journal of Banking and Finance, exhibiting a moderate degree of influence and interconnectedness. It encompasses clusters 3 and 4, which pertain to applied finance, followed by quantitative finance and derivatives, respectively. The findings provide a detailed examination of the relative influences and thematic relationships among high-impact journals related to finance research, which can be beneficial for both researchers and practitioners in this field.

Figure 2: Network of Top Research Outlets in the Field of Option Pricing.



Source: Created by VOSviewer

3.3. Co-occurrence network of keywords

A keyword co-occurrence network is critical for identifying the subject of research publications. Accessing scholarly papers using software programs is critical, as is being precise when picking keywords for bibliometric data extraction. This section focuses on constructing a co-occurrence network of author phrases from 419 sources. This paper adopted the methods that were proposed by M. Norouzi et al. (2021), M. Ullah et al. (2022), M. Wang et al. (2020), and TO Kehinde et al. (2023). They consisted of proper fractional count selections to maximize effectiveness in research processes. The analysis in Table 3 was the main focus of this paper. Table 3, containing 29 of the most frequently used authors' keywords, occurrences (O), total link strength (TLS), and average citations, shows that collaboration and information flow across academics can enhance the field further. In fact, we must adequately consider a total of 1,458 keywords culled from 419 research publications to understand their relevance and association with topics like "option pricing," "Black-Scholes model," and "stochastic volatility." Only 51 reached the minimum of five occurrences. The results show a considerable connection between keyword occurrences (O) and total link strength (TLS) for the majority of keywords, indicating a strong linear relationship. There is a strong positive correlation ($r = 0.82$) between keywords like "Black-Scholes model" and "option pricing" and the variables we are interested in. This shows that there is a nearly perfect linear relationship between how often these keywords appear and how connected the networks are. This in-depth analysis emphasizes the centrality and interconnectedness of pivotal option pricing and financial terms, highlighting their multifaceted roles within the research network and providing a nuanced understanding of their critical importance within the domain. Figure 3

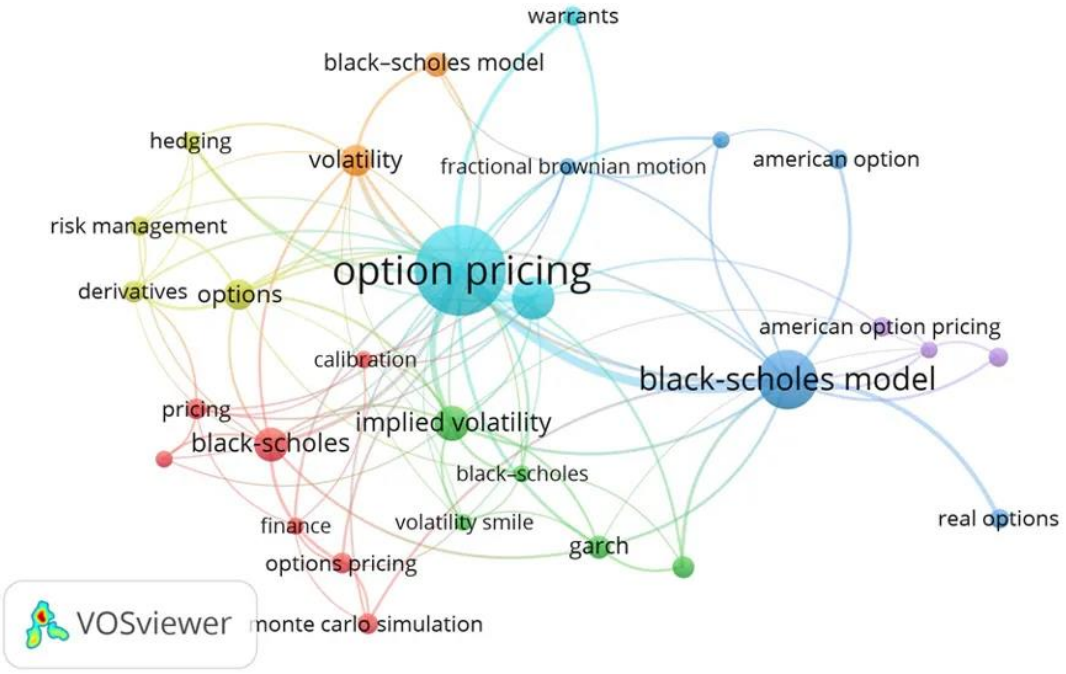
showcases a visual representation of the 29 authors' keywords, presenting closely associated keywords clustered together. The size of each node reflects the frequency of occurrence.

Table 3: Commonly used authors' keywords.

