Antifragility Capabilities for Service Firms: A Bibliometric Analysis

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Abstract

Antifragility is an emergent concept established in 2012 as an alternative to resilience and robustness. Since then, researchers have developed an interest in the concept that describes how firms can withstand disorders and attain higher performance when exposed to randomness. Service firms are significant to the economic growth of a society. However, these firms are susceptible to environmental turbulence due to service complexity and the inability to adapt to strong market fluctuations. The purpose of the study was to determine the research contributions, key research themes, and requisite capabilities of antifragility in service firms. A bibliometric analysis was conducted on antifragility documents published in the Scopus database in the period between 2012 and 2024. Co-citation and keyword analyses were conducted to reveal possible co-relationships and research contributions. Vosviewer and R-Studio tools were used to analyze and interpret the bibliographic data. The study highlights the possible capabilities for antifragility, strategies and factors that influence the development of antifragile systems in service firms.

The review revealed three key findings. First, firms build antifragility through collaborations, scenario planning and risk management strategies. Second, the key influential antifragility capabilities include the use of slack resources, capacity, adaptability and creativity. Third, factors that drive firms to adopt antifragility principles include digital technologies, innovation and sustainability. The study provides new insights into the emerging themes of antifragility in the literature. One of the limitations is that the study focused only on the Scopus database for data extraction. There could be a few publications that were not captured, hence future studies could focus on using multiple data sources. Future research could pursue the key research themes to build the possible theory on antifragility capabilities.

Keywords: Antifragility, Capabilities, Disruptions, Service Firms, Bibliometric, Keyword Analysis

Introduction

The global business environment is frequently challenged by strong, violent, and disruptive events that display both challenges and opportunities. Disruptions are caused by various natural catastrophes and/or global tragedies such as climate change, health hazards, earthquakes, fire outbreaks, political unrest, transport delays, operational issues, new regulations, accidents, and economic distress (Essuman et al., 2022; Pandey et al., 2023). With persistent unpredictable

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disorders, novel concepts such as robustness, resilience and antifragility have emerged. Antifragility was first devised by Nassim Taleb, a Lebanese-American scholar and author, as an alternative to robustness and resilience (Taleb, 2012). The concept describes four ways in which firms respond to disruptions in the business environment: fragility, robustness, resilience and antifragility (Ruiz-Martin et al., 2018). While a fragile system collapses when exposed to disorders, a robust system remains unchanged despite the turbulences; and a resilient firm bounces back to its prior state (Hillson, 2023). Antifragility combines both robustness and resilience to enable the firm to respond positively to the negative effects of volatility (Nikookar et al., 2024). The application of antifragility principles to the business sector is still in its infancy stages (Sagala & Őri, 2024).

The service entities are fundamental to the economic growth of a society. The contribution of the service industry is characterized by job opportunities, economic stability and leadership it generates to the overall growth of a nation (Attiah, 2019; Ndubuisi et al., 2023). Services are well described by diversity and complexity. Generally, service firms range in size from large multinational corporations to small companies. Services are offered in various fields such as airlines, banking, telecommunication, hotels, insurance and other numerous businesses (Attiah, 2019). Sampson and Froehle (2006) describe service firms as systems and processes that rely on customer inputs such as customers, tangibles and information. Johnston and Clark (2005) classify services into four broad sectors: consumer services, business services, public services and not-for-profit services. However, over time, these pervasive borderlines are gradually diminishing. Dutkowski (2018) adopted Taleb's concept and classified how firms react to abrupt disruptions based on fragility, robustness or resilience and antifragility principles. The service industry, just like other industries is prone to violent and unpredictable disruptions that emanate from both internal and external environments (Gorzeń-Mitka, 2022). Today's service sector is most transformational and hence requires strong mechanisms to handle disruptions including radical digital technologies (Ramezani & Camarinha-Matos, 2019). The global business environment is volatile as firms grapple with increasing expenses due to high costs of production (Ambani, 2023). However, the literature shows that some firms not only withstand shocks but also improve performance during crises (Cucino et al., 2022). For instance, during the COVID-19 pandemic, several firms sustained operations by enhancing capabilities such as agility, creativity, and adaptability (Ramezani & Camarinha-Matos, 2020). Today, with persistent volatility in the business environment, most firms employ various antifragility strategies such as industry collaborations (Juan et al., 2022); risk assessment (Aven, 2016) and scenario planning (Tiberius et al., 2020). Further, the constant evolution of the digital revolution (Baudier et al., 2023); disruptive innovations (Bamel et al., 2023); and sustainability (Paoloni et al., 2023) have become some of the drivers for the growth of antifragility.

