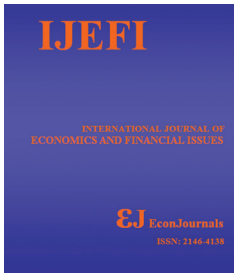


International Journal of Economics and Financial Issues

ISSN: 2146-4138

available at http: www.econjournals.com

International Journal of Economics and Financial Issues, 2025, 15(3), 337-350.

Evolution of Early Warning Models for Bank Failures: A Bibliometric Analysis

Mithushana Jonathan R[1]*, Neelangie S. Nanayakkara[2]

[1]Department of Economics and Finance, UC Business School, University of Canterbury, New Zealand, [2]Department of Finance, Faculty of Management Studies and Commerce, University of Sri Jayewardenepura, Sri Lanka.
*Email: mithuravi95@gmail.com

Received: 20 October 2024 **Accepted:** 21 March 2025 **DOI:** https://doi.org/10.32479/ijefi.17785

ABSTRACT

This bibliometric analysis examines the progression of early warning models in finance literature for predicting banking failures. Using the biblioshiny software in R and RStudio program, this study examined 40 English-language publications from 1989 to 2023 to identify the knowledge development and dissemination of early warning models. Initially, 1441 publications were downloaded from the SCOPUS database using the search criteria "Early Warning Models" and "Banking Failure" and the non-journal publications and articles written other than the English language equal to 1401 were excluded from the analysis. The data were reviewed and peer-reviewed before the bibliometric analysis and the systematic literature review. The results highlight that the application of machine learning models in predicting banking failures became prominent in 2010 and continued with simulation approaches in the next decade due to their higher level of accuracy in out-sample performances. At the same time, conventional logit, probit, signal extraction, and discriminant analysis were extensively used over time. The results contribute to the existing literature by identifying complex early warning models employed to forecast different scenarios of bank failures. The study suggests that terms of investment and financial variables combining the macro-network and institutional risk indicators outperform the models that merely included financial variables. Hence, relying only on balance sheet performance to predict bank failures may be futile. This study guides financial policymakers, analysts in macro-prudential surveillance units of Central Banks, bank managers, and practitioners in rethinking, reconstructing, and reevaluating existing early warning models by incorporating advanced techniques based on machine learning and simulation language.

Keywords: Bank Failures, Bibliometric Analysis, Early Warning Models, Logit Models, Machine Learning Models
JEL Classifications: G01, G41, G170, G210

1. INTRODUCTION

The ongoing global economic crisis has weakened the growth momentum in the United States (US), the European Union, and other developed nations, posing a threat to the rest of the world (United Nations, 2023). The downturn in the world economy raised concerns over financial architectural reforms to maintain financial systems stability. It is established in the academic literature that most banking crises are highly correlated with economic crises (Reinhart and Rogoff, 2009). The theoretical concept of the "crisis triplet" underlines that the default crisis in a country could pave the way to a foreign exchange crisis and eventually a banking/financial crisis. The United Nations (2023) highlights the intensifying signals of financial crisis around the globe through higher levels of inflation, hiking interest rates, balance of payment issues, and risks in debt sustainability. This is further proven by five banking crises already recorded for 2023 by the Federal Deposit Insurance Corporation (FDIC 2024).

For a country, resolving a banking crisis is expensive and burdensome (Ergungor and Thomson, 2006). Eichengreen (1999) emphasizes that the international financial architecture incorporates

This Journal is licensed under a Creative Commons Attribution 4.0 International License

crisis prevention, prediction, and management to mitigate or prevent the negative consequences of crises. In academic literature, preventive and predictive measures of crises involve the development of early warning models that can accurately predict bank failure, allowing banks and relevant authorities to take necessary actions to mitigate or prevent crises. These models are categorized as priori models or post-crisis models. Although these models were introduced in the 1930s, they have evolved from conventional to modern Artificial Intelligence-based models today.

An extensive quantitative analysis of empirical studies on bank failure models would contribute to the existing literature to assess and determine a suitable model based on the nature of the crisis. Similarly, the popularity of early warning models over time can be viewed from the usage of academic articles. Further, it is essential to consider the contributions of academic scholars to the development of early warning models especially during the crisis periods since the nature of analysis would differ in between a normal and crisis situation of an economy. This study of new literature review would display the banking industry's future development through an academic perspective (Lim et al., 2022a).

Thus, this study employs content analysis and bibliometric analysis to address the following two research questions (RQs):
RQ1. What is the publication trend, and which are the top contributing journals, authors, and regions for early warning models in predicting bank failures in finance literature?
RQ2. What are the key themes and topics developed in the literature of the early warning models and what insights can academic scholars gleaned from previous literature to enrich the analysis on predicting bank failures through future research?

To address these RQs, this study analysed research evidence employing a bibliometric analysis of 40 English-language publications from 1989 to 2023 in the Scopus database. This analysis aimed to gain a thorough understanding of the patterns, approaches, theoretical underpinnings, high-ranked journals, notable nations, and particular subjects in this field of study (Paule et al. 2021). We developed the bibliometric linkages using the Biblioshiny R language software version 4.3.1 (Aria & Corrado 2017; Bornmann and Marx, 2018).

This study develops a bibliometric analysis of the inception and growth of early warning models along with their methods to identify the best-suited model or models based on the context, data availability, and state of the industry. Most of the present research focuses on a statistical analysis of published literature, cluster analysis of high-frequency keywords, and co-occurrence analysis of authors and research institutions; it is deficient in information on highly cited literature, historical citations of core literature, and the evolving trends of popular themes (Xie et al., 2020). To advance the literature on preventive bank failures, this study's systematic literature review investigates the body of research on early warning models and their evolution from conventional models to models based on artificial intelligence.

The remainder of this study is divided into seven sections. Section 2 extensively reviews the theoretical bases for various early warning models and banking failures. Section 3 describes the methods and techniques of data analysis used in the research. Section 4 explains the results of the study. Section 5 discusses the results and how they affect theory, practice, and future studies. The sixth and final section gives conclusions and discusses the study's limitations.

2. THEORETICAL BACKGROUNDS

2.1. Ex-Post Approach for Early Warning Models

The ex-post approach in bank failures pools the immediate one to two-year performance of already failed banks through individual case studies, trends, and patterns and compares it with successful banks (Musdholifah and Hartono, 2017; Soana and Verga, 2010; Stuhr and Van Wicklen, 1974). As the next step, the classified bank set was further analyzed based on independent variables different from the previous period. The output of the formula employed, through a regression equation, discriminant function, or any other function, is the likelihood of failure in period t to the explanatory variables in the period of t-1.

There are several methods available to compare failure and non-failure banks. Initially, tabular and graphical-based comparisons were carried out; later, the comparison of financial ratios of failed banks at different periods with non-failure banks was used (Secrist, 1938). Present empirical studies utilize advanced techniques, including ordinary least-squares linear regression, discriminant analysis, and logit analysis, etc. Ordinary least squares linear regression was deployed by h and Meyer and Pifer (1970), while discriminant analysis was employed by Altman (1968) to predict the failures of non-financial firms. The same techniques were employed by financial firms enabling savings and loans in 1974. Stuhr and Van Wicklen (1974) and Sinkey (1975a) found the prediction of commercial bank failures using the same methodology. The logit model was applied to commercial loan customers to predict their non-compliance with repayments (Chesser 1974). Martin (1977) explained that the process behind the above-mentioned statistical techniques considers the real-world identification of failure and non-failure groups as the dependent variable and intends to explain the dependent variables in terms of multiple independent variables. Most of the time, the independent variables are considered as the ratios calculated based on institutions' financial statements, including banks and other financial and non-financial institutions. The supervisory agencies classify the banks that are relatively higher risk than the other banks using the 'problem list' maintained within their jurisdiction that requires remedies by management.

The ex-post knowledge approach is based on the crisis that already occurred and provides information on when it started and ended. Even when the bank failure can occur and the period is precisely mentioned to investigate a banking crisis, the ex-post approach requires waiting until a banking crisis occurs since there are no significant indicators of fragility that can be investigated before the banking crisis occurs. Therefore, the requirement of the second approach was developed to gauge the banking crisis before it occurs, which is referred to as an ex-ante or priori basis.

