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Three decennaries of artificial neural networks in finance: a bibliometric review and future research agenda

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Abstract: Artificial neural networks (ANNs) have revolutionised financial operations due to their abilities to learn from nonlinear and unstructured financial data. The current study aims to systematically map the conceptual and intellectual structure of research on ANNs in the finance domain based on bibliometric analysis and network visualisation of 3,106 articles published during the period 1992 to 2022. The study identifies the research trends, major contributors, and scientific collaborations in the field. Bibliographic coupling analysis and co-citation analysis of the documents revealed five clusters and three clusters of documents, respectively. Additionally, the current study intensively reviewed the important studies lying in each cluster to provide a comprehensive assessment of the relevant literature, thereby uncovered the knowledge gaps and challenges, and provided recommendations for future studies. Therefore, the study can be taken as a baseline by future researchers and financial practitioners to advance in the concerned field with the appropriate approach.

Keywords: neural networks; bibliometric; finance; forecasting; network analysis; research trends.

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1 Introduction

Artificial neural networks (ANNs) are data-driven and machine learning (ML)-based computational techniques inspired by the functionalities of a human nervous system that learn from experiences (Zhang and Lu, 2021). In the past few decades, ANNs have proven their efficiency and supremacy in performing several tasks such as classification, optimisation, approximation, identification, and forecasting under different domains. The finance domain has also not been untouched by the potential of ANNs, especially in the area of forecasting. Since there exists a strong link between different macroeconomic variables and financial market prices such as stock market prices (Keswani and Wadhwa, 2021) and forex rates (Philip, 2011), global financial markets recently witnessed significant volatility and nonlinearity in financial prices, especially due to coronavirus outbreak (Zhang et al., 2020a). ANNs outperformed various linear statistical models in forecasting financial prices owing to their superior ability to capture the nonlinearities and hidden relationships in the data (Abiodun et al., 2018). Indeed, the efficacious implementation of an ANN can significantly contribute to enhancing the comprehensibility of the stochastic data generation process of financial prices (Clements et al., 2004). Moreover, careful integration of ANNs with statistical and other ML methods can considerably improve their predictive efficacy in volatile financial markets (Tealab, 2018).

Due to the superior characteristics of ANNs, researchers across the world have leveraged their high potential for different applications in the finance domain such as credit scoring (Huang et al., 2004), stock index prediction (Kara et al., 2011), bankruptcy prediction (Nanni and Lumini, 2009), stock market crisis prediction (Chatzis et al., 2018), and volatility prediction (Pradeepkumar and Ravi, 2017). Consequently, the literature on ANNs witnessed rapid growth in the finance domain. There is an evident need to objectively synthesise such vast literature in order to gauge the contribution of ANNs in finance. The bibliometric technique is widely being adopted by researchers as a robust tool to objectively synthesise scholarly works and assess the trends in prominent areas, topics, journals, authors, publications, and countries with the aim of identifying major contributors who have been central to the development of a particular research field with a vast literature (Broadus, 1987).

Although the majority of the existing reviews adopted the approach of bibliometric analysis, it is noteworthy that they analysed the literature on ML and that too, in the specific areas of finance, and thus are narrowly focused and fragmented. One such review of 138 research articles on ML in stock market forecasting was presented by Kumbure et al. (2022) and the results evidenced the preponderance of ANNs, support vector machine (SVM), and fuzzy theory as predictive techniques in stock markets whereas technical indicators were found to be frequently used as inputs to ML-based models. Kumar et al. (2022) also provided a review of ML and statistical techniques used in stock market forecasting by examining 30 research articles. The review shed light on various methodological aspects of the articles such as datasets, performance measures, and also highlighted the prominent sources in the concerned area. Henrique et al. (2019) adopted the bibliometric approach to review 57 articles on stock market forecasting using ML. The findings showed the predominance of ANNs and SVM in forecasting stock market prices. Gandhmal and Kumar (2019) critically reviewed 50 papers in the area of stock market prediction and found that ANNs and fuzzy-based methods were frequently deployed for forecasting stock prices. Shi and Li (2019) adopted the approach of

bibliometric analysis to map the contribution of ML in predicting bankruptcy for corporate firms. Goodell et al. (2021) performed the bibliometric analysis of 283 articles on different financial applications of ML techniques and demonstrated the preponderance of ANNs as a promising ML-based tool among others such as SVM and random forest (RF).

Here, it is worth noting that no review, to date, comprehensively maps the contribution of ANNs in finance. It has acted as a motivation to conduct the present review to bridge this gap. Thus, the current study is a novel attempt that unveils the current state of research on ANNs in finance through bibliometric analysis and network visualisation. In addition, the present study contributes to the current discussion on using ANNs in finance by discovering the knowledge gaps and challenges for future researchers through intensively reviewing the relevant literature in the concerned field. Thus, in the current study, the adoption of the bibliometric technique facilitated the systematic investigation of the field with such vast literature and enabled to deconstruct the conceptual and intellectual structure of ANN research in finance. Particularly, the study has following objectives:

- 1 To identify the publication and citation trends, major contributors, and collaborations in the research on ANNs in finance.
- 2 To discover the main topics studied in the research on ANNs in finance.
- 3 To discuss the challenges and future research directions in the field.

The remainder of the paper is organised in the following mode: Section 2 describes the methodological framework of the study; Section 3 presents the results of bibliometric analysis and provides a detailed review of influential research works; and finally, Section 4 concludes the current study with discussion of challenges and future research areas.