Authors Keyword	Occurrences	Total link strength	Avg. citations
American Option	6	3	5.5
American Option Pricing	6	2	6
American Options	8	6	25.375
Barrier Options	6	3	28
Black-Scholes	19	12	17.6316
Black-Scholes Model	56	40	20.7321
Blackâ€“Scholes	5	5	0.8
Blackâ€“Scholes Model	10	4	3.8
Calibration	5	4	5.4
Derivatives	8	6	10.5
European Options	5	5	2.2
Finance	5	4	7.4
Fractional Brownian Motion	5	5	3
Garch	9	9	18.5556
Hedging	6	6	21.5
Heston Model	5	5	1.8
Implied Volatility	20	18	3.35
Monte Carlo Simulation	7	4	92.7143
Option Pricing	129	70	12.0698
Options	15	12	10.4
Options Pricing	7	6	4.5714
Pricing	7	5	6.7143
Real Options	6	4	89.5
Risk Management	6	4	3.1667
Skewness	5	3	6.2
Stochastic Volatility	29	22	5.931
Volatility	16	16	10.5
Volatility Smile	5	4	71.8
Warrants	6	6	11.6667

Source: Authors

Figure 3. Authors' Keyword Analysis



Source: Created by VOSviewer

3.4. Co-Authorship Patterns in Option Pricing Research

Researchers have critically analysed co-authorship patterns, so as to understand how collaboration affects the final research output. For the cutting across disciplines as well as the geography of present-day scientific collaborations, it is vital to identify those influential researchers to assess whether their partnerships are effective; this facilitates idea flow and innovative activities while upping aggregate productivity in conducting research in general. Mapping co-authorship networks will provide insight into who the key researchers are and the structure of their collaboration. This is core to informed institutional management and strategic policymaking. For the purpose of this study, authors analysed authors of at least three articles receiving at least 15 citations each. Of 832 such authors, only 14 qualified.

To describe researcher collaborations, a VOSviewer network visualisation map was used and, for the presentation of researches, nodes and TLS as publication volumes and influences. Thicker lines and color indicate higher collaborations. Activity from 2005 to 2020 was used to mark colors on the network in Figure 5. Most connections for the key people include the "Chen, Yibing,, " "Hui, C.H.,," and "Lee, John,, " which is important for its significant involvement in the current studies. Remarkably, Table 4 depicts that the first three co-authors have made a collective contribution to an alternate approach of finding an option pricing model in 2019. In a full co-authorship network based on these leaders of research in option pricing, quite separate patterns emerge concerning research impacts and collaborations. Chen and Lee also have equally tallied at 16 total citations, whereas Kim reached 26 total citations, indicating greater impacts for each paper. This was furthered also by the average citation score that Kim had scored as 5.92 in contrast to Chen and Lee's score of 2.88, which simply meant that Kim's work had greater impacts. However, although Kim has a higher citation impact, Chen and Lee have higher TLS values, 3, instead of 2 for Kim. The results showed complex interactions among the three variables. They also explained the influence of the impact of a scholar and the pervasiveness of collaborative engagement on academic influence. This reinforces further that the inclusion of co-authorship metrics increases our understanding of research dynamics and guides decisions within academia and institutions.

Table 4: Most collaborative authors analysis

Author	No. Articles	Tot. link strength(TLS)	Tot. Citations(TC)	Norm. Citations	Avg. pub. Year
Chen, Yibing	3	3	16	2.88	2019
Hui, C.H.	3	3	28	2.2978	2008
Lee, John	4	3	16	2.88	2019
Lo, C.F.	3	3	28	2.2978	2007
Fabozzi, Frank J.	3	2	28	6.0442	2017
Kim, Young Shin	3	2	26	5.9199	2019
Câmara, António	3	0	62	2.1497	2006
Jarrow, Robert a.	3	0	49	2.0767	1994
Kim, Sol	5	0	19	3.1746	2015
Korn, Ralf	4	0	38	3.3561	2010
Kou, S.G.	3	0	489	9.0895	2005
Ma, Chenghu	5	0	45	4.6595	2011
Mackenzie, Donald	3	0	443	14.0768	2004
Zimmermann, Heinz	3	0	20	2.0016	2008

Source: Authors

3.5. Network-based article citation analysis

The number of citations has become the primary metric for evaluating the performance of bibliometrics over the course of time (Szomszor et al., 2021; Bornmann et al., 2008). The emphasis has resulted in reliance on citation frequency to assess the value of research articles. The frequency of citations in an article usually represents the importance of such research in academic circles. A higher count of citations is considered indicative of more significant and valuable research. Even with a lot of discussion around it, citation counts really do play an important role in showing how influential research can be. This often puts scientists in a tough spot, forcing them to choose between focusing on high-impact studies that garner significant citations or boosting their overall number of publications. We decided to look at the articles that have shaped option pricing by using a straightforward benchmark of 40 citations for our evaluation. This method effectively identifies that quality surpasses quantity in terms of relevance. It prioritizes citations over publication frequency. This threshold led to the discovery of 40 articles out of the 419 analysed. Evidently, only fifteen of these articles showed a weak correlation. This practical application of citation counts underscores the significance of identifying impactful research, while also shedding light on the subtle variations in the application of citation metrics in various contexts.

Figure 4: Article Citation Network Analysis.