2.2. Priori-defined Approach for Early Warning Models

The priori-defined approach measures risk independently from historical records focuses on the likelihood of a specific event and intends to identify the causes beyond the incident based on explicit theory (Martin, 1977). Accordingly, the approach is developed by identifying expected probabilities for bank failures based on the probability distribution of variables such as earnings, loan defaults, and other determinants that could impact bank equity. It was pioneered in the collaborative work of Santomero and Vinso (1977) to forecast the likelihood of failure for commercial banks. The event is called bank failure when the bank's equity account becomes zero or negative, which can be predicted by observing the changes in the equity account over time, where the changes are considered random and its distribution stationary over time. Hence, by analysing the weekly financial reports of the banks, the parameters of weekly distributions for every bank can be predicted and transformed into the likelihood of failures. Although profitability, loan losses, liquidity, and other factors undoubtedly influence the distribution of changes in the equity account, they are not expressly considered in the analysis.

Nelson (1977) has developed a related model that considers capital as a function of earnings and loan charge-offs, and such variables are assumed to be random variables. Therefore, the current capital stock and the probability distribution of these variables can be employed to calculate the likelihood of failure of a given commercial bank within a specific time. Pantalone and Platt (1987) modified the same model with an autoregressive integrated moving average model to predict bank failures, a univariate method introduced by Box and Jenkins (1976). The model depends on the concept that the changes in equity in banks occur over time as a result of the random process of independent variables such as earnings, loan defaults, and other factors. It was noted by Cole and Gunther (1998) that the adoption of off-site surveillance tools helps analyse a larger number of banks. The supervisory agencies adopted these types of surveillance tools as early warning systems.

2.3. Priori-undefined Approach for Early Warning Models

The priori-undefined approach investigates bank failure with a broader concept termed bank vulnerability. The priori-undefined approach measures the failure of banks, not referring to any specific event; instead, the undefined vulnerability of the banks can be predicted based on arbitrary linear or quadratic functions of financial variables. Based on the functions, the vulnerability of banks can be referred to as the deviation of specific individual banks from the mean of a similar group of banks. Bank vulnerability can be referred to as how far a bank can face financial pressures, which initiates from declining earnings in the short term until total failure (Martin, 1977). Furthermore, based on the external economic environment and other factors, the bank can face different levels of failure for a given level of vulnerability. Hence, the probability of any specific events cannot be measured under an a priori-undefined model since a broad range of possible events is to be considered under this approach. Based on the above concept, Korobow et al. (1975) initially intended to construct an indicator for bank vulnerability which was merely considered independent from discriminant analysis and other models and, therefore, no fundamental classifications of actual bank failures as a failure and non-failure or problems and non-problems. Twelve financial ratios, which are linearly combined, were used as measures and the study finds that low-rank scores, as of 1 year, classify banks as problematic in the upcoming 2- 4-year period.

In addition, the priori-undefined approach is used to highlight exceptional circumstances for additional investigation rather than to create a gauge of risk. It is considered that if a bank significantly deviates from its group mean, it is referred to as not a problem. Instead, explanations are required for the variation. The deviations could be calculated based on individual variables or by multiple variables, including a rank score or multivariate Chi-square statistics.

The empirical studies have employed the same approach, considering the possibilities of not relying on several bank-specific factors such as the distribution of earnings, loan losses, and changes in the capital account. Beutel et al. (2019) employed the priori-undefined model by investigating the 19 banking crises in European countries from the perspective of asset prices, credit development, macroeconomic environment, and external and global imbalances. O'Brien and Wosser (2018) also investigated the failure of banks in 27 developed economies based on macroeconomic as well as bank-specific variables. Străchinaru (2022) followed the same approach to predict banking failures in 28 European countries, while Galán (2021) predicted based on 82 commercial and savings banks. Gupta and Kumar (2022) depicted four episodes of systemic banking crises, and Bussiere and Fratzscher (2006) analyzed banking failures in the context of 32 countries using the priori-undefined approach. Furthermore, the approach is extensively used in the studies of Bańbuła and Pietrzak (2017), Kick and Jahn (2014), Davis and Karim (2020), Lee et al. (2020), Oet et al. (2013), and Barrell et al. (2010).

3. METHODOLOGY

3.1. Explanations

The bibliometric analysis method, as explained by statisticians and mathematicians (Garfield, 1955), makes use of a broad variety of computational tools and statistical techniques to analyse and survey published works, including books and articles. Bilal et al. (2022) have stated that bibliometric analyses provide researchers with information about the past, present, and future directions of a field.

The focus of this bibliometric analysis study was early warning models for banking failures. Only empirical and review papers were included in this review. Additionally, any studies that were not written in the English language were excluded from the analysis. Other literary works, such as books, book chapters, or conference proceedings, were not included in the analysis. Indeed, Figure 1 shows the methodology of this study for gathering and analysing data. A typical bibliometric analysis consists of the following five stages: research design, data collection, analysis, visualization, and interpretation (Zupic and Cater, 2014) and is constructed in the below diagram.

3.1.1. Search database

Scopus is known as unrivalled for being the easiest to navigate and most comprehensive database in existence. This includes approximately 34,000 peer-reviewed and top-level journals that consist of the life sciences, social sciences, physical sciences, and health sciences. Hence, this study has chosen to use Scopus as the scientific database of choice to source for early warning model publications relevant to address its research questions (RQ1, RQ2) since it contains a greater diversity of publications than other databases like Web of Science (Sahoo et al., 2023).

3.1.2. Search criteria

The study entered "early warning models" and "banking failures" as search terms in the Scopus database and this has resulted in 1441 documents.

3.1.3. Inclusion criteria

Further, non-journal publications and articles written in languages other than English (1401) were eliminated to improve the review. Ultimately, 40 English-language journal publications were examined. Scopus found 1441 publications consisting of the content of early warning models and bank failures; of these, 40 (3.5%) were original research articles, 511 (35%) were conference proceedings, 23 (2%) were review articles, and 867 (60%) were other types of publications such as books, book chapters, editorials, errata, letters, retracted papers, and short surveys. The majority of the papers, around 1,197 (83%), were published in English. In the end, 40 articles were chosen for extended analysis in this study.

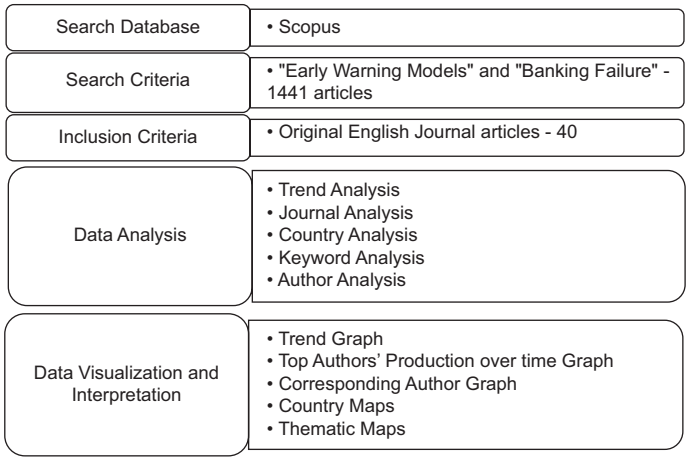
3.2. Data Analysis

This study examines and illustrates the present state and future directions of extensively utilized early warning models for banking failures using the Biblioshiny program. Subsequently, this study examined publication trends, sources, countries, authors, and keyword analyses using bibliometric analysis techniques. The h-index, g-index, m-index, and total citations are used to analyse the journal productivity of the authors.

3.2.1. Data visualization and interpretation

Lastly, tables and figures are used to visualize the data. These include trend graphs, the production of the top authors on the graph, corresponding author country figures, country maps, and thematic maps. To arrive at significant conclusions, these tables and figures are further interpreted.

Figure 1: PRISMA flow diagram



4. RESULTS

Trend analysis, author analysis, source analysis, country analysis, and keyword analysis are all explained in this section.

4.1. Quality of the Data

According to Bradford (1934), the first (and smallest) group consists of the topic's core journals; the second group consists of journals that publish articles on the topic frequently; and the third group consists of journals that publish articles on the topic infrequently. The analysis determines the presence of Bradford distribution by evaluating the document distribution across journals (Table 1).

This shows that 14 documents in total in group 1 from 9 journals. Core journals are part of group 1, which is a subset of the core zone. Group 2 is formed by combining the next 14 sources, totalling 14 articles, into a single group known as the middle zone. The third group consists of the remaining sources, which total 13 journals with 13 articles and are placed in the minor zone. Therefore, Bradford's law is applicable in this case and can be used to analyze the current Scopus database. This illustrates the database's high quality.