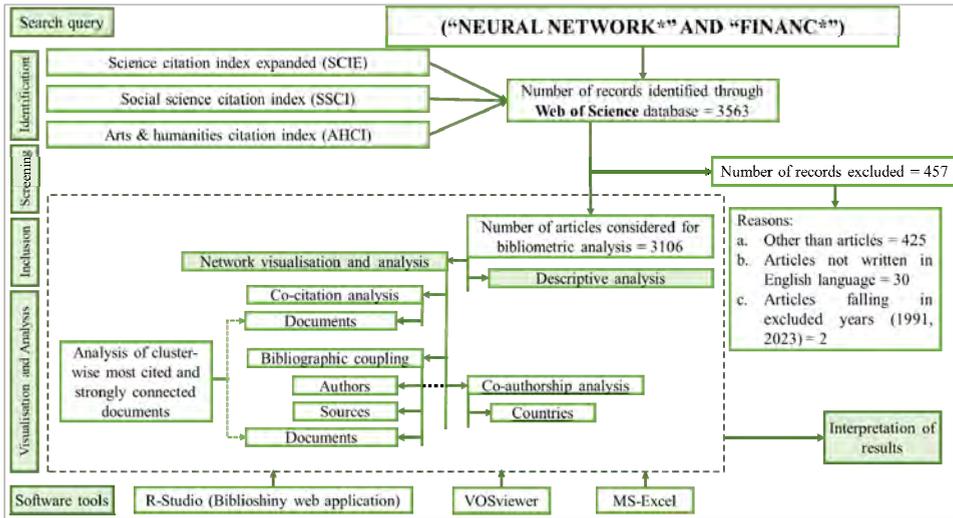
2 Research methodology

2.1 Data collection

In light of the objectives of the study, a search query has been finalised by combining the keywords, i.e., ‘neural network’ and ‘finance’ with required Boolean operators and search modifiers as shown in Figure 1. The Science Citation Index Expanded (SCIE), Social Science Citation Index (SSCI), and Arts and Humanities Citation Index (AHCI) of the Web of Science (WOS) database have been used as a source of data collection. The rationale for the selection of the WOS database is its reliability, frequent usage in bibliometric studies, trustworthiness, and inclusiveness as it is considered to be the largest database with wide coverage of scientific literature (van Eck and Waltman, 2010). Initially, 3,563 documents were identified. After excluding the documents as per the selection criteria (see Figure 1), a corpus of 3106 articles published during 1992–2022 was taken as the final sample of studies to conduct bibliometric analysis. The data of the selected 3,106 articles was collected from WOS in ‘.txt’ format. Articles are undergone a

rigorous and standardised process for ensuring their quality aspect before getting published in journals and thus are considered as a source of certified knowledge (Ramos-Rodríguez and Ruíz-Navarro, 2004). It is the reason behind the selection of only articles in the corpus for the current study.

Figure 1 Methodological framework (see online version for colours)



Source: The author

2.2 Data analysis

To achieve the objectives of the study, bibliometric analysis has been performed on the collected data of 3,106 articles. The bibliometric method is a powerful way to objectively synthesise the existing literature in a particular field based on bibliographic networks in an unbiased manner (Fauzi, 2022). As shown in Figure 1, the current study performs:

- a descriptive analysis to identify the research trends, major contributors, and research collaborations
- b network analysis to systematically map the conceptual and intellectual structure of ANN research.

In addition, the study intensively reviewed the relevant literature to uncover the knowledge gaps, challenges, and directions for future studies. To perform the analysis, different software packages/tools including VOSviewer 1.6.18 (van Eck and Waltman, 2010), biblioshiny web platform supported by the bibliometrix package of R 4.2.1 (Aria and Cuccurullo, 2017), and MS-Excel 2019, have been deployed.

3 Results

3.1 Descriptive analysis

Figure 2 shows the publication and citation trends over the period of three decades from 1992 to 2022. The total coverage period has been divided into three intervals to perform a decade-wise analysis of article production and citations. The first interval covers the years starting from 1992 to 2002, the second interval covers the years starting from 2003 to 2012, and the third interval is from 2013 to 2022. The total citations received by 3,106 articles are 13,783 over the three decades while the average citation per document is 25.50. In the first interval, a sluggish growth has been observed in the number of both articles (175, 5.63% of 3,106 articles) and citations (568.17, 4.12% of the total 13,783 citations). In the second interval, the growth started getting momentum when the publications increased by approximately 243% to 600 articles (19.32% of 3,106) and citations increased by approximately 309% to 2,324.91 citations (16.87% of 13,783). The number of publications and citations witnessed a precipitous proliferation and thus, an exponentially growing trend during the third interval when 2,331 articles (75.05% of 3,106) have been published and 10,890.18 citations (79.01% of total 13,783 citations) have been received. An overall growth of 18.39% per annum has been found in the number of publications over the period of three decades. The results evidence the upward trend in publications of citation-worthy research articles and thus indicate the growing fascination of the concerned field among the researchers' community and the contemporary relevance of the field for conducting future studies. Furthermore, the international co-authorship is found with a considerable percentage of 23.63% which indicates a high degree of inter-country collaborations among authors across the world. Therefore, it can be deduced here that the research field concerning ANNs in finance is a topical one and continuously ingesting the attention and endeavours of worldwide researchers, as well.

Table 1 Top 10 journals with highest number of publications

<i>Sources</i>	<i>Articles</i>	<i>% of 3106</i>
<i>Expert Systems with Applications</i>	340	10.95
<i>IEEE Access</i>	112	3.61
<i>Applied Soft Computing</i>	89	2.86
<i>Neurocomputing</i>	72	2.32
<i>Neural Computing & Applications</i>	67	2.16
<i>Computational Intelligence and Neuroscience</i>	59	1.90
<i>Knowledge-Based Systems</i>	50	1.61
<i>Sustainability</i>	50	1.61
<i>European Journal of Operational Research</i>	48	1.54
<i>Decision Support Systems</i>	43	1.38