Several studies, Aven (2015, 2016); Kennon et al. (2015); Nikookar et al. (2021) and Ramezani and Camarinha-Matos (2020), assert that the current desirable risk management approaches advocating for evading and resisting disruptions have proven futile in the disruptive environment. Instead, the volatility of the current business environment requires innovative approaches to respond to disruptions (Munir et al., 2022). Similarly, in the past, disruptions were perceived as negative events that should be avoided or resisted; however, recent studies reveal that firms grow swiftly when they embrace disruptions (Nikookar et al., 2024). In addition, Cucino et al. (2022); Hillson (2023); Munoz et al. (2022); and Nikookar et al. (2021) contend that robust and resilient

business systems are not sufficient in today's unpredictable business environment. As a result, most firms endeavour to build and leverage their capabilities to enhance antifragility (Essuman et al., 2022). Volatility in the business environment entails optimal solutions to unpredictable "black swans", which requires antifragile capabilities (Micheli et al., 2021).

Though antifragility was introduced a decade ago, the concept has made little progress in both empirical research and practical implementations in the business (Hillson, 2023). A few scholars, such as Corvello, et al. (2022); Cucino et al. (2022), and Nikookar et al. (2021), have attempted to develop and suggest frameworks for antifragility. However, its requisite capabilities are still not well understood among scholars, organizational decision-makers, and other key strategic representatives in the industry (Kennon et al., 2015). To systematize the research landscape on antifragility, this study conducted a bibliometric analysis of antifragility to determine its conceptual structure, and emerging themes, and suggest its specific capabilities for service firms. The study answers four key research questions: *a) who are the most influential authors in terms of publications on antifragility? b) which are the most cited journals on antifragility? c) what are the main antifragility research themes and trends, and d) what are the requisite antifragility capabilities?* The study contributes to the literature by illustrating the static picture of the topic within the business research with a focus on service firms. The remaining sections are structured as follows. *Section 2* explains the theoretical background of the study. *Section 3* describes the methodology of the study. *Section 4* describes the results of the bibliometric analysis. *Section 5* presents the key findings and the discussion. *Section 6* highlights the conclusions, practical and theoretical implications, limitations and suggestions for future research studies.

Theoretical Background

The Concept of Antifragility

Antifragility is well understood by assessing business firms from four perspectives: fragile, robust, resilient, and antifragile (Ruiz-Martin et al., 2018). Fragile organizations are those that are susceptible when exposed to stressors or disorders such as dynamic markets or internal challenges (Ghasemi & Alizadeh, 2017). Similarly, Taleb (2012) describes fragility as what distastes unpredictable, volatile, uncertain, disorder, or stressor; also known as "black swans'. Fragile systems operate well in mechanistic and stable economies where changes are infrequent, which is rare in the current business environment (Jaaron & Backhouse, 2014b). Scholars and policymakers visualize that the frequency of disastrous events could escalate in the future due to climate change, extinction of natural resources, and pollution (Corvello, et al., 2023). According to Dutkowski (2018), the most fragile services may include hospitality services; legal and financial services, movie theatres, private medical services, media and printed services, theatres, sports, tourism and leisure, and security agencies. Robust organizations are firms with the ability to resist pressure that may alter their usual way of doing things (Hillson, 2023; Munoz et al., 2022). Robust systems were first recognized in the early 1980s, and since then, the concept has been applied extensively in the literature. A closely related concept is 'business continuity', which describes efforts firms put in place to ensure continuous delivery of their operations despite disruptions (Schmid et al., 2021). According to Taleb (2012), robust is not robust enough. Though robust systems may possess shock absorbers in the short run but could be affected by outlier events, or a black swan (Größler, 2020; Taleb, 2012). Resilience is the ability of a system to rebound back to its normal operations, within a particular period, after exposure to unpredicted disturbances (Essuman et al., 2023). Most resilient systems adopt process improvement