Lotka's law (Lotka 1926) can be applied to analyze the publication output of authors. The following conclusion is drawn when Lotka's law is applied to the current early warning models for banking failure databases. The evaluation considered each document's original author only. According to Table 2, just 4 authors were involved in more than 2 publications overall. 94 authors contributed to only one publication.

4.2. Trend Analysis

This study explains the evolution of trends in early warning models for banking failures using time series analysis and stages of development analysis (Figure 2). Research trends are represented in the annual distribution of documents, and

Table 1: Results of the Bradford law distribution

Bradford Law's Distribution Zones	Number of sources	Percentage of sources	Number of articles
Core zone	9	25	14
Middle zone	14	38.89	14
Minor zone	13	36.11	13
Total articles	36	100	41

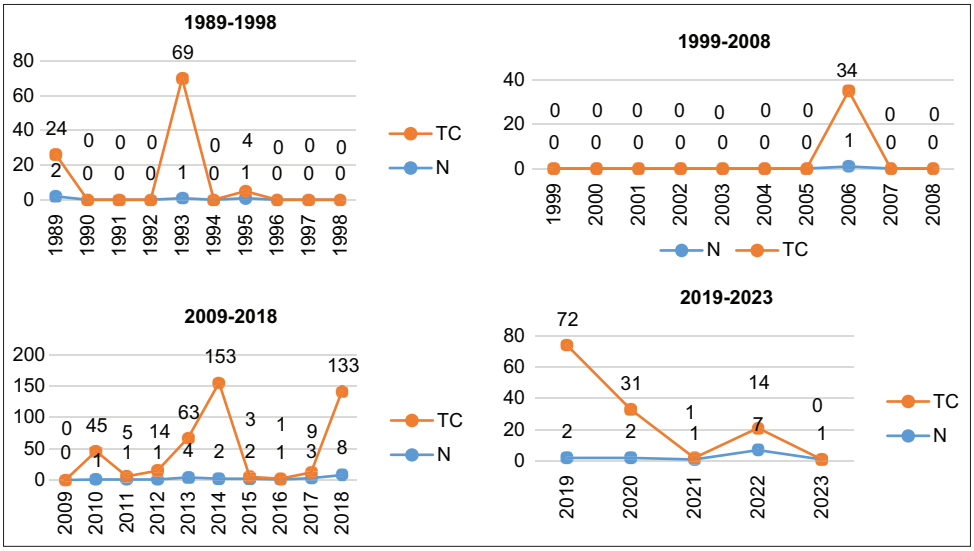
Source: Developed based on Biblioshiny software

Table 2: Results of Lotka law

Number of articles	Number of authors	Proportion of authors
1	94	0.959
2	2	0.020
3	2	0.020

Source: Developed based on Biblioshiny software

Figure 2: Trend analysis



Source: Developed by the author

a time series analysis enables an annual assessment of the development based on the overall circumstances. The articles are divided into distinct phases, and by describing the different stages of development, the characteristics of the overall trend are presented. A ten-year period was used for the analysis of the articles, except for the last category. Accordingly, four time periods are depicted in Figure 2: 1989-1998, 1999-2008, 2009-2018, and 2019-2023.

From 1989 to 2008, a maximum of 2 publications per year were recorded in 1989, and in some years, there was not even one publication, especially from 1996 to 2005. In fact, during this period, there is a long gap in early warning model publications for banking failures. Nevertheless, these few published papers have all received nearly 70 citations, making them seminal works. The first paper in the Scopus database that was published, "An Examination of Misclassifications with Bank Failure Prediction Models," by Looney, Wansley, and Lane, obtained 7 citations (Looney et al., 1989). "An Envelopment-Analysis Approach to Measuring the Managerial Efficiency of Banks" by Barr et al. (1993) was the most highly cited article in this period.

During the next decade, publications on early warning models for banking failures were not popular, as can be seen that there was only one publication in the Scopus database in 2006 titled "Market Discipline and the Use of Stock Market Data to Predict Bank Financial Distress," which was authored by Distinguin et al. and received a total of 34 citations.

Interestingly, the period from 2009 to 2018 demonstrates an upward movement in several publications. In 2018, the largest number of publications was recorded, which is 8, while in all other years, at least one paper was published, except for 2009. The highest number of citations received in the year 2014 was 153 for 2 papers titled "Predicting Distress in European Banks," authored by Betz et al. (151 citations); and "Modelling the Causes and Manifestation of Bank Stress: An Example from the Financial Crisis," authored by Kandrac (2 citations).

The last 5 years from 2019 to 2023 illustrated a fluctuating pattern in the number of publications. In 2022, the highest number of publications was recorded (7), while in all other years, it was maintained between 1 and 2 publications. The largest number of citations obtained in the year 2019 was 72 for 2 papers. In this period, the highest number of citations was received for "Does Machine Learning Help Us Predict Banking Crises?" which was authored by Beutel et al. and received 51 citations (Beutel et al., 2019). The most updated article in the Scopus database was "Reassessing Bank Monitoring Models: An Empirical Analysis of the Value of Market Signals in the Period 2008-2020" authored by Costa et al. (2023).

4.3. Author Analysis

The study included 98 authors in total, of whom 94 contributed one paper, 2 contributed two, and 2 contributed three. The authors with the highest citation counts, with over 50 citations, are Peltonen TA, Sarlin P, Betz F, Oprica S, Barr RS, Seiford LM, Siems TF, Beutel J, List S and Von Schweinitz G (Table 3).

Peltonen TA and Sarlin P have published the highest number of early warning model articles for banking failures. They have an h-index of 3, a g-index of 3, and a total citation count of 211. Because of the excellent quality of the numerous publications they have written and published on the subject, the authors are highly regarded in the field of banking failure research. As can be seen in Figure 3, Peltonen TA and Sarlin P started publishing papers in 2014. The year 2018 saw the highest number of published papers as well as the highest frequency of average citations per item. The size of the circle in the figure represents the number of documents, and the shade of the color represents the number of citations. Accordingly, Peltonen et al. (2019) wrote an article in the Journal of Financial Stability, titled "Network Linkages to Predict Bank Distress," which was cited 39 times. This study estimated equity-based-tail network links into an early-warning model to forecast European bank distress. Therefore, the study concludes that benchmark models tailored to individual banks that do not include networks consistently perform worse than early warning models that incorporate estimated tail dependencies.

Table 3: Most relevant authors

Authors	h-index	g-index	m-index	TC	NP	PY-Start
Peltonen TA	3	3	0.3	211	3	2014
Sarlin P	3	3	0.3	211	3	2014
Betz F	1	1	0.1	151	1	2014
Oprica S	1	1	0.1	151	1	2014
Barr RS	1	1	0.032	69	1	1993
Seiford LM	1	1	0.032	69	1	1993
Siems TF	1	1	0.032	69	1	1993
Beutel J	1	1	0.2	51	1	2019
List S	1	1	0.2	51	1	2019
Von Schweinitz G	1	1	0.2	51	1	2019

Source: Developed based on Biblioshiny Software

Table 4: Most relevant journals

Journal name	h-index	g-index	m-index	TC	NP
Journal of financial stability	4	4	0.364	148	4
International journal of forecasting	2	2	0.333	32	2
Journal of banking regulation	1	2	0.167	7	2
Agricultural finance review	1	1	0.091	8	1
Annals of operations research	1	1	0.032	69	1
Applied economics	1	1	0.1	2	1
Auco Czech economic review	1	1	0.077	5	1
Central European journal of economic modelling and econometrics	1	1	0.333	1	1
Computational economics	1	1	0.167	14	1
Computational intelligence and neuroscience	1	1	0.5	1	1

4.4. Source Analysis

A total of 36 sources were used in the study; the 9 core journals produced 14 papers, the middle zone of 14 journals produced 14 papers, and zone three contained 13 journals and 13 articles (Table 1). According to Table 5, the Journal of Banking and Finance, the Journal of Financial Stability, and the Annals of Operation Research are the highest-cited sources, which obtained more than 50 citations. The Journal of Banking and Finance has published the most cited research papers on early warning models for banking failures. This journal has 151 total citations, an h-index of 1, and a g-index of 1.