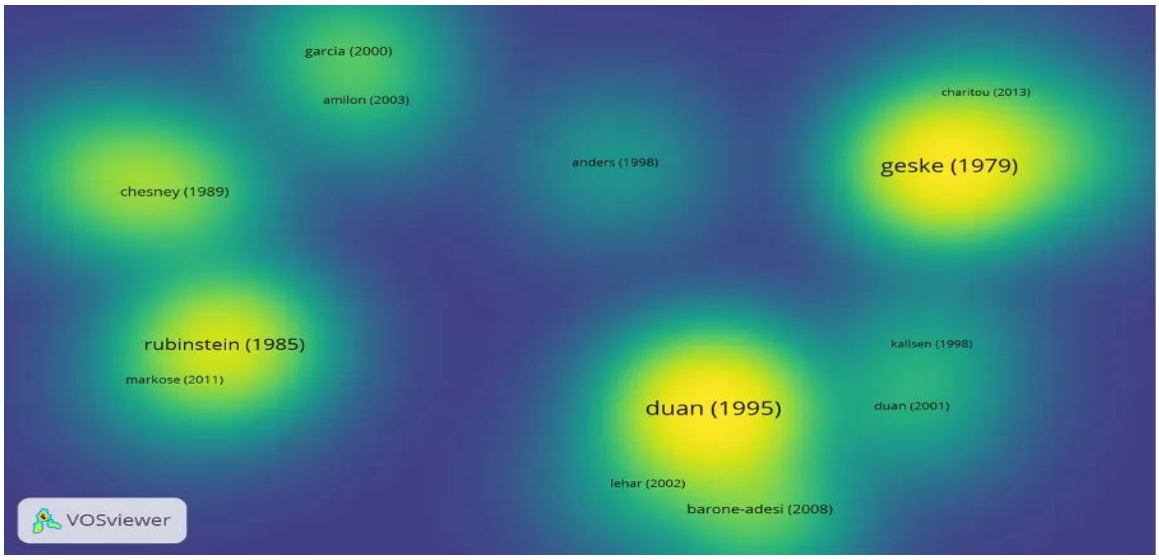


Figure 4 shows a density map of relevant articles, and Table 5 provides more extensive lists of seminal works in option pricing. The table organizes key works by focus, year of initial publication (YFP), age, total citations (TC), citation rate (TC/AGE), and the number of links to other research. Table 5 contains several notable observations. For example, the field acknowledges Duan (1995) for his influential work on the GARCH Option Pricing Model and Locally Risk-Neutral Valuation Relationship (LRNVR), which has received 634 citations in 29 years, demonstrating its significant and long-term impact. Similarly, Geske (1979) and Rubinstein (1985) have made substantial contributions with their studies on compound options and nonparametric tests, respectively. The contributions of Geske have received 581 citations over 45 years, and those of Rubinstein have received 368 citations over 39 years, which would show that they remain contemporary and influential. Of course, some of the latest studies, such as by Barone-Adesi (2008) and Chesney (1989), yield a thorough understanding of the underlying option pricing and volatility models. Barone-Adesi (2008) made significant contributions to the understanding of option pricing and volatility, garnering 170 citations in just 16 years, while Chesney (1989) concentrated on European currency options and modified Black-Scholes models, garnering 169 citations over 35 years. Although their publication histories are shorter than earlier works, these studies have made a significant impact in their respective fields. The number of citations obtained highly ranks all other works referred to in the paper, such as Yao (2000), Garcia (2000) in neural networks and nonparametric methods, and Ball (1994) in stochastic volatility and Fourier methods.

Table 5 The most frequently cited scientific papers on option pricing

No	Author(s)	Focus of Study	YFP	AGE	TC	TC/AGE	Links
1	Duan (1995)	GARCH Option Pricing Model and Locally Risk-Neutral Valuation Relationship (LRNVR)	1995	29	634	21.86207	8
2	Geske (1979)	Compound Options, Call Option on Stock, Put and Call Options& Option Pricing, BSM	1979	45	581	12.91111	5
3	Rubinstein (1985)	Nonparametric Tests, Option Pricing Models, CBOE Option Classes, Trades and Bid-Ask Quotes	1985	39	368	9.435897	3

4	Barone-Adesi (2008)	Option Pricing, GARCH Models and Filtered Historical Innovation and S&P 500 Index Option Implied Volatility Smiles	2008	16	170	10.625	1
5	Chesney (1989)	European Currency Options, Modified Black-Scholes Model &Random Variance Model	1989	35	169	4.828571	3
6	Yao (2000)	Neural networks; Forecasting; Option pricing; Black Scholes model	2000	24	132	5.5	1
7	Garcia (2000)	Option pricing, Nonparametric methods, Feedforward and networks Homogeneity hint	2000	24	133	5.541667	1
8	Ball (1994)	Stochastic Volatility Option Pricing and Fourier Methods	1994	30	165	5.5	1
9	Duan (2001)	Black–Scholes model American options GARCH Markov-chain Sparse matrix	2001	23	82	3.565217	3
10	Lehar (2002)	Option Pricing GARCH Model, Stochastic Volatility, BSM & Risk Management (VaR)	2002	22	66	3	1
11	Markose (2011)	Options, tail risks, VAR and use of alternative risk measures of trading risk	2011	13	55	4.230769	1
12	Charitou (2013)	Option-Pricing Theory, Bankruptcy Prediction, Black-Scholes-Merton (BSM) Model	2013	11	46	4.181818	1
13	Amilon (2003)	Neural networks; option pricing; hedging; bootstrap; statistical inference	2003	21	55	2.619048	3
14	Kallsen (1998)	Option Pricing in ARCH-type Models and Financial Time Series	1998	26	53	2.038462	3
15	Anders (1998)	Option Pricing, Neural Networks, Statistical Inference, Model Selection.	1998	26	54	2.076923	3