approaches such as just-in-time and lean to enhance performance; however, these standardized approaches are only ideal in stable and predictable environments (Castillo, 2023). The robust or resilient service activities may include gambling, logistics, education, public medical services, and religious services (Dutkowski, 2018). Resilience focuses on the stability and return to the original state of the system following a short-term disruption (Lin et al., 2023). Today, firms are focusing on building resilience through digital transformation (Klöckner et al., 2023).

Antifragility is a system that resists, withstands, and grows when exposed to volatility (Nikookar et al., 2024). Antifragility is the capability of a firm or a system to not only withstand disruptions; but also achieve higher performance emanating from them (Größler, 2020). Further, antifragility is a performance gain a firm obtains when exposed to turbulences (Munoz et al., 2022). Rather than resisting or avoiding disruptions, antifragility focuses on positive growth during turbulences. Antifragile systems are desirable, though the process to develop them remains unclear (Corvello, et al., 2022; Ramezani & Camarinha-Matos, 2020). Examples of antifragile services include construction, repair and maintenance services, delivery services, accounting and information services, taxi transport services, beauty services, retail trade, and performing arts (Dutkowski, 2018); and IT services (Munoz et al., 2022). Antifragile systems embrace chaos, learn and gain from them, rather than evading them (Nikookar et al., 2021). Hence, these systems not only withstand the pressure of disorders such as disruptive technologies and economic instabilities but also benefit from their forces.

Antifragility Capabilities in Service Firms

The current business environment frequently encounters the most unpredictable disruptive scenarios that have substantial impacts on socioeconomic systems (Ramezani & Camarinha-Matos, 2020). Disruptions are predictable or unpredictable events that interrupt normal business operations. In the contemporary world, for firms to survive and thrive they need antifragile capabilities (Taleb, 2012). Antifragile systems can achieve new and better conditions through the given opportunities brought by the crises. One of the ways is through the internal capabilities of firms. Capabilities are the firm's ability to organize resources using the firm's resources to deliver a desired service or product (Manuj et al., 2024). Recently, Corvello, et al. (2022) identified three antecedents of antifragility for firms: absorptive capacity, uncommitted or slack resources, and intellectual capital. Similarly, Cucino et al. (2022) identified four antifragile capabilities that enhance the performance of startups during crises: creativity, flexibility, simplicity and collaboration. Antifragile systems are regularly exposed to unthreatening stress events that enable them to withstand unpredictable and catastrophic occasions. Managing disruptions such as power shortages, technological failures, raw materials shortages, people lockdowns, and failure of suppliers is a key element of organizational capabilities (Essuman et al., 2020).

A few studies have attempted to suggest ways to develop antifragile systems. For instance, the literature has explored antifragile methodologies (Derbyshire & Wright, 2014); assessment tools for antifragility (Kennon et al., 2015); antifragility for risk analysis (Aven, 2015; dos Passos et al., 2019); approaches to antifragility (Ramezani & Camarinha-Matos, 2020; Sagala & Őri, 2024); significance of antifragile systems (De Bruijn et al., 2020); operationalization of antifragility (Größler, 2020; Jaaron & Backhouse, 2014a; Munoz & Zhou, 2023); antecedents of antifragility (Corvello, et al., 2022; Cucino et al., 2022; Nikookar et al., 2024); and digital technologies for antifragility (Corvello, et al., 2023). Considerable studies have linked service firm's internal

capabilities with the development of antifragile systems. For instance, capabilities such as absorptive capacity, flexibility, slack resources, adaptability, and financial strength are connected to the firm's antifragile ability to endure variations and gain from randomness (Essuman et al., 2020; Nikookar et al., 2024; Ramezani & Camarinha-Matos, 2020). For decades, firms assumed that the solution to disorders was to build robust or resilient systems that tolerate volatility or maintain functionality (Nikookar et al., 2021). However, the unending disastrous global events such as global pandemics, political unrest, economic struggles, energy shortages and climate change, have exposed the vulnerabilities of modern businesses (Essuman et al., 2023; Pandey et al., 2023; Wagner & Bode, 2006). The need to develop antifragile capabilities to flourish during disruptive events has become more critical than before (Essuman et al., 2020; Hillson, 2023). This prompts the need to re-examine how service firms can withstand and gain from unforeseen disruptive occasions.