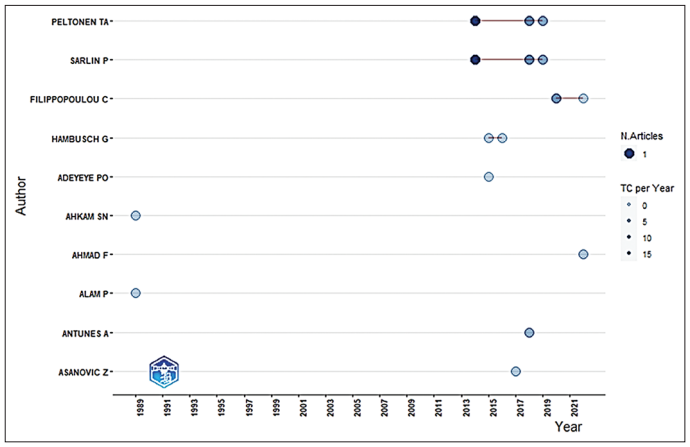
The Journal of Financial Stability published a larger number of articles and shows an h-index of 4 and a g-index of 4 (Table 4 & 5). Furthermore, this journal is well recognized in the field of early warning models for banking failures and risks, as a larger number of publications are produced on this particular topic (Table 4). Since it started publishing papers in 2013, this journal has had the highest average number of citations per item in that same year. The most cited article in this journal is titled "Does machine learning help us predict banking crises?" authored by Beutel et al. (2019).

Table 5: Most cited sources

Journal Name	h-index	g-index	m-index	TC	NP
Journal of banking and finance	1	1	0.1	151	1
Journal of financial stability	4	4	0.364	148	4
Annals of operations research	1	1	0.032	69	1
Omega	1	1	0.071	45	1
Journal of financial services research	1	1	0.056	34	1
International journal of forecasting	2	2	0.333	32	2
Journal of economic behavior and organization	1	1	0.25	22	1
International journal of finance and economics	1	1	0.2	21	1
Decision sciences	1	1	0.029	17	1
International journal of economics and financial issues	1	1	0.091	17	1

Source: Developed based on Biblisohiny Software

Figure 3: Top author's production over time



Source: Developed based on Biblioshiny Software

4.5. Country Analysis

A nation's influence and prominence in the field of banking failure prevention research may be determined by the quantity of articles it publishes on a given subject. Authors from 19 different countries and regions published their research between 1989 and 2023. Accordingly, Table 6 indicates the highest ten countries. Only China represents the research in Asia; seven continents are in Europe (Germany, France, Greece, Italy, Finland, Portugal, and Spain); and USA and UK. Furthermore, it shows that Germany, USA, and UK are the top publication countries in the field of banking failure prediction.

Table 6 demonstrates that the majority of research articles on preventing measures of banking failures are published in developed regions such as North America and Europe. These results imply that these regions are in the lead in this particular field. Although academic research mostly focuses on developed countries, studying predicting approaches for bank failures may

Table 6: Most cited nations

Country	Total citations	Total publications
Germany	56	10
USA	1	9
UK	89	7
China	20	3
France	48	3
Greece	22	3
Italy	35	3
Finland	211	2
Portugal	18	2
Spain	14	2

Source: Developed based on Biblioshiny software

have a greater theoretical impact on developing countries. There can be various factors that have an impact on this. Supporting more academic research is challenging since most developing regions receive insufficient funding for investigating banking failures (Dissanayake et al., 2022).

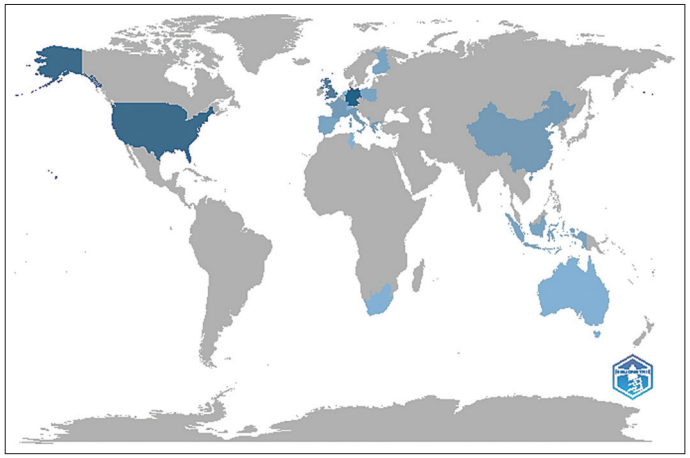
According to Figure 4 and 5 illustrates, China performs extremely well when collaborating with other nations. Table 6 shows that at least 3 studies have involved international cooperation. The rates of collaboration between Finland, Greece, and Italy are 1, 1, and 1 time annually, respectively (Figure 5). This shows the multiple country publication ratio of 33.3%, 50%, and 50% for Finland, Greece, and Italy. While China and the UK have published on early warning models for banking failures higher than any other countries and all of these studies are carried out independently (Figure 5). Country analysis provides the information that publications with solely domestic authors exceed those with authors from other nations.

4.6. Keyword Analysis

The keywords provide a high-level summary and refinement of the article's content (Xie et al., 2020). The study's most commonly used keywords, which include cluster and multiple correspondence analysis, eloquently and naturally express the idea of the content and its writing style in early warning models for banking failures. The high-frequency keywords of the research publications are subjected to statistical analysis and data mining by the software application Biblioshiny. Words with a word frequency of more than or equal to 5 are selected and shown as a word cloud in Figure 6. Early warning models, logit, bank distress, bank failure, and financial crisis are the most frequently used keywords in preventive measures of banking failure studies (Table 7).

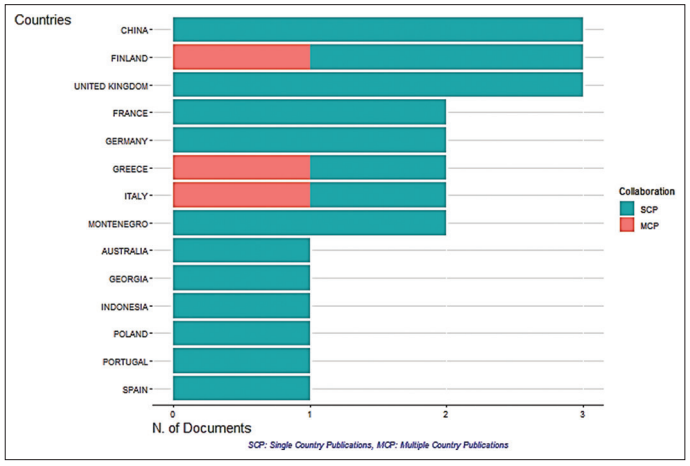
Figure 6 displays the thematic map developed for the studies carried out on early warning models for banking failures. The fundamental themes that reflect the well-established research questions in this field are displayed in the bottom-right portion of the map. The main themes are indicated as early warning systems, systemic risk, bank failure, financial crisis, banks, early warning models, bank distress, and distance to default. The top-right corner of the map displays the themes that have become more significant recently. These include logit model, systemic banking crises, and Bayesian model averaging. Keyword analysis shows fewer researches in these fields. Hence, it shows the requirement for extensive studies in this area.

Figure 4: Country scientific production



Source: Developed based on Biblioshiny software

Figure 5: Corresponding author's countries



Source: Developed based on Biblioshiny software

In this field, there are no declining themes, and the niche theme consists of logit, early warning system, principal component analysis, early warning model, bank failure, and banking crises. A thematic evolution map is used to analyze early warning models for banking failures throughout the research process. In addition, Figure 7 presents the co-occurrences of keywords where the frequency of the keywords is represented by the size of the nodes. The closeness of the interactions between two nodes is indicated by the thickness and length of the edges, and the cluster that the keywords belong to is indicated by the colors of the nodes of the keywords. The analysis includes nine clusters such as bank, early warning models, bank failure, early-warning model, logit model, early warning systems, bank risk, logit, and bank failures.

Furthermore, the thematic evolution trend is used to determine the direction of early warning models through evolution (Figure 8). It is evident that research on preventive measures for banking failures is still in its early phases and has not yet attained its full potential when comparing the evolutionary path map to the evolutionary state of each era. The considerable diversity of study themes across eras and the complex nature of thematic evolution interactions provides definitive proof of theme differentiation, integration,

Figure 6: Thematic map

Source: Developed based on Biblioshiny software

Table 7: Frequently used keywords

Words	Occurrences
Early warning models	6
Logit	5
Bank distress	4
Bank failure	4
Financial crisis	4
Banks	3
Early warning model	3
Early-warning model	3
Logit model	3
Systemic banking crises	3
Early warning systems	3
Systemic risk	3
Bank risk	2
Distance to default	2
Banking crises	2
Early warning system	2
Principal component analysis	2
Probit	2
Bayesian model averaging	2
Bank failures	2
Bank	2

Source: Developed based on Biblioshiny Software

transfer, and regeneration. Accordingly, the process of evolution is very unpredictable.