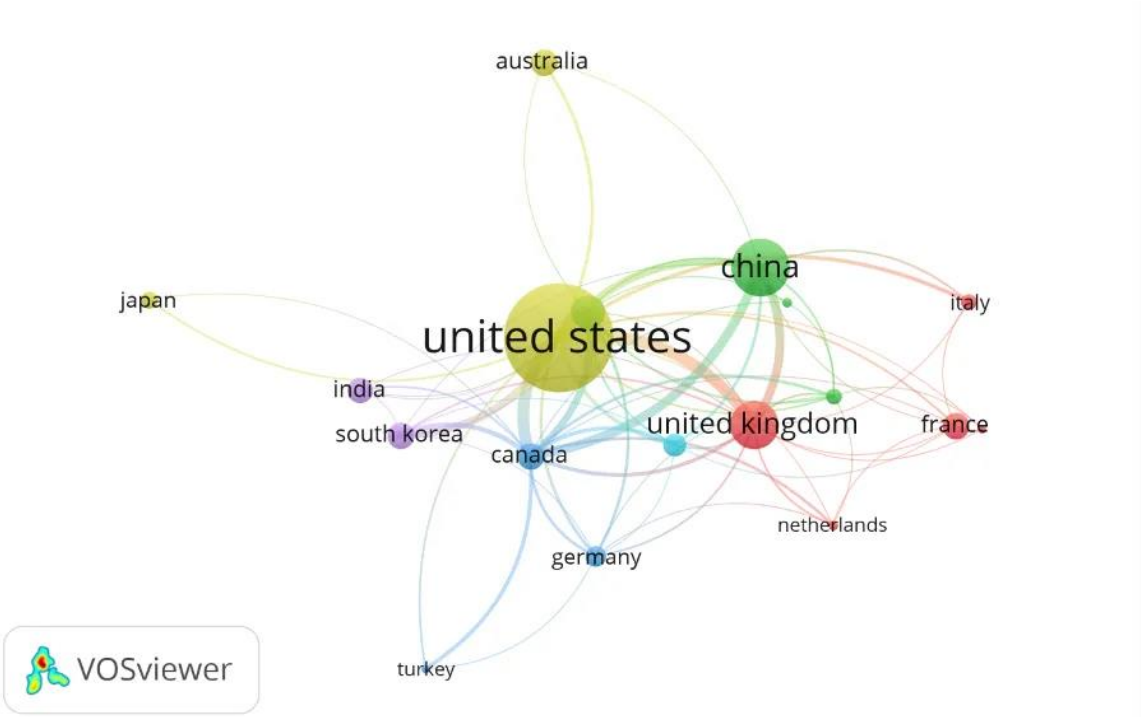
Source: Authors

In contrast, other current works, such as Markose (2011) and Charitou (2013), have recently focused much attention on alternative measures of risk and bankruptcy predictions; their respective citation counts and rates point toward their emerging relevance within the research community. Overall, from this table, it will be noticed that there's a trend where foundational work done by Duan in 1995 and Geske in 1979 has endured, but research efforts recent are still adding to this growing body of literature on options pricing and also changing the nature of studies conducted.

3.6. Key Nations in the Study of Option Prices

Many countries have dedicated significant resources to understanding option pricing in international finance. This is because of significant financial assistance for academic programs through grants, scholarships, and fellowships. When national authorities wisely distribute these resources, they enhance research quality and create a supportive atmosphere for groundbreaking developments in the field.

Figure 5: Network of influential countries in option prices research



Source: Created by VOS viewer

Figure 5 provides a detailed network visualization of the global landscape for option pricing research. The map above shows how different countries are connected and working together, based on a threshold of 5 documents and 34 citations. The visualisation reveals that 18 out of 62 countries meet these criteria, highlighting the ways in which nations participate in and contribute to the field. Further, the node sizes and connection thicknesses in the map reflect each country's research output and collaborative influence. The biggest node is the United States, representing both research output and international collaboration. Presenting 115 documents, the United States is the leading producer in the research field of option pricing. The United Kingdom ranks second with 42 documents, but its influence is somewhat less pronounced than that of the United States. Table 6 presents an opportunity for closer investigation of the metrics that underline the research impact and productivity at all levels of variation across countries. However, Table 6 includes total citations, average citations per document, and total link strength, providing an adequate evaluation of the research performance in each country. For instance, with 7,416 total citations and an average of 64.49 citations per document, this country (the United States) leads in both the total number of documents and citation metrics. The total link strength of 80 also suggests that the discipline is characterised by significant influence and widespread collaboration. In a comparable manner the United Kingdom has a well-developed research portfolio, with 42 articles and 1,154 total citations, an average of 27.48 citations per article, and 43 linkages.

Table 6: Country Profiles of High-Influence Papers on Options Price Research.