Methodology

Bibliometric analysis is a form of literature review that enables researchers to recognize patterns in the literature for a particular study area (Aria & Cuccurullo, 2017). Bibliometric data is used to identify the evolution of a research topic and its emerging trends (Verma & Gustafsson, 2020). This study adopts the bibliometric analysis to create a visual representation of key research components on the concept of antifragility. Bibliometric analysis has become a popular quantitative technique for performing a comprehensive performance analysis (research contribution) and science mapping (co-relationships) on a particular concept (Donthu *et al*., 2021; Moosa *et al*., 2022; Zupic & Čater, 2015). The method has gained popularity, particularly in social sciences due to its ability to manage large scientific data volumes and produces impactful research; and the advanced and accessible bibliometric software such as *Vosviewer*, and *R-Studio* tools for data analysis and interpretation (Aria & Cuccurullo, 2017; Donthu *et al*., 2021). Performance analysis comprises analytical profiling of various research components and their contributions such as key journals, authors, countries and institutions (Donthu *et al*., 2020). Science mapping evaluates the associations among the research components using indicators such as citation analysis, co-citation analysis, bibliographic coupling, co-word analysis and co-authorship analysis (Aria & Cuccurullo, 2017; Erboz *et al*., 2023; Zupic & Čater, 2015). The bibliometric technique examines the keyword occurrence, co-citation networks and collaboration patterns to determine the conceptual, intellectual, and social structures of a concept (Donthu *et al*., 2021). One of the limitations of bibliometric analysis is that the technique overlooks controversial articles, which could often be highly cited or negatively cited in the data.

To systematize the research landscape on antifragility, this study examines the performance analyses (journals, authors and countries) and science mapping (citation, co-citation analyses and keyword occurrence) to determine the key themes in the antifragility subject area; and addresses the main research questions of the study. The study contributes to the literature by providing a broad understanding and position of antifragility. The following section describes the steps undertaken on bibliometric analysis.

Procedure for Bibliometric Analysis

The study adopted the bibliometric four guidelines developed by Donthu et al. (2021) as follows: *i)* outline the aims and scope of the bibliometric study; *ii)* select the techniques for bibliometric

analysis; *iii)* collect the data for bibliometric analysis; and *iv)* run the bibliometric analysis and report the findings. The steps are described in detail as follows:

Aims and Scope of the Study

Though antifragility was introduced a decade ago, the concept has made little progress in both empirical research and practical implementations in the business world (Hillson, 2023). Hence a bibliometric study is necessary to identify the general knowledge on the antifragility construct to determine the emerging trends on the topic and suggest the key insights useful for future research. By conducting this analysis, the researcher illustrates the static picture of the topic within the business research in a predetermined timeframe, from 2012-2024. The bibliometric study depicts the past, current and future disposition of antifragility in the existing literature and suggests further research constructs.

Techniques for Bibliometric Study

The analysis was conducted using two software tools, *Vosviewer* (Van Eck & Waltman, 2010) and *R-Studio* (Aria & Cuccurullo, 2017). The tools were selected based on their abilities to visualize large bibliometric data. The performance analysis was conducted to determine the key journals, authors and countries' components and their contributions. The citations and co-citations networks were analyzed to measure their performance and influence on the antifragility concept. The keyword occurrence analysis was conducted to evaluate the frequent keywords related to antifragility to determine the key research themes.