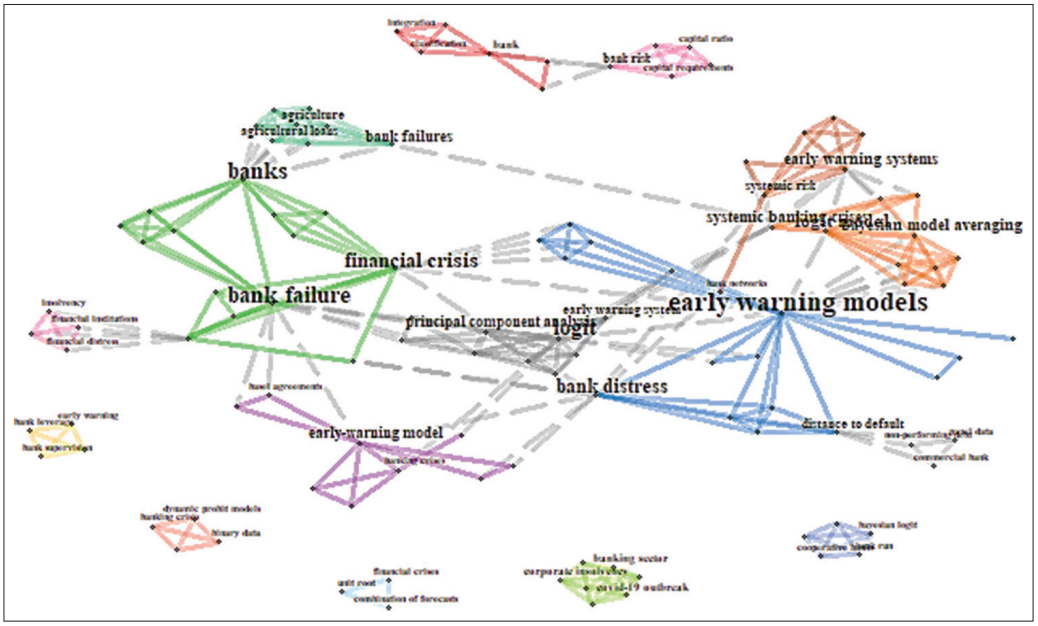
Based on the author's keywords, banking distress following logit model analysis has initiated with 1989. Indeed, the extensive discussion of early warning models has evolved during the period from 2015 to 2018. Also, the logit model-based analysis on banking distress was strongly dominated during this period. Continuously, the studies were focused entirely on early warning models from that period onwards until 2023.

4.7. Qualitative Analysis of Highly Cited Articles

The ten most cited articles about early warning models for banking failures are reviewed in this section and given an explanation of their chronological order. Table A1 in the appendix section contains the data pertaining to the highly cited papers. Barr et al. (1993) carried out an envelopment-analysis technique to measure the managerial efficiency based on 930 banks. The analysis, based on a 5-year period, reveals significant variation in the management-quality scores of failing and surviving institutions. It is further stated that these discrepancies become more obvious as the failure date approaches and can be seen well in advance of failure. This study points out that the efficient quality scores depend on the variables selected, and therefore the variables in such a model must be chosen carefully. It also helps readers who are experimenting with preventive measures of banking failures to concentrate on enhancing these variables and the underlying models.

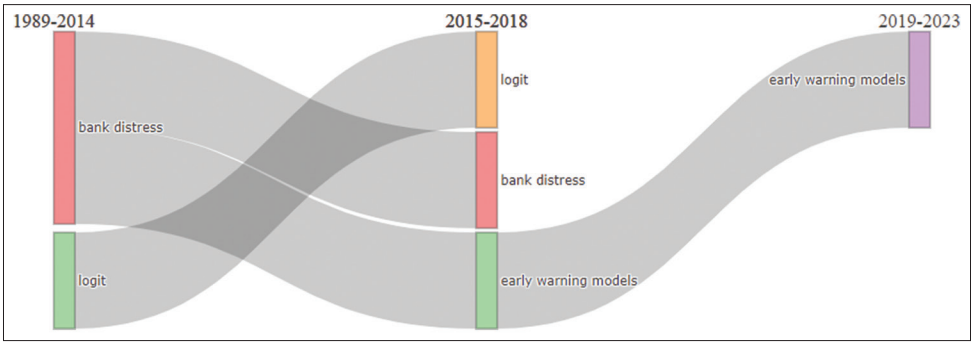
After a significant time gap, at the beginning of 2006, Distinguin et al. (2006) took the events of downgrades or the absence of downgrades related to 64 European banks from 1995 to 2002 in order to test the value of market-based indicators in predicting bank financial distress. This study suggests that the accuracy of the predictive power of logit models depends on the degree to which bank liabilities are revealed to the public. Furthermore, following the global financial crisis in 2008, Ioannidis et al. (2010) focused on the significance of early warning models in measuring banking failures consisting of 944 banks from 78 countries. Accordingly, the accuracy of the models, which include extensive information related to regulatory environment, macro-economic factors, and institutional development, was tested against the models that merely include the financial variables. Based on the findings, the models with the highest

Figure 7: Keyword co-occurrences network



Source: Developed based on Biblioshiny software

Figure 8: Thematic evolution



Source: Developed based on Biblioshiny software

accuracy are those created using artificial neural networks and multi-criteria decision aid compared to classification and regression trees and nearest neighbors.

Moreover, Karim et al. (2013) employed the logit model to predict the banking crisis of 14 OECD countries. This study specifically considered the off-balance-sheet exposures on the subprime crisis. Accordingly, it was generally believed that after 2003, the nature of off-balance sheet activity shifted from risk diversification to regulatory arbitrage-driven securitization, leaving banks unprepared to handle the risks they faced. Hence, the findings of the study supported this by indicating that after 2003, off-balance sheet activity had a substantial impact on the likelihood of a crisis. Thus, the study emphasized that the inclusion of movements in house prices as the proxy for balance sheet activity in the early warning system would enable forecasting the subprime crisis in advance.

Afterwards, Betz et al. (2014) incorporated both bank and macroeconomic data from the first quarter of 2000 to the second quarter of 2013 with the aim of constructing an early warning model that can forecast the vulnerabilities causing the failures of European banks. This study employed the benchmark logit model and presented that the model predicted the distress of banks eight quarters before the event. Additionally, the study demonstrated that, during the global financial crisis, an early warning model (logit) based on publicly available data produces valuable out-of-sample predictions of bank distress.

However, apart from the above studies, Constantin et al. (2016) have investigated the linkages of networks into early warning models. Accordingly, the study followed the multivariate extreme value theory, which enables capturing bank interdependencies beyond what is reasonable in normal times and further justifies estimating interbank exposures and contagion risk to construct equity-based tail-dependence networks. The study added that in times of increased financial stress, a tail-dependence network offers more insight into the market's perception of bank interconnectedness than typical bank-level risk drivers and macro-financial indicators. In line with that, when it comes to predicting bank distress events, the early warning models with estimated tail dependencies consistently outperform the benchmark models,

which only account for vulnerabilities arising from bank-specific, sector-level, and macro-financial imbalances.

Antunes et al. (2018) attempted to find the impact of dynamics and exuberance on the forecasts of early warning models based on 22 European countries from 1970Q1 to 2012Q4. Accordingly, to examine the data in the crisis indicator variable better, the study initiated with the basic probit approach that has been used traditionally in the early warning literature and continuously included a dynamic component in the model. Findings concluded that the dynamic probit model was especially effective in lowering the percentage of false alarms for the estimation of the total and late periods. Accordingly, this confirmed that the multivariate modeling of systemic banking crises gains significant in- and out-of-sample accuracy when a dynamic component is added. Also, the incorporation of the exuberant effect of explanatory variables during the crisis would improve the predicting accuracy of early warning tools.