Country's	No. of Documents	Tot. Citations	Avg. Citations per Document	Tot. link strength	Avg. Publication Year	Normalized Citations
United States	115	7416	64.49	80	2008.42	1.1202
China	53	214	4.0377	42	2018.566	1.0009

United King-dom	42	1154	27.48	43	2009.29	1.7196
Taiwan	27	192	7.11	30	2014.7	0.7965
Canada	20	1008	50.4	64	2010.25	0.9835
Australia	20	225	11.25	5	2010.4	0.8343
France	20	192	9.6	10	2010.85	0.8333
South Korea	20	107	5.35	21	2014.85	0.9659
India	19	39	2.05	6	2018.53	0.6029
Hong Kong	17	371	21.82	18	2009.06	1.0974
Germany	15	207	13.8	16	2009.87	0.8203
Japan	12	177	14.75	3	2008	0.8334
Switzerland	11	352	32	15	2007.55	1.4826
Italy	11	248	22.55	8	2009.82	0.9557
Netherlands	6	70	11.67	9	2000	0.6488
Iran	6	50	8.33	4	2018.5	1.4157
Israel	5	41	8.2	5	2006.2	0.1184
Turkey	5	36	7.2	7	2016.4	1.3993

Source: Authors

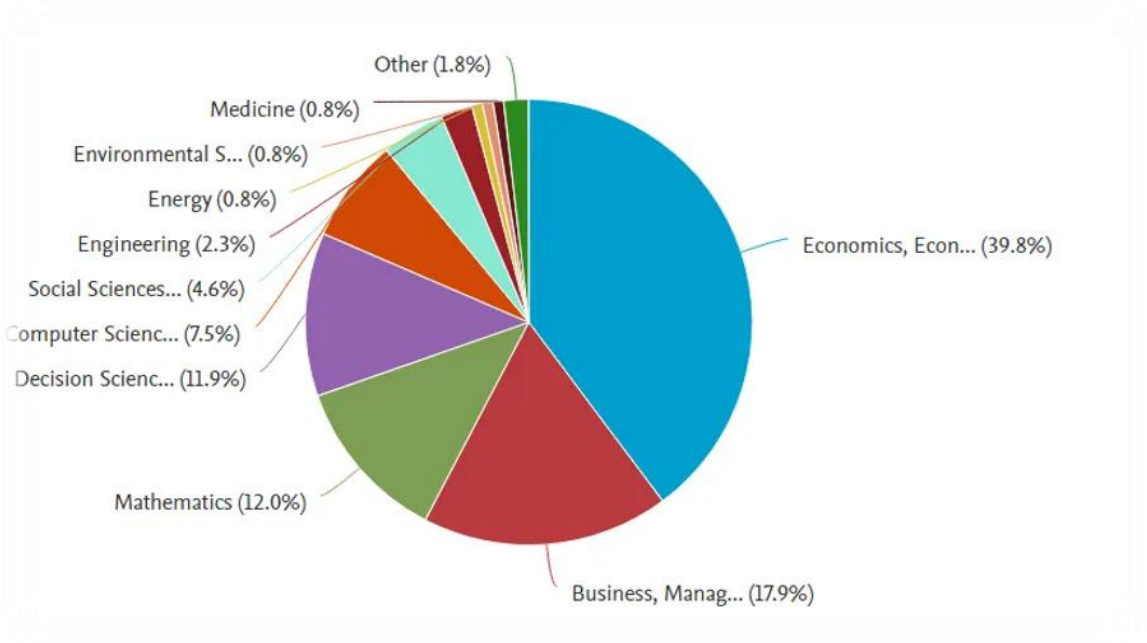
Canada has submitted 20 documents and 1,008 citations, thereby reflecting a high research influence. The average citation count, which is 50.4 for each document alongside a total of 64 link strength, really comes out to be apparent from this. Taiwan has its 27 documents and 192 citations, and with that, it has moderated research influence. The average citations per document are 7.11, and the overall link strength is 30. Figure 7 and Table 6 outline country-level differences in research production and impact. India has been an interesting case since, although it produced 19 documents, it accumulated only 39 citations- thus a relatively lower impact for its research in terms of output. A normalized citation score of 0.6029 and a total link strength of 6 indicate its rather constrained position within the global research network. Fig 6 and Tab. 6 describe in some more detail which nations exactly have an influence over studies of option pricing. Moving into further details, many highly famous countries appear that have done tremendous work along with extensive collaboration in such studies. However, still contrasts seem to appear relevant with the impact in other utterly different regions. It clearly points out to the need for international co-operation and financial investment more advanced research in option pricing.

3.7. Distribution by Top-Level Subject Categories

Different disciplines have significantly contributed to the development of research in option pricing, which is a significant model and very relevant for evaluating depth and breadth in this kind of advancement. We find ten different academic disciplines of Scopus that have really made contributions to this area. Economics, econometrics, and finance is the largest category accounting for 312 articles which represent 39.8% of all publications done in the area of research on option pricing. That percentage clearly indicates that it is in financial theory as well as econometric analysis that the design and the application of models on the option

prices need to be. Business, Management, and Accounting stands second rank, with 140 articles; this is indicative of a lot of importance given towards the practical usage of methods of option pricing.

Figure 6: Distribution of Subject Areas in Option Pricing Research



Mathematics takes the third position, with 94 articles, considering the fact that mathematical accuracy plays a fundamental role in the development and evolution of option pricing methods and price formulas. Literature also includes 93, 59, and 36 articles on the topics of decision science, computer science, and social sciences. Optimisation algorithms, computational techniques, and psychology of financial behavior fall within these disciplines. However, Figure 6 indicates the percentages of the main disciplines that are involved in research on option pricing and their importance, as well as their contributions to this area. In this respect, Table 7 offers support by showing the number of publications within the six primary areas that focus on the development of research in this field.