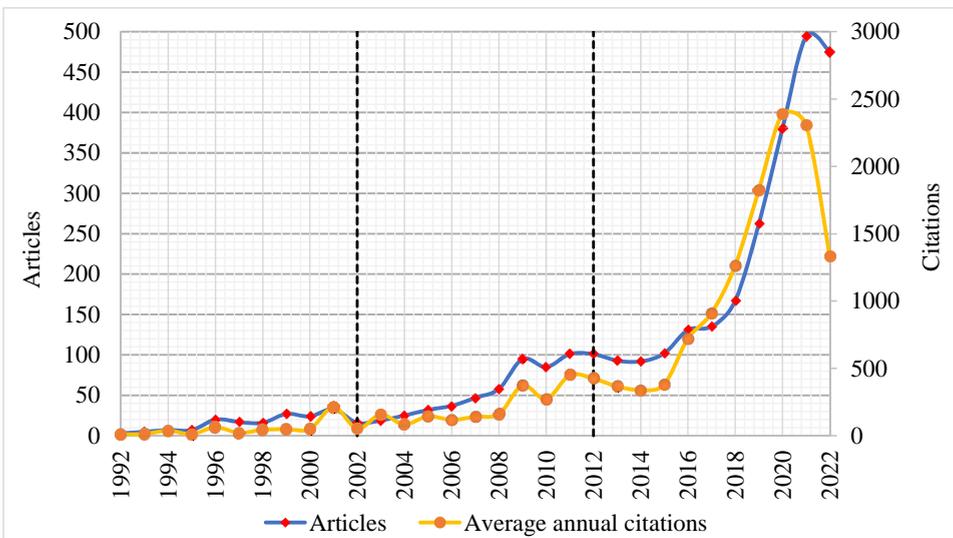
Source: The author

In the concerned research field, the three major subject areas are:

- a 'computer science' comprising the highest number of published articles (1,549, 49.87% of 3,106)
- b 'engineering' (977, 31.45% of 3,106)
- c 'business economics' (542, 17.45% of 3106).

Out of the 3,106 articles, 2,712 articles (87.32% of 3,106) are published in the journals indexed in SCIE of the WOS database. There are 788 journals comprising a total of 3,106 articles. The top ten journals having the highest number of publications are presented in Table 1.

Figure 2 Article production and citation trend over three decades (1992–2022) (see online version for colours)



Source: The author

3.2 Network visualisation and analysis

3.2.1 Bibliographic coupling

In this study, the bibliographic coupling analysis has been performed considering the documents published in the past six years starting from 2017 to 2022. The first rationale behind selecting the limited time period of the past six years is that the bibliographic coupling method, unlike co-citation analysis, deals with the primary documents (included in the corpus) and therefore, this method is sensitive to the literature growth in the earlier phase of the research field, the second rationale builds on the recommendations provided by Zupic and Čater (2015) for the appropriate application of this method, and the third and the most important rationale is the exponential surge in the number of articles since the year 2017 as depicted in Figure 2. Consequently, 1,913 articles out of a total of 3,106 articles were published during the selected period of six years (2017 to 2022) and

considered to conduct the bibliographic coupling analysis at the source level, author level, and document level.

3.2.1.1 Source-wise bibliographic coupling

An analysis has been performed on bibliographically-coupled sources which comprise articles published between 2017–2022. Figure 3 depicts the network of bibliographically-coupled 60 sources fulfilling the inclusion criteria of having at least five articles with a minimum sum of 20 citations. The node size represents the total bibliographic linkage strength (BLS) of a journal and the colour indicates the clusters of sources based on their BLS with each other as shown by the size of edges between nodes. BLS between two journals is based on the number of bibliographically-coupled articles published in them. The higher the number of such documents, the higher the BLS. After analysing the network, the top ten most relevant journals between 2017 and 2022 were identified based on their BLS as shown in Table 2. The analysis revealed the dominance of *Expert Systems with Applications* with the highest BLS and its robust bibliographic coupling with *IEEE Access* and *Applied Soft Computing* as represented by the thick red edges connecting them in the red cluster. It implies two things. First, these prominent journals consist of the highest number of bibliographically-coupled articles in the concerned field. Second, the research on ANNs in finance substantially lies in the fields (subject areas) of these journals, i.e., generally, the computer science.

In the green cluster, *Computational Economics*, *Sustainability*, and *European Journal of Operational Research* are with the highest BLS over others. On the other hand, the remaining journals are with small-sized bubbles (low BLS) which indicate that the research on ANNs in finance has started entering other areas, too.

Table 2 Top ten journals with the highest BLS, bibliographically-coupled documents, and citations

Source	Documents	Citations	BLS
<i>Expert Systems with Applications</i>	117	2,959	33,609
<i>IEEE Access</i>	112	978	20,452
<i>Applied Soft Computing</i>	52	977	13,371
<i>Computational Economics</i>	32	211	7,512
<i>Sustainability</i>	48	424	6,169
<i>Neural Computing & Applications</i>	42	492	6,133
<i>European Journal of Operational Research</i>	13	967	5,866
<i>Applied Sciences-Basel</i>	31	184	5,726
<i>Mathematics</i>	28	66	5,067
<i>Neurocomputing</i>	28	397	4,883