Based on the interconnectedness of the banking sector, Peltonen et al. (2019) deployed a macro-network and linked it with the banking failures in Europe. The study analyzed the data as crisis events, macro-financial early-warning indicators, and macro-networks based on 14 European countries from 2000Q1 to 2012Q2. Hence, a macro-network was developed as the proxy for financial interdependencies and combined with an early warning model by incorporating the measurements of the centrality of the banking sector as drivers for banking crises. Therefore, this framework considers the variety of complex risks that the banking industry is supposed to experience. The study found that the banking crisis is more likely when the banking industry has a more prominent role in the macro-network. Furthermore, the study identified that the risks from lending activities and the investment-related risks tend to predict the banking crisis more accurately. Finally, it stated that the early-warning models enhanced with macro-networks performed better than traditional models for the out-of-sample prediction of recent European banking crises.

Virtanen et al. (2018) predicted banking failures using unit root exuberance tests and tested their effectiveness in terms of accuracy in prediction. The study included 15 EU countries and used signaling and logit models as benchmark models to compare performance. Based on the findings, the credit and debt servicing factors were identified as the most significant variables in predicting banking failures compared to housing market variables. It was also confirmed that the exuberance tests outperformed conventional models in forecasting the accuracy of banking failures.

Furthermore, Beutel et al. (2019) compared the predictive performance of different machine learning models with the logit model. The study was conducted based on 15 European countries from 1970 to 2016 and incorporated basic economic factors that could have an impact on banking crises. The study employed machine learning models such as decision trees, k-nearest neighbor, random forest, support vector machines, and neural networks. The results of the study claim that although the machine learning models had a highly performed in-sample fit, the logit model outperformed them in recursive out-of-sample evaluations.

Finally, to analyze the risk indicators in the Macroprudential Database (MPDB) for predictive validity, Filippopoulou et al. (2020) employed a multivariate binary logit model. This was considered significant in this study since the MPDB was developed to assist the functions of central banks and the European Systemic Risk Board. For the purpose of this study, the data from 1999Q1 to 2007Q4 was analyzed for early warning periods divided into 4 years (16 quarters), 3 years (12 quarters), 2 years (8 quarters), and 1 year (4 quarters). The results indicated that the majority of the risk indicators of the MPDB were significant for predicting the crisis event from 4 to 1 year prior. It was also added that the EWM used in this study (logit model) is "forward-looking," based on historical crisis indicator values, and has a notable success rate in terms of prediction accuracy.

5. DISCUSSION

The following research gaps and suggestions for the future can be identified based on the bibliometric analysis of highly cited documents using quantitative and qualitative analysis. Based on the analyzed highly cited articles, the incorporation of machine learning to predict banking failure is still in its early phases, and future studies could focus more on the below-mentioned perspectives:

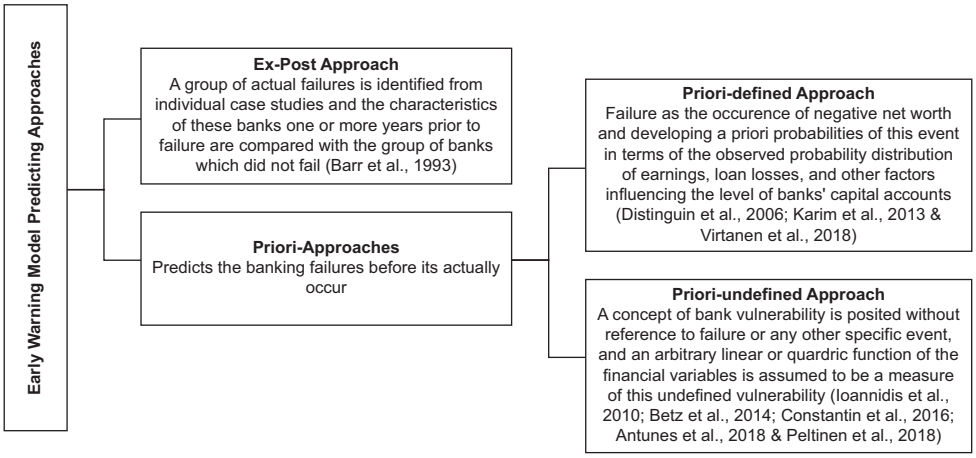
Even though, the machine learning models are becoming popular in predicting the financial variables, the conventional models such as logit, probit, signaling are employed by majority of the articles which are investigated in this study (Distinguin et al., 2006; Karim et al., 2013; Betz et al., 2014; Antunes et al., 2018; Virtanen et al., 2018; Beutel et al., 2019 and Filippopoulou et al., 2020). Also, claimed that in terms of the out-sample performance, the logit model was accurately predicts the future crisis events Beutel et al. (2019). On the other hand, the studies also proved that the machine learning models such as artificial neural networks and multi criteria decision aid are high in predicting accuracy Distinguin et al. (2006). Hence, the machine learning approaches are considered more advanced models, it is recommended to the future studies to investigate using these models by eliminating the negative impacts of such models. For example, the overfitting.

It is also identified that a significant part of early warning models is to recognize factors that could lead to banking crises. Accordingly, the analyzed studies have mainly highlighted lending activities, investment-related risks, and credit and debt servicing factors as crucial for predicting banking failures (Peltonen et al., 2019; Virtanen et al., 2018). Apart from this, the studies confirmed that the impact of bank interdependencies through networks is also an important factor that causes bank failures (Constantin et al., 2016). It is also stated that the likelihood of banking crises is high when the banking industry has a more prominent role in the macro-network (Peltonen et al., 2019).

Hence, the analysis of banking failures can be structured as given in the below diagram (Figure 9) which explains in detail.

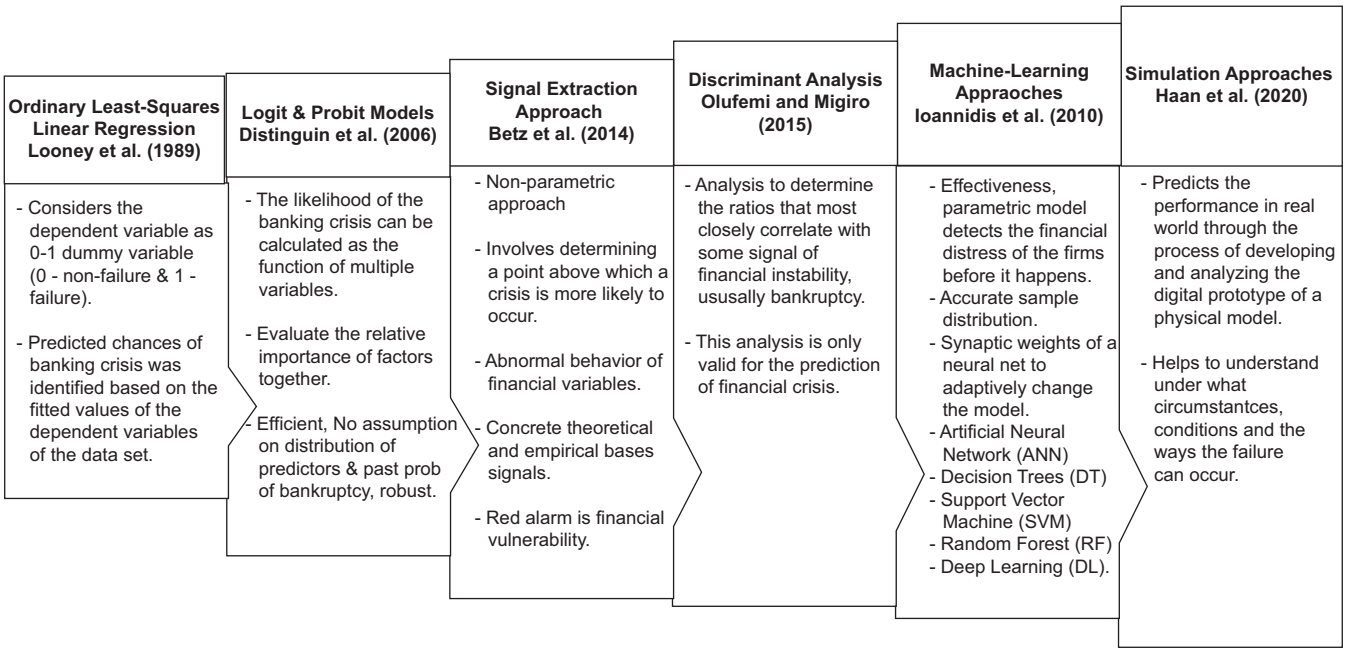
- As shown in the Figure 10, present study observed the evolution of various early warning models that were employed

Figure 9: Early warning approaches in developing early warning models to the banking sector



Source: Developed by the researcher

Figure 10: The use of various early warning models for predicting banking failures over the time



to predict the bank failures over the time and the explanations are given accordingly.