Table 7: Academic Involvement in Option Pricing Research

Subjects Area	Documents
Economics, Econometrics and Finance	312
Business, Management and Accounting	140
Mathematics	94
Decision Sciences	93
Computer Science	59
Social Sciences	36

Source: Authors

3.8. Key Trends in Option Pricing Research

Analyzing keywords is critical for understanding the core areas of research in option pricing (Gupta & Dhawan, 2018). Keywords are frequently closely associated with the content of research articles, including titles and abstracts, providing insight into the specific topics and themes pursued by researchers. By

examining these keywords, we can discover significant patterns and trends in option pricing. Researchers believe that keywords are critical for identifying and mapping out significant research themes, thus giving a clearer view of the subject's focus (Chen & Song, 2017; Su et al., 2010). This test increased our observation to the words of not only the abstracts but also the keywords of titles, meeting minimum occurrence thresholds at 5, which is pretty much standard in ensuring an outlook is quite comprehensive (Yin et al., 2019). We used 51 of 1,458 keywords based on domain relevance. Here are some of the findings from our examination: "Option Pricing" had the highest frequency (138) and total link strength (250), indicating that it was most central to the research domain. So there were 198 links, 73 mentions of "Black-Scholes Model" because of its connection to option pricing theory, and 30 citations of "Statistical Volatility," which has strong connections 55 to volatility modelling. In summary, the term "costs" appears 34 times with a link strength of 214, while the term "investments," mentioned 23 times with a link strength of 140, primarily relates to the practical application of the model in option pricing. All these keywords identify the research themes that concentrate on the most crucial intersections between the theoretical and practical aspects of the domain. Table 8 shows how important high-frequency keywords and link strengths are in option pricing research. Besides the dominant themes, this analysis illuminates evolutionary trends and theory-practice integration in current studies.

Table 8: Frequently Appearing Keywords in Option Pricing Research Publications

Keywords	Occurrences(O)	Tot. link strength	Avg. Citations	Avg. norm. citations
Option Pricing	138	250	16.2029	0.8961
Black-Scholes Model	73	198	21.726	0.7884
Stochastic Volatility	30	55	6.4667	0.9169
Costs	34	214	19.8529	0.9369
Economics	28	158	25.6786	0.8679
Financial Markets	24	152	21.0833	0.4879
Investments	23	140	31.7826	1.0882
Black-Scholes	23	60	14.6522	0.8919
Implied Volatility	22	56	3.0455	0.3295
Options Pricing	16	80	10.5	0.5585
Volatility	16	28	10.5	0.709
Options	15	31	10.4	1.0553
Mathematical Models	13	39	42.2308	0.8648
Commerce	12	83	1.1667	0.3076
Option Pricing Models	12	71	21.75	0.5508
American Options	11	30	18.8182	0.8582
Finance	10	52	11.4	0.6757
Black–Scholes Model	10	9	3.8	1.0507

Source: Authors

4. Discussion and Analysis

Black-Scholes' framework evolved through trades that incorporated advanced methodologies while minimizing the model's constraints. Most studies across the board center on improving traditional models to suit the dynamics of the market, especially with the characteristics of new assets, such as cryptocurrencies and changing conditions around market fluctuations.

4.1. Approaches to Valuing Options: Traditional and Alternative.

Option pricing models are concerned with mathematical modelling that utilises certain variables to calculate option pricing value. Jalan et al. (2021) emphasize the unique challenges posed by cryptocurrency options, which result in essential adjustments to the conventional Black-Scholes model. In parallel, Talponen and Turunen (2022) enhance the process by simplifying complex pricing methods, ensuring they are user-friendly while preserving accuracy. Meanwhile, Choi et al. (2022) examine the change of approach to the Bachelier model during the pandemic, whereby extreme market events demand agile pricing to support the transaction flow. In addition, Neuberger (2023) and Zhang et al. (2021) compare the basic assumptions and practical applicability of the Black-Scholes and Bachelier models in a more general and adaptable sense to the needs of different markets. Along the same lines, Xiang and Wang's (2020) advances in computer simulations that are similar to Monte Carlo make pricing more efficient, especially for complicated American options. Lee, H. et al. (2023) allow new multi-step barrier options, while Levy and Levy (2024) developed a logistic return-based model that better represents real-life data. Lastly, Lee, C. et al. (2023) introduced the finite difference method. This article aids in streamlining the computation of boundary conditions for European options. These studies clearly demonstrate the processes of modification and enhancement in option pricing models. These studies demonstrate the crucial role of modification in adapting to changes in market conditions and advances in computing power, in line with emerging trends.

4.2. Methods of Computation.

Studies show that deep learning, artificial intelligence, and neural networks improve option pricing's precision and effectiveness. To help with pricing American puts, Maitra and Arora (2024) propose a solution that combines a Fractional Order Black-Scholes-Merton (FOBSM) model with a feed-forward neural network. This model outperforms others, such as BSM and Binomial Tree, because it employs fractional derivatives. Umeorah and Mba (2022) use feedforward neural networks to solve partial differential equations with single barriers. They achieve fast and accurate results by converting the Black-Scholes PDE to a restricted optimization transaction. According to Guo and Tian (2022), classic models, such as Black Scholes, face issues when handling non-stationary data. A powerful model, and more appropriately, a transformer, outdoes the rest in deep learning algorithms for time series data when it comes to options related to the ETF Chinese market. Arin and Ozbayoglu (2022) suggest hybrid deep learning models that have a mean square error that is 94.5% lower than the Black-Scholes model. This leads to better pricing because the models account for variance more deeply. Finally, İltüzer (2022) discusses the performance of the Black-Scholes model and neural networks in option pricing on the BIST30 index. The study suggests that neural networks have outstanding performance in stable periods in call options, but Black-Scholes models tend to perform better when periods are volatile, especially with put options. These studies emphasize that the applications of artificial intelligence—or deep learning capabilities—will further advance option pricing models, especially when dealing with high-level market volatility dynamics.