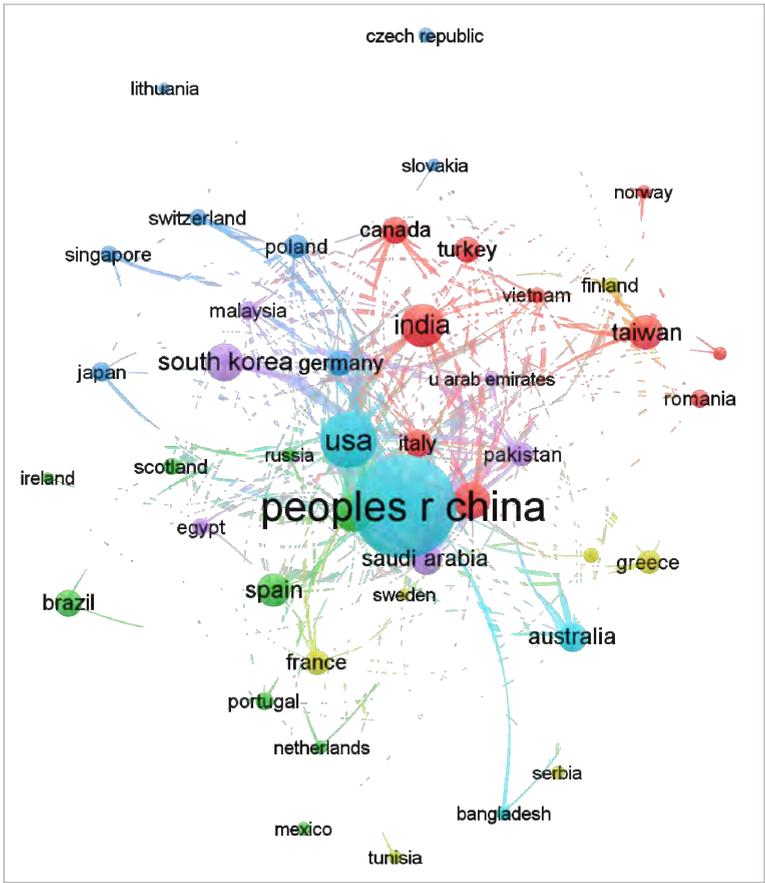
Source: The author

Table 4 Top ten dominant countries having highest publications, citations, and connectivity strength

Country	Documents	Citations	Total link strength
Peoples R China	745	7,464	246
USA	226	5,056	185
India	131	1,367	95
South Korea	105	1,334	58
England	100	835	111
Iran	95	1,514	67
Taiwan	84	867	57
Spain	80	754	44
Saudi Arabia	68	405	103
Australia	62	1,009	62

Source: The author

Figure 5 Co-authorship network of countries (see online version for colours)



Source: VOSviewer

3.2.1.3 Cluster wise bibliographically-coupled document analysis

Bibliographic coupling occurs between two documents when they cite a common third document or when they have one or more identical references (third document) in the list of their bibliographies. A high number of common cited documents in the bibliographies of any other two documents indicates the likelihood that these two documents deal with related research areas (Kessler, 1963). Bibliographic coupling helps in mapping the current conceptual structure within a particular research field, thus is retrospective in nature, while the co-citation analysis has the potential to colligate the different research fields in a particular domain, and thereby provides prospective and intellectual insights into the relationships among these fields, thus is prospective in nature (Ferreira, 2018). In this way, these two methods of bibliographic analysis are complementary to each other and enable a researcher to map the conceptual and intellectual structure of research in a particular research domain and unveil the contiguity of the domain to other fields.

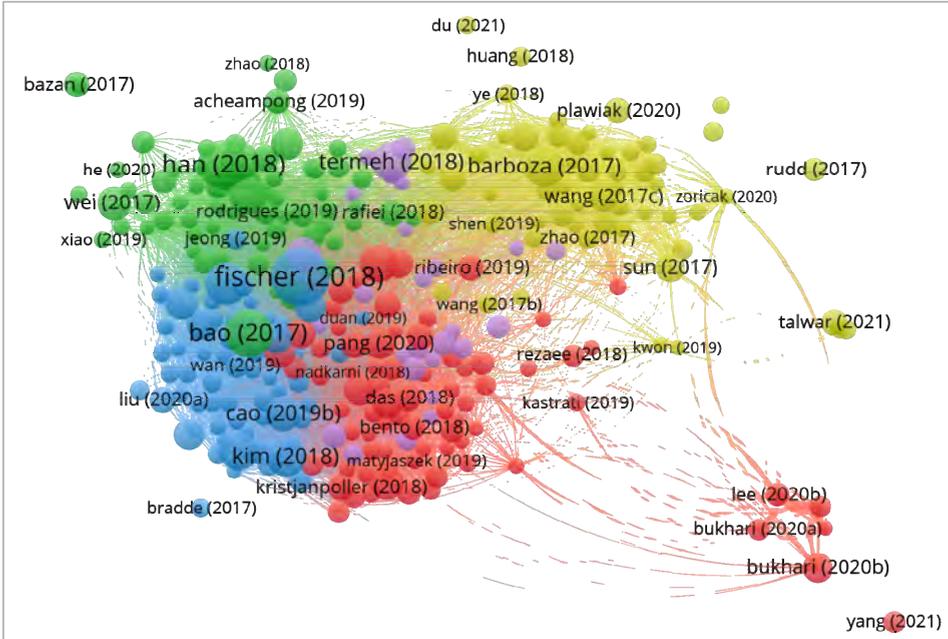
In the present study, an inclusion criterion of at least 20 citations has been set to perform a detailed and meaningful analysis of the most relevant articles. Out of 1,913 articles published between 2017 and 2022, 300 articles met the set threshold but the largest set of connected articles includes 288 articles that were analysed to map the current conceptual structure of ANN research in finance. Five clusters of documents emerged based on their bibliographic similarities as shown in Figure 6. The bubble size denotes the citations of a document, while the colours represent the clusters of bibliographically-coupled documents.