Data Collection for Bibliometric Study

The data collection method followed a two-step approach. First, Scopus was selected since it is a commonly accepted database due to its wide coverage of publications (Moosa et al., 2022),. Scopus is a top-notch database of academic articles widely used to determine the potential documents from which the appropriate interpretations and conclusions would be derived (Singh et al., 2021). Second, the specific search criteria of documents for inclusion and exclusion were determined. The documents were retrieved based on the search query TITLE-ABS-KEY using the following keywords, "*antifragility*" OR "*antifragile*" OR "*anti-fragil*". This yielded a total of 3200 documents on antifragility. The search was conducted on October 13, 2024. These were further filtered to the four relevant subject areas confined to Social Sciences (643), Business Management and Accounting (523), Economics, Econometrics and Finance (213), and Decision Sciences (225). The range was also restricted to three document types: journal articles (1017), conference papers (109), and review papers (76). Finally, the documents were limited to the English language. A total of 1202 were included in the bibliometric analysis. Figure 1 displays the flowchart on the applied inclusion and exclusion search criteria.

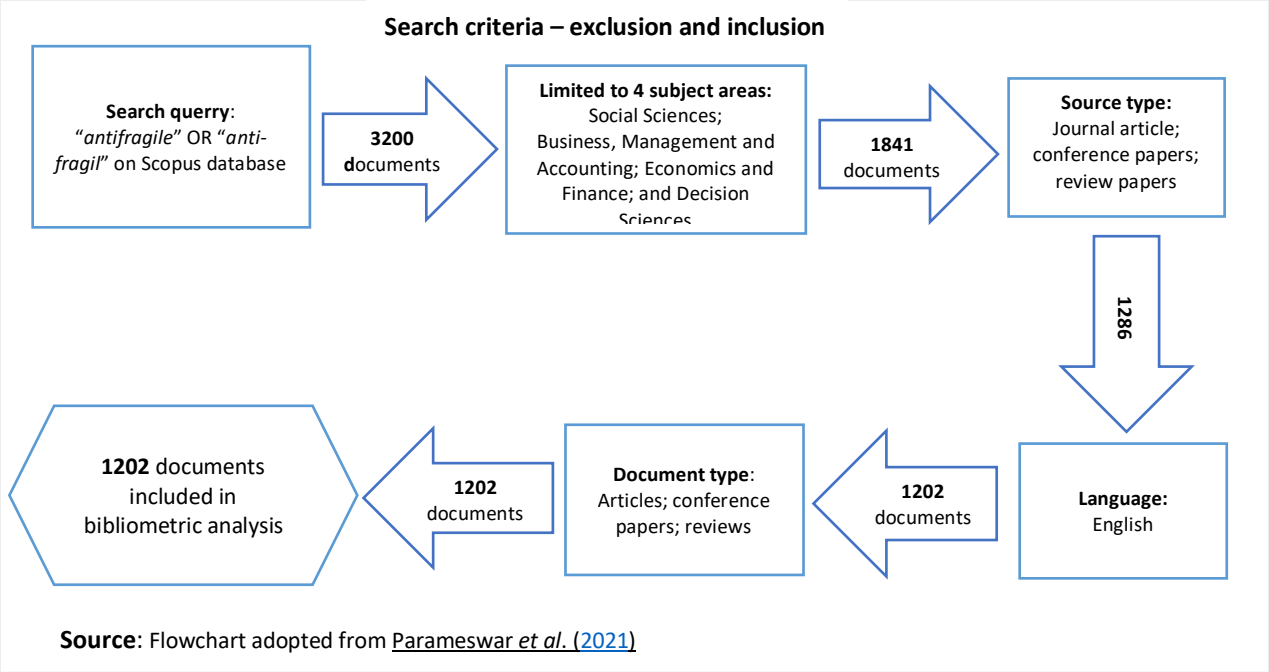

Figure 1: Search criteria

Results From Performance Analysis of Bibliometric Data

The performance analysis results focus on the annual research output analysis, influential authors and relevant sources. The *R-Studio* tool was applied to analyze the performance of key data sources, authors, documents and countries. According to Aria and Cuccurullo (2017), the quality of data collected is critical. Thus, the raw file from Scopus was harmonized for any duplicates and misspelt characters, and the final data was stored as a bibliometric file for importing in the *R-Studio* tool. Tables and figures were used to display the results. The following is a comprehensive bibliometric analysis. The research output on antifragility was conducted in the period between 2012 and 2024. Antifragility was first proposed in 2012 by Nassim Taleb (Taleb, 2012). Since then, researchers have developed an interest in antifragility as shown in the upsurge of published articles, particularly between 2020 and 2024, this was during and after the COVID-19 crisis. The highest number of publications was between 2023 (233) and 2024 (213) [Figure 2].