4.3. Stochastic Volatility, Risk Models, and GARCH Transactions.

The research in stochastic volatility together with risk models and GARCH have thrown light into the dynamic interaction of a couple of factors relating to the pricing of an option, in particular, mostly across volatilities-driven markets. For instance, Arunsingkarat et al. (2021) outline a number of merits of the GARCH based on conventional techniques, significantly Black-Scholes utilised within estimation, whilst

the time varying volatility turned out to be the predominant focus point of interest as regards Thailand SET50 index. Belhachemi (2024) attempts to overcome some of the problems of the Black-Scholes model by adding the HTN-NGARCH model. This allows it to consider timevarying economic factors and helps further insight into the behavior of the market, such as the volatility smirk, making pricing options even more accurate. Aguilar & Kirkby (2023) provide an organized approach for the pricing of both normal and exotic options under a variety of exponential Lévy models. They make use of the Mellin transform and residue calculus to provide neat closed-form representations that make the practical application much easier. This aspect of studying the intricately knitted interactions which transform themselves into the dynamics in markets, Dufera is concerned with (2024) and goes a mile in exploring how the Brownian motions play roles during the option prices formation procedures, where the use of Hurst exponent may bring out dynamic delta hedging strategies. That just goes to say the rest: it's a journey or step towards more potential bett(er) predicts of what is set up to be an aftermath effect in the event being observed. Apart from that, Carr and Torricelli (2021) introduce new techniques in pricing products that follow conditions of arbitrage-free principles. These are simpler to work with the transactions because it applies much more straightforward closed form equations demonstrating the working of the market. In contrast, Guo and Tian, in 2022 propose that deep learning models; transformers are capable of better processing the non-stationary time series data involved in the option pricing problem. Redmann et al. in 2021, in a simplification of a very complex asset pricing model focus purely on exact transactions thereby transferring theoretical finance into real application thereby making it more approachable. In conclusion, Mollahasani 2023, discusses how the thoughtful review of ideas on time-fractional Black-Scholes equation were given a more sensitive study. The approach, therefore, involves the merging of the two methods mentioned above in improving both precision and efficiency as applied for the models of fractional dynamics in the computation of an option's value. This paper will detail how the more advanced adaptive models-which are quite well-linked to the complications associated with the financial transactionality-are being bettered at the research frontier.

4.4. Dynamics of the Market and Traders

Looking into how markets and traders behave helps us better grasp the transactions tied to the dynamics of option pricing. Hu et al. (2020) develop a model for knowledgeable traders that utilizes the Black-Scholes framework to address disruptions in the option pricing problem. This helps us understand the implied probability and trader data volume better. In such scenarios, Srinivasan (2021) employs a tailored LSTM-based neural network to predict the stock price while using Monte Carlo simulations to calculate option prices. This means that these models are compatible with all types of financial operations. Li, Liu, and Xu (2023) consider psychosocial barriers in managing option pricing transactions. Li, Liu, and Xu (2023) propose an LVM that incorporates the behavioral side to enable smoother transactions with implied volatility, defined by fluctuations around specific major price levels. Studies show that the LVM works better than common models, like Black-Scholes and CEV models. Real-life applications of the LVM include delta hedging transactions for the SSE 50 Index and S&P 500 options. The integration of concepts from behavioral finance and option pricing has resulted in improved analytical frameworks for exchanges. It also introduces psychological factors into the understanding of market anomalies, contributing to the discussion of pricing models through the application of unconventional methods.

4.5. Sector-Specific Real Options and Applications

The exploration of real options and sector-specific applications facilitates innovative transactions of traditional models across a variety of contexts. Modni et al. (2021) investigate how the Black Scholes model is used in the football industry, particularly in relation to the pricing of buyback options involved in player transfer agreements. They make a theoretical framework for this application by connecting the Black-Scholes results with those from Monte Carlo simulations. This shows how useful the model is, even though it is limited in how it can be used. Further, Hunsader et al. (2022) analyze the impact of new accounting standards on default risk across different industries, showing complex relationships between financial reporting practices and investors' creditworthiness assessments. Their detailed analysis shows how transactions in accounting regulations can affect a company's perceived financial stability. These studies together demonstrate that traditional financial models, for example Black-Scholes, can apply to different transactions

other than the conventional markets, thus highlighting the role of accounting practices in the determination of risk perceptions in different fields.