Cluster 1: Deep learning and stock market prediction

The first cluster, coloured in red, consists of 76 articles. In this cluster, the studies focused on utilising deep learning techniques for stock market forecasting, and thus the cluster can be labelled as ‘Deep learning-based stock market prediction’. Among the important works on deep learning-based stock market prediction, Krauss et al. (2017) developed several ensembles by integrating deep neural networks (DNNs) with gradient-boosted-trees (GBT) and RF to forecast the prices of stocks listed on S&P 500 index. The findings revealed that the models posed challenges to the semi-strong form of market efficiency due to their high predictive power with the greatest degree of accuracy. Zhong and Enke (2017) developed a hybrid model by integrating the potential of ANNs and principal component analysis (PCA) to forecast the directional changes in S&P 500 index. Xing et al. (2018b) surveyed natural language processing techniques comprising various ML and deep learning techniques, and discussed their utilities in financial forecasting including volatility prediction, stock price prediction, credit scoring, and sentiment analysis. Henrique et al. (2019) found that SVM and ANNs were preponderantly deployed for stock market prediction. Long short-term memory (LSTM)-based models have also shown their superior performance in predicting stock markets (Baek and Kim, 2018; Pang et al., 2020). Hoseinzade and Haratizadeh (2019) showed the superior abilities of convolutional neural network (CNN) in extracting the features from the data collected from multiple sources as compared to feedforward neural networks (FFNN) and backpropagation neural networks (BPNNs). Chatzis et al. (2018) developed an early warning system based on DNNs for stock market crisis prediction and compared its predictive performance against decision trees (DT), RF, SVM, extreme gradient boosting, and FFNN. The findings revealed the superior performance of DNNs

over other models in terms of higher predictive accuracy, and the researchers also recommended central banks to use DNNs to timely adjust their monetary policies and ensure financial stability. Pradeepkumar and Ravi (2017) utilised the particle swarm optimisation (PSO) to train the quantile regression neural network to predict the volatility in the financial prices including exchange rates, commodity prices, and stock market indices. The results evidenced the high predictive efficacy of the model which may be due to the high ability of PSO in locating the better solutions or effectively optimising the parameters of the model.

Figure 6 Network of bibliographically-coupled documents (see online version for colours)



Source: VOSviewer

Cluster 2: Deep learning and high dimensionality problem

The second cluster, coloured in green, comprises 65 articles focusing on utilising deep learning techniques for solving the high dimensionality problem in the financial environment. Thus, the cluster is labelled ‘Deep learning and high dimensionality problem’. Among the important works on solving high-dimensionality problems using deep learning, Han et al. (2018) introduced DNNs to solve high-dimensional partial differential equations (PDEs) and the results evidenced the efficacy of the model. Thus, the study argued that the proposed approach can successfully be applied to solve different economic and financial problems in a high-dimensional environment. Bao et al. (2017) utilised wavelet transforms (WT) to decrease the noise effect in the data and deployed stacked autoencoders (SAE) to reduce the feature dimensionality aiming at providing LSTM with deep high-level features for stock price prediction. Weinan et al. (2017) adopted an approach of deep reinforcement learning and applied DNNs to solve high-dimensional parabolic PDEs and backward stochastic differential equations

(BSDEs) while Beck et al. (2019) applied DNNs with stochastic gradient decent to solve high-dimensional nonlinear second order PDEs and second order BSDEs. The researchers in both of the studies, i.e., Weinan et al. (2017) and Beck et al. (2019) argued that their proposed approaches can be effective in developing financial derivative pricing models, credit valuation models, and portfolio optimisation models in a nonlinear and high-dimensional environment. Cai et al. (2018) found that increasing the number of hidden layers in DNNs enhanced their stability and accuracy for classification tasks with high-dimensional features. Rafiei and Adeli (2018) added a SoftMax layer to an unsupervised deep Boltzmann machine (DBM) with the aim of reducing the feature dimensionality. Acheampong and Boateng (2019) utilised the sigmoid function (SMF) (output layer) and rectifier function (ReLU) (hidden layer) as activation functions, and stochastic gradient descent with backpropagation algorithm (BP) as an optimisation algorithm to develop a multilayer perceptron (MLP)-based prediction model with high-dimensional data in the area of environmental economics. Rodrigues et al. (2019) adopted a data fusion approach integrating the features from textual and time-series data, and deployed attention mechanism to decrease the dimensionality of the features extracted from the textual data using convolutional layer while LSTM was deployed to extract the features from the time-series data.

Cluster 3: Recurrent neural networks (RNN) and prediction-based financial trading

The third cluster, coloured in blue, includes 61 articles focusing on utilising RNN and its advance form, i.e., LSTM, in supporting and framing prediction-based trading and investment decisions in the financial domain. Thus, the cluster is labelled 'RNN and prediction-based financial trading'. Among the important works on prediction-based financial trading using RNN and LSTM, Fischer and Krauss (2018) applied LSTM to develop prediction-based trading strategies for the stocks listed on S&P 500 index. Deng et al. (2017a) integrated recurrent DNNs with fuzzy logic (FL) in a reinforcement learning environment to generate trading signals and perform self-taught reinforcement trading of stock and commodity future contracts. Long et al. (2019) developed a multifilters neural network by combining CNN and RNN to perform forecasting and signal-based trading for the Chinese stock market index CSI 300 in a simulated environment. Kraus and Feuerriegel (2017) applied DNNs including RNN and LSTM with the approach of transfer learning to process the information related to the financial disclosures of listed German companies with the aim of developing a prediction-based decision support system for investors and traders. Xing et al. (2018a) developed an ensemble of evolving clustering method (ECM) and LSTM to analyse the market sentiments for portfolio optimisation and simulated trading. The findings revealed the high functional efficacy of the ensemble over equal weighted portfolio optimisation strategy, autoregressive integrated moving average, and Holt-Winters portfolio optimisation strategy, owing to the capability of ECM in estimating the market views with high accuracy and the ability of LSTM in learning the long term dependencies in stock prices. Long et al. (2020) utilised CNN to discover the investment patterns based on the fusion of market data and trading information of investors with the aim of supporting trading decisions through accurate prediction of stock price trends by using the extracted patterns as inputs to an attention-based bidirectional LSTM. Zhang et al. (2020b) integrated LSTM with complementary ensemble empirical mode decomposition and

PCA, aiming at providing the model with most relevant features to perform prediction-based simulated trading in the Chinese stock market.