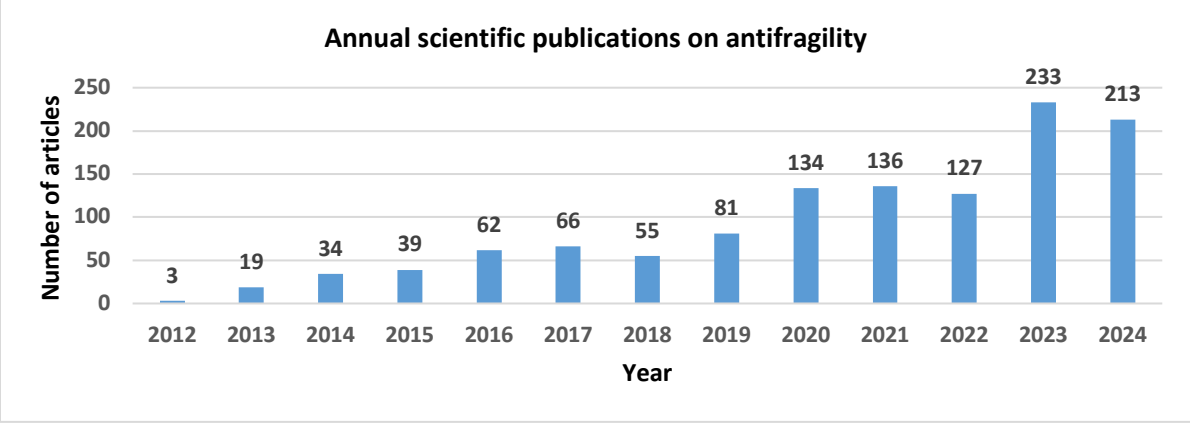

Figure 2: Annual scientific publications
Source: Bibliographic data from Scopus

The number of publications was presented for the top twenty countries. The publication analysis reveals that most articles on the antifragility concept are from developed countries. These include the USA, followed by Italy and the UK [Figure 3]. This signifies that there are still limited research outputs originating from developing countries.

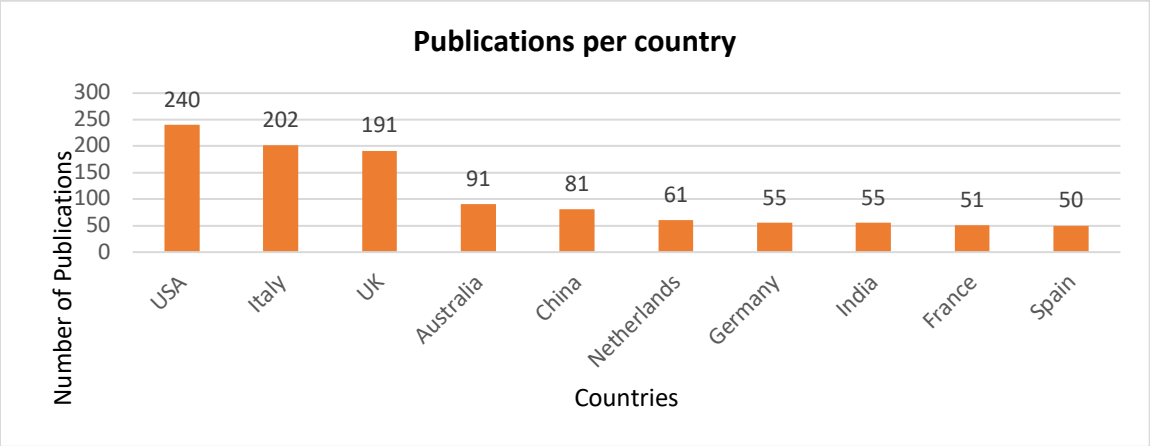

Figure 3: Most productive countries
Source: Bibliometric data from Scopus

Author Influence

Based on the article publications, out of the top ten most influential scholars on antifragility, Scorza, Murgante and Derbyshire have published the highest number of articles [Table 1]. These scholars have also recorded a high number of collaborations. A considerable number of these papers were co-authored by Scorza, Murgante and Saganeiti.