- Further, the majority of the researches are carried out from Europe. China is the only country which has published the article on early warning models from Asia. However, in terms of citations, again European continents are obtained more. However, the risk of banking failures and crisis events are more subject to developing nations since their financial vulnerability is not stable. Therefore, it is encouraged to carry out more investigative studies on such countries to prevent bank failures.

6. CONCLUSIONS

This bibliometric analysis examines the evolution of early warning models in finance literature for predicting banking failures. From 1989 to 2023, there were 1441 publications downloaded from the SCOPUS database and 1401 were eliminated due to the non-journal publications and written in the languages other than English. According to the bibliometric analysis, the results highlight that the application of machine learning models in predicting banking failures became prominent in 2010 and continued with simulation approaches in the next decade due to their higher level of accuracy in out-sample performances. At the same time, conventional logit, probit, signal extraction, and discriminant analysis were extensively used over time due to its statistical nature. The findings significantly contribute to the existing literature by identifying complex early warning models employed to forecast different scenarios of bank failures. Further, recommends that the priori-undefined early warning models consisting of the terms of investment and financial variables combining the macro-network and institutional risk indicators outperform the models that merely included financial variables.

Hence, this study provides insights into early warning models that can guide bank officials including the policy makers, analysts in

macro-prudential surveillance units of Central Banks to develop strategies and to prevent the negative impact of bank failures, practitioners in rethinking, reconstructing, and reevaluating existing early warning models by incorporating advanced techniques based on machine learning and simulation language.

This study mainly used articles in peer-reviewed journals, therefore, other information sources like books, chapters, and conference proceedings about early warning models for bank failures were not considered. Another flaw was our sole dependence on the Scopus database. Although the Scopus is one of the most reliable sources for bibliometric-related articles, our exclusive focus on this database may have caused us to miss some significant ones (Rejeb et al., 2022). Hence, future studies can use Web of Science, a Google Scholar database for the data collection. Still, concentrating solely on English-language articles might have ignored important contributions from networks and publications that based on other languages. Despite these drawbacks, the study adds to the synthesis of the literature on early warning models for bank failures, which will be helpful for researchers in identifying trends and making recommendations for future research.

REFERENCES

Altman, E.I. (1968), Financial ratios: Discriminant analysis and the prediction of corporate bankruptcy. Journal of Finance, 23(4), 589-609.

Antunes, A., Bonfim, D., Monteiro, N., Rodrigues, P.M. (2018), Forecasting banking crises with dynamic panel probit models. International Journal of Forecasting, 34(2), 249-275.

Aria, M., Corrado, C. (2017), bibliometrix: An R-tool for comprehensive science mapping analysis. Journal of Informetrics, 11(4), 959-975.

Bańbuła, P., Pietrzak, M. (2017), Early Warning Models of Banking Crises Applicable to Non-Crisis Countries, NBP Working Papers, Narodowy Bank Polski, Economic Research Department, no. 257.

Bank Failures in Brief-Summary. (2024), Available from: https://www.fdic.gov/resources/resolutions/bank-failures/in-brief/bfb2023.html-fdic [Last accessed on 2024 Jan 15].

Barr, R.S., Seiford, L.M., Siems, T.F. (1993), An envelopment-analysis approach to measuring the managerial efficiency of banks. Annals of Operations Research, 45(1), 1-19.

Barrell, R., Davis, E.P., Karim, D., Liadze, I. (2010), Bank regulation, property prices and early warning systems for banking crises in OECD countries. Journal of Banking and Finance, 34(9), 2255-2264.

Betz, F., Oprică, S., Peltonen, T.A., Sarlin, P. (2014), Predicting distress in European banks. Journal of Banking and Finance, 45, 225-241.

Beutel, J., List, S., Von Schweinitz, G. (2019), Does machine learning help us predict banking crises? Journal of Financial Stability, 45(C), 100693.

Bilal, Hysa, E., Akbar, A., Yasmin, F., Rahman, A., Li, S. (2022), Virtual learning during the COVID-19 pandemic: A bibliometric review and future research agenda. Risk Management and Healthcare Policy, 15, 1353-1368.

Bornmann, L., Marx, W. (2018), Critical rationalism and the search for standard (Field-normalized) indicators in bibliometrics. Journal of Informetrics, 12(3), 598-604.

Box, G.E.P., Jenkins, G.M. (1976), Time series analysis: Forecasting and control. Revised Edition, San Francisco: Holden Day.

Bradford, S.C. (1934), Sources of information on scientific subjects. Engineering: An Illustrated Weekly Journal, 137, 85-86.

Bussiere, M., Fratzscher, M. (2006), Towards a new early warning system of financial crises. Journal of International Money and Finance, 25(6), 953-973.

Chesser, D.L. (1974), Predicting loan noncompliance. The Journal of Commercial Bank Lending, 56(12), 28-38.

Cole, R.A., Gunther, J.W. (1998), Predicting bank failures: A comparison of on-and-off-site monitoring systems. Journal of Financial Services Research, 13(2), 103-117.

Constantin, A., Peltonen, T.A., Sarlin, P. (2018), Network linkages to predict bank distress. Journal of Financial Stability, 35(C), 226-241.

Costa, T., Lobão, J., Pacheco, L. (2023), Reassessing bank monitoring models: An empirical analysis of the value of market signals in the period 2008-2020. Journal of Banking Regulation, 24(2), 206-227.

Davis, E.P., Karim, D. (2016), Early Warning Systems for Banking Crises-Research Advances and Policy Utilization, Economics and Finance Working Paper Series, Brunel University London.

Dissanayake, H., Iddagoda, A., Popescu, C. (2022), Entrepreneurial education at universities: A bibliometric analysis. Administrative Sciences, 12(4), 185.

Distinguin, I., Rous, P., Tarazi, A. (2006), Market discipline and the use of stock market data to predict bank financial distress. Journal of Financial Services Research, 30(2), 151-176.

Eichengreen, B. (1999), The regulator's dilemma: Hedge funds in the international financial architecture, International Finance, 2(3), 411-440.

Ergungor, E.O., Thomson, J.B. (2006), Systemic banking crises. Research in Finance, 23, 279-310.

FDIC. (2024, January 15). Bank Failures in Brief – Summary. Available from: https://www.fdic.gov/resources/resolutions/bank-failures/in-brief/bfb2023.html%20-%20FDIC

Filippopoulou, C., Galariotis, E., Spyrou, S. (2020), An early warning system for predicting systemic banking crises in the Eurozone: A logit regression approach. Journal of Economic Behavior and Organization, 172, 344-363.

Galán, J.E. (2021), CREWS: A CAMELS-Based Early Warning System of Systemic Risk in the Banking Sector, Documentos Ocasionales, No 2132.

Garfield, E. (1955), Citation indexes for science. Sciences 122(3159), 108-111.

Gupta, N., Kumar, A. (2022), Comparing parametric, semi parametric and non-parametric early warning systems for banking crisis: Indian Context. Global Business and Economics Review, 26(2), 111-134.

Ioannidis, C., Pasiouras, F., Zopounidis, C. (2010), Assessing bank soundness with classification techniques. Omega, 38(5), 345-357.

Karim, D., Liadze, I., Barrell, R., Davis, E.P. (2013), Off-balance sheet exposures and banking crises in OECD countries. Journal of Financial Stability, 9(4), 673-681.

Kick, T., Jahn, N. (2014), Early warning indicators for the German banking system: A macro-prudential analysis. Credit and Capital Markets, 47(1), 5-47.

Korobow, L., Stuhr, D.P., Martin, D. (1976), A probabilistic approach to early warning of changes in bank financial condition. Monthly Review, 7, 187-194.

Lee, S.J., Posenau, K.E., Stebunovs, V. (2020), The anatomy of financial vulnerabilities and banking crises. Journal of Banking and Finance, 112, 105334.

Lim, W.M., Kumar, S., Ali, F. (2022a), Advancing knowledge through literature reviews: 'What', 'why', and 'how to contribute'. The Service Industries Journal, 42(7-8), 481-513.