Cluster 4: ANNs and creditworthiness assessment

The fourth cluster, coloured in yellow, comprises 58 articles. In this cluster, the studies focused on utilising ANNs for evaluating the creditworthiness of listed companies. Thus, the cluster can be labelled ‘ANNs and creditworthiness assessment’. Notably in the context of firms, creditworthiness assessment encompasses financial distress prediction, credit risk evaluation, and forecasting of bankruptcy of listed companies. Indeed, an accurate and timely evaluation of the creditworthiness of companies can significantly contribute to the decision-making process of financial institutions (lending decisions), investors (investing decisions), and auditors (preparing reports). Among the important works on evaluating creditworthiness using ANNs, Wang et al. (2017) utilised single hidden layer FFNN with a grey wolf optimisation algorithm to develop a novel kernel extreme learning machine (KELM) for forecasting bankruptcy and compared its performance against PSO-KELM, genetic algorithm (GA)-KELM, SVM, and RF in terms of classification accuracy and speed. On the other hand, Zhao et al. (2017) deployed a two-step grid search optimisation strategy to train KELM for bankruptcy prediction and compared its classification performance against SVM, RF, PSO-fuzzy k-nearest neighbours (kNN), and logit model. The findings of both of the studies Wang et al. (2017) and Zhao et al. (2017) evidenced the superior performance of the proposed KELM approaches with high classification accuracy. Vochozka et al. (2020) deployed LSTM to forecast the bankruptcy of companies operating in the Czech Republic. Pławiak et al. (2020) adopted an ensemble approach to develop a deep genetic hierarchical network of learners by combining the probabilistic neural networks (PNNs), kNN, SVM, and fuzzy systems with GA for the task of credit scoring. Moreover, Huang et al. (2018) found the superior performance of PNNs with minimum error rate in evaluating the credit risk of Chinese small and medium-sized enterprises. Mselmi et al. (2017) utilised various prediction techniques comprising ANNs, logit model, SVM, partial least squares (PLS), and a hybrid model integrating SVM with PLS to forecast the financial distress of French small and medium firms while Liang et al. (2018) adopted an approach of unanimous voting to develop an ensemble of bagging-based MLP, boosting-based classification and regression DT, and SVM for financial distress prediction.

Cluster 5: Adaptive neural networks (ADNNs)-based prediction and optimisation

The fifth cluster, coloured in violet, consists of 28 articles considering the usage of ADNNs such as fuzzy neural networks, adaptive neuro-fuzzy inference system (ANFIS), and dynamic neural networks, e.g., LSTM and RNN for financial prediction and portfolio optimisation. Thus, the cluster can be labelled ‘Adaptive neural networks-based prediction and optimisation’. The lowest number of articles and sparse presence of violet bubbles in the network indicate the scant research on ADNNs in the finance domain. Among the important works on using ADNNs in financial prediction and optimisation, Luo et al. (2019) utilised evolving recurrent interval type-2 intuitionistic fuzzy neural network to reduce the noise effect and model the uncertainties in high-frequency financial data aiming at forecasting the financial prices of financial futures, commodity futures, and precious metal. Singh (2018) integrated ANNs with FL and self-organising feature

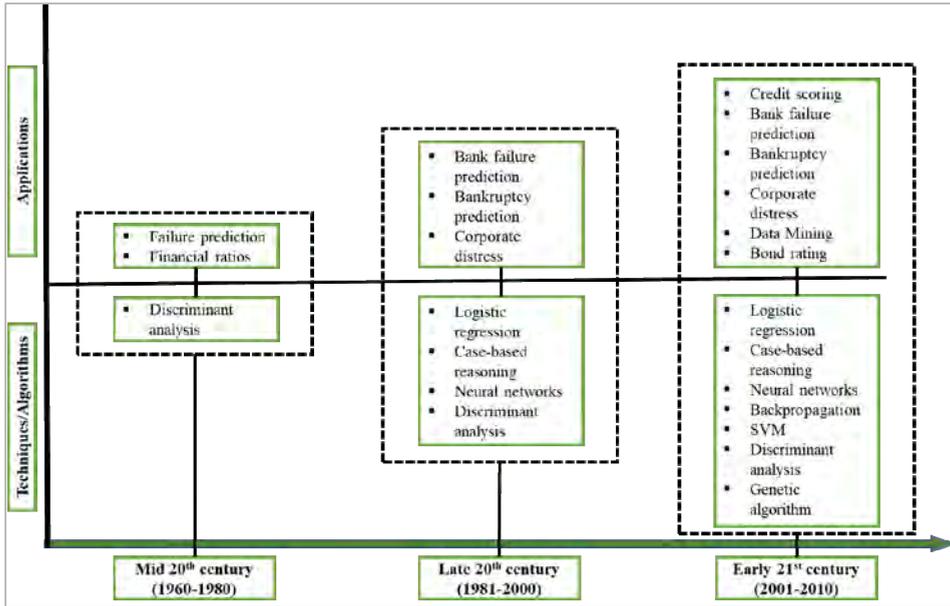
maps to forecast the daily values of the stock index of the National Stock Exchange and the Taiwan Stock Index Futures. Deng et al. (2017b) proposed fuzzy DNNs by hybridising DNNs with FL in a hierarchical manner to forecast the stock price trends based on high-frequency tick data. Maciel et al. (2017) compared the performance of evolving possibilistic fuzzy modelling approach against an adaptive network-based fuzzy inference system, MLP, and the heterogeneous autoregressive model for the task of predicting the realised volatility with jumps. Leung and Wang (2021) adopted collaborative neurodynamic approaches and deployed RNN with PSO to solve the Markowitz mean-variance (MV) and mean-conditional value-at-risk (CvaR)-based minimax and bi-objective portfolio optimisation problems. Ma et al. (2021) used several ML and deep learning models comprising dynamic LSTM, deep MLP, CNN, RF, and SVM to predict the returns of stocks listed on the China Securities 100 index and further constructed the optimal portfolios by incorporating the predicted results in MV and omega portfolio optimisation models.