Table 1: Top ten Most influential authors

Author	Documents
Scorza, F	13
Murgante, B	10
Derbyshire, J	8
Oppio, A	7
Pilogallo, A	7
Saganeiti L	6
Taleb, N.	7
Ali, S.	6
Calabrese, M.	6
Dezio, C.	6

Source: Bibliometric data from Scopus

Relevant Sources

Most of the articles on antifragility have been published in the journals of Sustainability (Switzerland), Technovation, Technological Forecasting and Social Change, and Smart Innovation, Systems and Technologies [Table 2]. Other sources which have contributed between 5 and 7 articles each on the concept of antifragility include the International Journal of Services

and Operations Management, Journal of Cleaner Production, Industrial Marketing Management, Journal of Purchasing and Supply Management, and TQM Journal.

Table 2: Relevant sources on antifragility

Sources – Journals	Articles
Sustainability (Switzerland)	**78**
Technovation	**27**
Technological Forecasting and Social Change	**24**
Smart Innovation, Systems and Technologies	**14**
European Journal of Innovation Management	**8**
International Journal of Services and Operations Management	**7**
Journal of Business Research	**6**
Journal of Purchasing and Supply Management	**6**
TQM Journal	**6**
Industrial Marketing Management	**5**

Source: Bibliometric data from Scopus

Citation and Co-citation Network Analysis

Citation Analysis

The most influential publications on antifragility are illustrated to determine its research dynamics. The visual networks were used for the interpretation of the results of citation and co-citation analysis. The Vosviewer tool was used for mapping the citations and co-citations analysis. One of the benefits of Vosviewer software is its ability to visualize bibliometric networks and maps (Dhiaf et al., 2021). Citation analysis describes the scholarly linkages between published articles created when one article cites the other (Donthu et al., 2021). Hence the impact of an article is influenced by the number of citations it obtains. Citation analysis shows the impact of articles and significant journals on a particular phenomenon (Pilkington & Meredith, 2018). The analysis identifies the most frequently cited and influential research papers, which are considered critical to the subject of study. Figure 4 displays the 144 documents with a minimum of 20 citations. The results reveal that Aven (2015), Linnenluecke (2017) and Conz & Magnani (2020) are the most cited documents on antifragility. Table 3 shows the most influential documents widely cited on antifragility.

Figure 4: Most cited documents

Table 3: Top ten most cited documents

Author	Title	Journal	Citations	Pub. Year
Aven T.	Risk assessment and risk management: review of recent advances on their foundation	*European Journal of Operational Research*	746	2016
Linnenluecke M.K.	Resilience in business and management research: a review of influential publications and a research agenda	*International Journal of Management Reviews*	648	2017
Saltelli A.; Giampietro M.	What is wrong with evidence-based policy, and how can it be improved?	*Futures*	143	2017
Conz E.; Magnani G.	A dynamic perspective on the resilience of firms: a systematic literature review and a framework for future research	*European Management Journal*	133	2020
Ritter T.; Pedersen C.L.	Analyzing the impact of the coronavirus crisis on business models	*Industrial Marketing Management*	119	2020
Baruch Y.; Rousseau D.M.	Integrating psychological contracts and ecosystems in career studies and management	*Academy of Management Annals*	119	2019
Haywood K.M.	A post-COVID-19 future - tourism re-imagined and re-enabled	*Tourism Geographies*	114	2020
Culot G.; Orzes G.; Sartor M.; Nassimbeni G.	The future of manufacturing: a Delphi-based scenario analysis on industry 4.0	*Technological Forecasting and Social Change*	112	2020
Capano G.; Woo J.J.	Resilience and robustness in policy design: a critical appraisal	*Policy Sciences*	101	2017

The citation analysis of the sources on the concept of antifragility reveals that the most influential source is Sustainability, followed by Technological Forecasting and Social Change and Technovation [Table 4]. Other sources include Industrial Marketing Management, Journal of Cleaner Production, Journal of Purchasing and Supply Management, International Journal of Services and Operations Management, and TQM Journal.