Looney, S.W., Wansley, J.W., Lane, W.R. (1989), An examination of misclassifications with bank failure prediction models. Journal of Economics and Business, 41(4), 327-336.

Lotka, A.J. (1926), The frequency distribution of scientific productivity. Journal of the Washington Academy of Sciences, 16(12), 317-323.

Martin, D. (1977), Early warning of bank failure: A logit regression approach. Journal of Banking and Finance, 1(3), 249-276.
Meyer, P.A., Pifer, H.W. (1970), Prediction of bank failures. The Journal of Finance, 25(4), 853-868.
Musdholifah, M., Hartono, U. (2017), Assessing early warning system model for banking crisis in Asian countries. International Journal of Economics and Financial Issues, 7(4), 358-364.
Nelson, R.W. (1977), The Optimal Capital Policy of the Commercial Banking Firm in Relation to Expectations Concerning Loan Losses, Federal Reserve Bank of New York Working Paper.
O'Brien, M., Wosser, M. (2018), An Early Warning System for Systemic Banking Crises: A Robust Model Specification. Research Technical Papers, Central Bank of Ireland, no. 9/RT/18.
Oet, M.V., Bianco, T., Gramlich, D., Ong, S.J. (2013), SAFE: An early warning system for systemic banking risk. Journal of Banking and Finance, 37(11), 4510-4533.
Olufemi, A.P., Migiro, S.O. (2015), An investigation on nigerian banks' status using early-warning signal. Banks and Bank Systems, 10(1), 53-64.
Pantalone, C.C., Platt, M.B. (1987), Predicting commercial bank failures since deregulation. New England Economic Review, 37-47.
Paul, J., Merchant, A., Dwivedi, Y.K., Rose, G. (2021), Writing an impactful review article: What do we know and what do we need to know? Journal of Business Research, 133, 337-340.
Peltonen, T.A., Rancan, M., Sarlin, P. (2019), Interconnectedness of the banking sector as a vulnerability to crises. International Journal of Finance and Economics, 24(2), 963-990.
Reinhart, C.M., Rogoff, K.S. (2009), The aftermath of financial crises. American Economic Review, 99(2), 466-472.
Rejeb, A., Rejeb, K., Abdollahi, A., Treiblmaier, H. (2022), The big picture on instagram research: Insights from a bibliometric analysis. Telemat Informatics, 73, 101876.
Sahoo, S., Sahoo, J., Kumar, S., Lim, W.M., Ameen, N. (2023), Distance is no longer a barrier to healthcare services: Current state and future trends of telehealth research. Internet Research, 33(3), 890-944.
Santomero, A.M., Vinso, J.D. (1977), Estimating the Probability of Failure for Commercial Banks and the Banking System, Journal of Banking and Finance, 1(2), 185-205.
Secrist, H. (1938), National Bank Failures and Non-Failures. Bloomington: The Principia Press.
Sinkey, J.F. (1975), Franklin National Bank: A Portfolio and Performance Analysis of Our Largest Bank Failure. Federal Deposit Insurance Corporation, Financial, and Economic Research Section, Division of Research Working Paper, Washington. p75-10.
Soana, M.G., Verga, G. (2010), Supply and demand in the european credit market during the recent crisis. Applied Financial Economics, 22(16), 1355-1366.
Străchinaru, A.I. (2022), Early warning systems for banking crisis and sovereign risk. Journal of Financial Studies and Research, 2022, 441237.
Stuhr, D.P., Van Wicklen, R. (1974), Rating the Financial Condition of Banks: A Statistical Approach to Aid Bank Supervision. New York: Federal Reserve Bank of New York. p233-238.
United Nations. (2023), World Economic Situation and Prospects: February 2023 Briefing, No. 169. Department of Economic and Social Affairs Economic Analysis. Available from: https://www.un.org/development/desa/dpad/publication/world-economic-situation-and-prospects-february-2023-briefing-no-169/#:~:text=The%20current%20global%20economic%20slowdown,rest%20of%20the%20world%20economy
Virtanen, T., Tölö, E., Virén, M., Taipalus, K. (2018), Can bubble theory foresee banking crises? Journal of Financial Stability, 36(C), 66-81.
Xie, H., Zhang, Y., Wu, Z., Lv, T. (2020), A bibliometric analysis on land degradation: Current status, development, and future directions. Land, 9(1), 28.
Zupic, I., Cater, T. (2014), Bibliometric methods in management and organization. Organizational Research Methods, 18(3), 429-472.

APPENDIX

Table A1: Classification of articles analysed in the study

S. No.	Year	Authors	Title	Source title	Aims and findings	Methodology
1	2020	Filippopoulou, C., Galariotis, E., and Spyrou, S.	An early warning system for predicting systemic banking crises in the Eurozone: A logit regression approach	Journal of Economic Behavior and Organization	This study describes the significant of the risk indicators of MPDB to forecast 4 to 1 years prior to the systemic banking crisis. Mainly highlighted that the bank specific variables such as assets, funding and liquidity are important than the macroeconomic variables.	Quantitative Research
2	2019	Beutel, J., List, S., and von Schweinitz, G.	Does machine learning help us predict banking crises?	Journal of Financial Stability	In terms of out-sample predictive performance of different early warning models, the study finds that machine learning methods often attain a very high in-sample fit based on the 45-year data. However, they are outperformed by the logit approach in recursive out-of-sample evaluations based on the sample of advances economies.	Quantitative Research
3	2018	Peltonen, T. A., Rancan, M., and Sarlin, P.	Interconnectedness of the banking sector as a vulnerability to crises	International Journal of Finance and Economics	This study discovers that the possibility of a financial crisis is greatly increased when the banking sector occupies a more central position within the macro network. Also reveals that the early-warning models enhanced with interconnectivity measures perform better than traditional models in the out-of-sample predictions.	Qualitative and Quantitative study
4	2018	Antunes, A., Bonfim, D., Monteiro, N., and Rodrigues, P. M. M.	Forecasting banking crises with dynamic panel probit models	International Journal of Forecasting	The study indicates that adding dynamic components and exuberance indicators to the models improves the performances of early warning models for banking crises significantly.	Quantitative Research
5	2018	Virtanen, T., T¨ol¨o., E., Viren., M., and Taipalus., K.	Can bubble theory foresee banking crises?	Journal of Financial Stability	The variables based on credit- and debt-service are identified as better predictors than housing market variables, which in turn outperform stock market variables on predicting banking crises. Accordingly, the deployment of exuberance indicators outperforms the signalling and logit models and suggests that exuberance tests can be used in crisis prediction in a manner similar to conventional early warning models.	Quantitative Research
6	2016	Constantina, A., Peltonenb, T. A., and Sarlin, P.	Network linkages to predict bank distress	Journal of Financial Stability	This study finds that early warning models including estimated tail dependencies consistently outperform bank-specific benchmark models without network linkages. Also allows the measures of interconnectedness in early-warning models and moves toward a unified representation of cyclical and cross-sectional dimensions of systemic risk.	Quantitative Research
7	2014	Betz, F., Oprica˘, S., Peltonen, T. A., and Sarlin, P.	Predicting distress in European banks	Journal of Banking and Finance	The study identifies that complementing bank-specific vulnerabilities with indicators for macro-financial imbalances and banking sector vulnerabilities improves model performance and yields useful out-of-sample predictions of bank distress during the current financial crisis.	Qualitative Research
8	2013	Karima, D., Liadzec, I., Barrell., R., Davis, E. P.	Off-balance sheet exposures and banking crises in OECD countries	Journal of Financial Stability	This study reveals that variables capturing off-balance sheet activity have been neglected in most early warning models to date. Accordingly, it shows that real house price growth is a good proxy for off balance sheet activity prior to the sub-prime episode.	Quantitative Research
9	2010	Ioannidis, C., Pasiouras, F., and Zopounidis, C.	Assessing bank soundness with classification techniques	Omega	The study compares models merely developed with financial variables, with models that incorporate additional information in relation to the regulatory environment, institutional development, and macroeconomic conditions. Accordingly, the models developed with multi-criteria decision aid and artificial neural networks achieve the highest accuracies.	Quantitative Research
10	2006	Distinguin, I., Rous, P., and Taraz, A.	Market discipline and the use of stock market data to predict bank financial distress	Journal of Financial Services Research	This study emphasizes that the logit early warning model developed for European Banks adds more predictive value when market-based indicators are incorporated rather merely depends on accounting data.	Quantitative Research