3.2.2 Cluster wise co-cited document analysis

Co-citation analysis has been performed by considering the cited references (documents) as the unit of analysis. The co-citation method establishes the relationship between two documents from earlier literature based on their frequency of being cited together in later work. Frequent citations of two documents together in the third document evince a high degree of relationship and similarity in their research fields (Roblek et al., 2022). However, the co-cited documents may also belong to two broad, distinct, or unrelated areas (Garfield, 2009). A careful analysis of such documents may unveil the new research dimensions, and the prominent, peripheral, and bridging researchers in a particular research field. In addition, the co-citation analysis of documents enables a researcher to map the intellectual structure and evolution of a research field (Calabretta et al., 2011).

Since the co-citation analysis is based on secondary documents which are cited in articles (primary documents) included in the corpus, the analysis is less sensitive to the literature growth in the earlier phase of a research field (Garfield, 2009). Therefore, the current study processed 3,106 documents published during 1992–2022. An inclusion criterion of at least 20 citations has been set to perform a detailed and meaningful analysis of the relevant literature. Out of a total of 91,348 cited references (secondary articles), 425 meet the set threshold. Table 5 shows the top 20 cited references having the highest citations, links, and link strength. The oldest cited articles were found to be published during the mid-20th century (1960–1980). Beaver (1966) was the oldest cited article with 237 citations, published in the *Journal of Accounting Research*, followed by Altman (1968) with 393 citations, published in the *The Journal of Finance*. These cited articles focused on predicting bankruptcy and financial distress by considering the financial ratios as inputs to the models of discriminant analysis. Accordingly, considering the highest number of citations of these cited articles (secondary articles), it can be deduced that the earlier studies (primary documents) in the concerned domain focused on predicting the failures in the corporate and banking sectors by deploying ANNs with various kinds of accounting information from the financial statements as inputs to them. Figure 7 depicts the evolution of various statistical and nonlinear techniques, algorithms, and financial applications during the mid-20th century (1960–1980), late-20th century (1981–2000), and early-21st century (2001–2010) based on the analysis of highly cited references (see Table 5) in the concerned research field.

Figure 7 Evolution of applications and techniques/algorithms in the finance field based on top 20 highly cited references (see online version for colours)



Source: The author

Table 5 Top 20 most cited references having highest link strength and number of links

Cited reference	Citation	Total link strength	Links
Altman, E. (1968) <i>J. Finance</i> , V23, P589	393	5,851	336
Ohlson, J. (1980) <i>J. Account. Res.</i> , V18, P109	261	4,159	311
Beaver, W. (1966) <i>J. Account. Res.</i> , V4, P71	237	3,732	301
Tam, K. (1992) <i>Manage. Sci.</i> , V38, P926,	162	2,210	297
Kumar, P. (2007) <i>Eur. J. Oper. Res.</i> , V180, P1	138	2,541	300
Min, J. (2005) <i>Expert Syst. Appl.</i> , V28, P603	127	2,487	283
Shin, K. (2005) <i>Expert Syst. Appl.</i> , V28, P127	114	2,310	275
Huang, Z. (2004) <i>Decis. Support Syst.</i> , V37, P543	113	1,634	293
Kim, K. (2003) <i>Neurocomputing</i> , V55, P307	110	1,292	330
Wilson, R. (1994) <i>Decis. Support Syst.</i> , V11, P545	109	1,867	269
Zmijewski, M. (1984) <i>J. Account. Res.</i> , V22, P59	106	1,711	257
West, D. (2000) <i>Comput. Oper. Res.</i> , V27, P1131	104	1,738	296
Atiya, A. (2001) <i>IEEE Trans. Neural Netw.</i> , V12, P929	100	1,701	282
Altman, E. (1994) <i>J. Bank. Finance.</i> , V18, P505	97	1,391	254
Zhang, G. (1999) <i>Eur. J. Oper. Res.</i> , V116, P16,	94	1,697	275
Tsai, C. (2008) <i>Expert Syst. Appl.</i> , V34, P2639	84	1,810	295

Source: The author

Table 5 Top 20 most cited references having highest link strength and number of links

<i>Cited reference</i>	<i>Citation</i>	<i>Total link strength</i>	<i>Links</i>
Frydman, H. (1985) <i>J. Finance.</i> , V40, P269	80	1,479	233
Martin, D. (1977) <i>J. Bank. Financ.</i> , V1, P249	80	1,462	245
Jo, H. (1997) <i>Expert Syst. Appl.</i> , V13, P97	72	1,508	220
Min, S. (2006) <i>Expert Syst. Appl.</i> , V31, P652	68	1,435	219

Source: The author

In Figure 8, the co-citation network has been portrayed. Three clusters of articles have been emerged based on their co-citation similarities. The node size denotes the citations of a document, whilst the colours represent the clusters of co-cited documents. Table 6 presents a succinct overview of the clusters in terms of applications and techniques.

Cluster 1: ANNs and stock market prediction

The first cluster, consisting of 211 documents, is represented in red colour in Figure 8. The studies in this cluster considered the vital role of ANNs in predicting stock prices and compared their predictive accuracy against other statistical and nonlinear models in stock markets. Thus, cluster 1 can be labelled as ‘ANNs and stock market prediction’. Among the influential works in this cluster, Hochreiter and Schmidhuber (1997) argued that LSTM has the fastest learning ability than any other recurrent network algorithms and can effectively solve more complex and long-time-lag forecasting problems such as stock prices. Hornik et al. (1989) argued that multilayer FFNN with adequate hidden layers are the universal approximators that can approximate any measurable function to the desired level of accuracy. Tay and Cao (2001), Kim (2003) and Huang et al. (2005) compared the predictive performance of SVM against ANNs in stock markets and found the supremacy of SVM over ANNs, whereas Kara et al. (2011) found the greater predictive accuracy of ANN-based model (75.74%) than that of SVM-based model (71.52%) in forecasting the directional changes of Istanbul Stock Exchange (ISE) National 100 Index. Atsalakis and Valavanis (2009) evidenced the preponderant usage of soft computing techniques over the traditional statistical models for the task of studying and evaluating stock market behaviour. Fischer and Krauss (2018) deployed LSTM to predict the directional changes for the stocks listed on S&P 500 and evidenced the supremacy of LSTM over RF, feedforward DNN, and logistic regression (LR) in terms of predictive preciseness and profitability. Kim and Han (2000) utilised GA to decrease the dimensionality of features and optimise the weights of ANNs to enhance their predictive efficacy for the task of forecasting stock price index.