4.6. Unique Financial Instruments, Limitations, and Distinct Variables

Exotic options, barriers, and special variants are under research for novel transactions that can better provide the pricing accuracy to combat the complexity of the market. In 2024, Mandal and Bhattacharya started working on the FJD model, expanding the work of Merton further to incorporate fuzzy logic for capturing variations in the prices of stocks and parameters in the model. When assessed by transactions incorporating the NIFTY 50 and Nikkei 225 indices, the results revealed that the FJD model was superior to benchmark models. Pirjol (2023) also enriches the Asian option price by a transaction, which determines an O(T) correction to the volatility imputed in the Black-Scholes model. For that, he uses large deviations theory, which better delivers results for short maturity. Ma et al. (2020) propose the willow tree method as a transaction for determining the prices of American and exotic options using various stochastic volatility models. This approach is significantly more effective and aligned than conventional methods, which enhances its utility for intricate derivatives that include early exercise characteristics. Chval (2022) examines the Heston-Hull-White (HHW) model through transactions involving data from the DAX. The HHW model, then, would be hybrid; it captures stochastic volatility alongside stochastic interest rates to still perform effective in any instance where the interest rates can go below zero. By these comparisons, one could argue that diverse models would help in answering market concerns in interest rate transactions and thereby help manage market imperfections. Thus, together these studies deepen our understanding of exotic options and urge flexibility in models used to price complex transactions in a rather imperfect market.

4.7. Methods and Models for Analysing and Pricing Options

The analytical methods and mathematical modeling of the option pricing field help introduce new trends in the development of a more advanced version of existing models. Catalo and Rosenfeld, in a 2020 paper, have suggested a path-integral formalism transaction toward the volatility smile problem and achieved this by using a non-Gaussian distribution with adjustable absorbing barriers, thus stretching the traditional Black-Scholes model. Guo et al. (2023) pushes further to the application of Hawkes-based models on the limit order book enabling European and spread options priceable. As opposed to various other models, the EMGCHP demonstrates in its structure that volatility together with order flow changes and gives us better insight to understand how the markets can be worked upon. Even more, Lin et al. (2021) has suggested to modify Black-Scholes model. Here, it adds a corrective term with a functional given as implied volatility. The alignment of the expected prices with the market data would increase prediction accuracy to a large extent. Finally, Alghalith (2021) offers a conclusive valuation for European options that helps in making transactions with random interest rates using the Frasca-Farina process. This reduces calculations and resolves some of the issues associated with the earlier Black-Scholes model. Collectively, these studies underpin the necessity of binding advanced analytical techniques with mathematical models so that an optimal precision and relevance are achieved in option pricing in a dynamic financial market.

5.0. Conclusion

This scientometrics review covers all comprehensive analyses of the intellectual structure and evolution of research work concerning option pricing, focusing here specifically on the model due to Black-Scholes, along with numerous ensuing developments from 1979 until 2024. A mapping of contributors to such work, as well as dominant themes and newly appearing trends in the specific study line, would generate meaningful insight into what has produced, and continues to define, option pricing models from an academic and practice-investment perspective.

Findings suggest that the model by Black-Scholes still is a basis model for pricing options but there has been substantial progress in mitigating the weaknesses of that model. Extensions including the consideration of stochastic volatility and jump processes, among others, added richness to the field but resulted in highly advanced models that reflect even closer reality. Still, what is revealed in this analysis is that problems in the capturing of much of the complexity of contemporary financial markets occur mainly regarding extreme

market states, liquidity constraints, and behavioural factors. Advances in computational methods-from Monte Carlo simulations, through to the emerging applications of machine learning-have expanded the analytical toolkit available to researchers. However, the intersection of state-of-the-art computation methods with traditional frameworks on the pricing of options represents a relatively unexplored yet full of promise area of study. The study has pointed out critical gaps within multi-asset and exotics options, the use of ESG factors on options pricing, and the practice of inverse optimization and Data Envelope Analysis (DEA). These are promising areas for further inquiry, with potential to refine the option pricing models even further, and more applicable in increasingly complex and dynamic financial markets. Summary In general, despite the fact that option pricing research has covered great ground compared to the last four decades, innovation on both theoretical and computational approaches is still very imperative. Further research would allow further advancement in the field and furthering of the results toward robust, adaptable models. Subsequent research will work to bridge identified knowledge gaps by embracing interdisciplinary methodologies in model construction. The new insights that this study contributes add not only to the existing academic debate but also come with important practical implications for scholars, practitioners, and policymakers facing the new context of evolving financial markets related to option pricing.

Future Research Direction

Renewable energy contracts and cryptocurrencies are some essential areas that require research on option pricing, with regards to the work about the Black-Scholes model and its extensions, since these cannot be controlled for their volatility and market structure. Insights in the behavioral finance are relevantly applicable to models for pricing options because it commonly overrules the effect of investor's irrationality and emotions as well under the presently prevailing models. In addition, machine learning models, through the use of the explainable AI techniques will be explained better for increased clarity in the data-driven methodology. There would be future research taking on board challenges unique to the developing economies, such as political risk and liquidity constraints. Further research into the non-Gaussian processes as well as non-stationary data would improve better pricing accuracy. Real time model calibration under extreme market conditions such as negative pricing and shock in markets has worth of future research. Other areas of complex research that are important include: investigation of efficient pricing strategy for exotic and path dependent options, the impact of the changing regulatory framework on options pricing. Other promising future research directions include applications of quantum computing to solutions of difficult pricing challenges. There is a reasonable amount of advancement in further extending the Black-Scholes model and developing alternate frameworks to some extent; however, in areas of application in the real time scenario, behavioral model for market, management of extreme cases, huge gaps exist in this alternative system.

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