Cluster 2: ANNs and bankruptcy prediction

The second cluster, coloured in green, includes 128 documents and is labelled as ‘ANNs and bankruptcy prediction’. The papers in this cluster focused on utilising ANNs for bankruptcy prediction and compared their predictive performance against the linear and nonlinear models. Beaver (1966) provided valuable insights into alternative usage of accounting data as inputs to failure prediction models and argued that accounting ratios can be one of the best alternative predictors of corporate failures. Altman (1968) investigated the forecasting ability of the economic and financial ratios by deploying

et al., 2004). Lessmann et al. (2015) extended the work of Baesens et al. (2003) and compared the relative performance of 41 classifiers in credit scoring. The results indicated the superior performance of ANNs over extreme learning machines (ELM), and RF performed better than rotation forest. Huang et al. (2007) developed SVM-based hybrid models and compared their performance against ANNs, genetic programming, and DT for analysing the credit score. The findings revealed the supremacy of GA-SVM over other models in terms of producing accurate classified results owing to the integrated potential of GA in selecting the appropriate features and optimising the model parameters. Some other studies showed that MLP and MLP-based ensemble classifiers yielded a higher generalisation ability for the task of credit scoring (West et al., 2005; Nanni and Lumini, 2009). Lee and Chen (2005) developed an integrated model by combining the ANNs and multivariate adaptive regression splines (MARS) for analysing the credit score.

Table 6 Summary of clusters based on the co-citation network (clusters 1–3)

<i>Cluster</i>	<i>Label</i>	<i>Financial applications</i>	<i>Techniques/algorithms</i>
1	ANNs and stock market prediction	Financial time series, data mining, stock price, stock index, inflation rate,	ANNs, SVM, autoregressive conditional heteroskedasticity (ARCH), DT, RNN, FFNN, neuro-fuzzy
2	ANNs and bankruptcy prediction	Financial ratios, bankruptcy prediction, failure prediction, financial distress	ANNs, artificial intelligence, SVM, LR, discriminant analysis
3	ANNs and credit scoring	Credit scoring, corporate distress, corporate failure prediction, credit risk, credit rating analysis, bond rating prediction, pattern recognition, banking	ANNs, MLP, BPNNs, SVM, radial basis function (RBF) classifiers, polynomial classifiers, multivariate adaptive regression splines

Source: The author

4 Discussion and conclusions

The study identifies the research trends in journals, authors, and countries and maps the conceptual and intellectual structure of ANN research in finance by performing the network visualisation and analysis of the extant literature over the period of three decades. In addition, the study has intensively reviewed the citation-worthy articles with the highest link strength and thereby identified knowledge gaps and challenges in the field that need to be discussed here to further recommend the directions for future studies.

One of the notorious challenges is the limited explanatory capability of ANNs and thus known as the black box (Alaka et al., 2018). Future studies can integrate ANNs with FL by using the membership function of FL for establishing a linkage between ANNs and symbolic reasoning to enhance the explanatory capability along with improving the predictive performance.

The second challenge that is faced during the training process of ANNs is the selection of the number of hidden nodes which is critical in determining the high performance of ANNs. Generally, the trial & error method is adopted by researchers

which may lead to overfitting or underfitting. Future studies can use the standardised formula suggested by Hecht-Nielsen (1987) to determine the upper limit of the number of hidden neurons:

$$N^h \leq 2N^i + 1$$

where N^h represents the number of hidden nodes in the hidden layer and N^i denotes the number of input parameters.

In addition, Rogers and Dowla (1994) also proposed a formula to compute the upper limit of the number of hidden nodes which can also be adopted by future researchers:

$$N^h \leq \frac{N^{tr}}{N^i + 1}$$

where N^h represents the number of hidden nodes in the hidden layer, N^{tr} represents the number of training samples, and N^i denotes the number of input parameters.

Another important task in enhancing the performance of ANNs is parameter optimisation. Most of the studies used GA and PSO to optimise the parameters, future studies can adopt novel optimisation methods such as grey wolf optimisation, fruit fly optimiser, and multi-verse optimiser.

As far as the applications of ANNs in the finance domain are considered, the study revealed several areas including stock market prediction, credit scoring, bankruptcy prediction, financial trading, solving high dimensionality problems, and portfolio optimisation. The major challenge in predicting bankruptcy, crisis, and distress is the availability of varying company-related data due to differences in accounting methods followed by different countries for a specific item. The problem can be resolved by preparing the data before using it for training the models. Notably for portfolio optimisation, future researchers can develop neurodynamic approaches to solve cardinality-constrained multi-period, multi-level portfolio optimisation problems. In the future, researchers can utilise ANNs for volatility prediction, anomaly detection, cryptocurrency prediction, algorithmic trading, sensitivity analysis, exchange rate prediction, and sentiment analysis.

The study has also some limitations. First, only articles were selected to perform the analysis, future reviews can also consider other document types in their sample such as 'proceeding paper', 'early access', 'review article', 'book chapter' and 'book review'. Second, the study considered only the WOS database, future studies can consider other prominent databases such as Scopus, Science Direct, Google Scholar, JSTOR, and IEEE Xplore. Third, the selection criteria (citations and link strength) for research articles chosen for undertaking the review and their interpretation in the current study are also based on the preferences and perceptions of the authors.

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