Table 4: Most cited sources

Label	Documents	Citations
Sustainability (Switzerland)	**78**	1067
Technological Forecasting and Social Change	**24**	394
Technovation	**27**	285
Industrial Marketing Management	**5**	215
Journal of Cleaner Production	**6**	92
Smart Innovation, Systems and Technologies	**14**	91
Journal of Purchasing and Supply Management	**5**	73
International Journal of Services and Operations Management	**6**	20
European Journal of Innovation Management	**8**	14
TQM Journal	**5**	12

Source: Bibliometric data from Scopus

Co-citation Network Analysis

Co-citation analysis is used to determine the scholarly structure of a particular field of study and possible knowledge foundations. Co-citation is when two papers are cited together in a third document (Aria & Cuccurullo, 2017). The general assumption of co-citation is that articles that

are often cited together are comparable thematically (Donthu *et al*., 2021). Using the *Vosviewer*, the following co-citation network was developed, which reveals the top-notch researchers on the concept of antifragility.

Co-citation by Cited References

The analysis is performed by counting the times two articles are cited together to obtain the most influential publications (Erboz *et al*., 2023). However, one limitation of co-citation analysis is that it relies only on highly-cited publications and omits newly published articles (Donthu *et al*., 2021). The co-citation analysis of 51 publications with 5 clusters, 222 links between references and a total link strength of 779 was created. The results indicate the dots showing the main articles in the clusters, while diverse colours signify articles in each cluster [**Figure 5**].

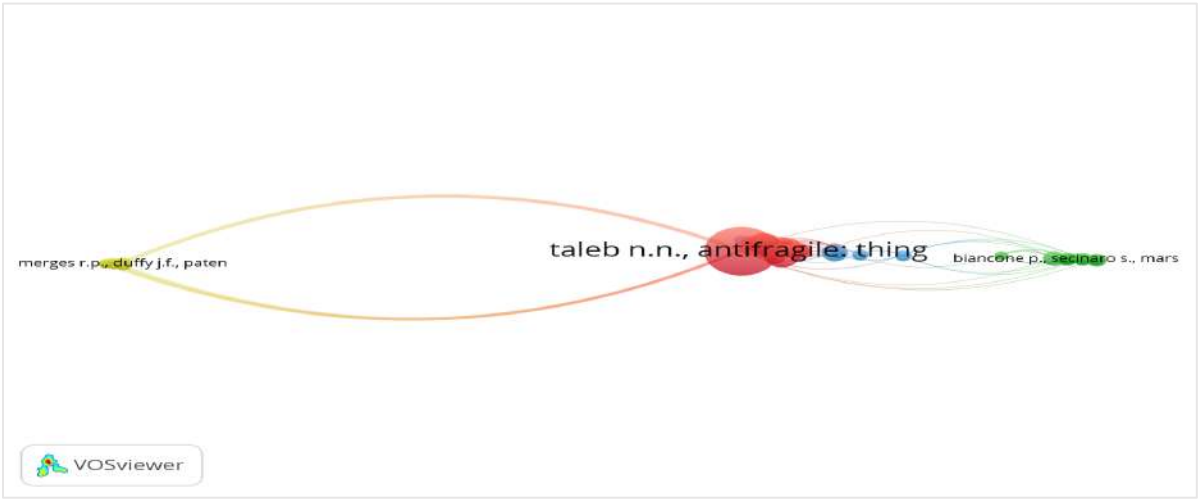

Figure 5: Co-citation by documents
Source: Bibliometric data from Scopus

Co-citation by Authors

The analysis on co-cited authors was 359 items, with 9 clusters, 24359 links and a total strength of 197,973. The dots represent the main authors in each cluster represented by different colours.

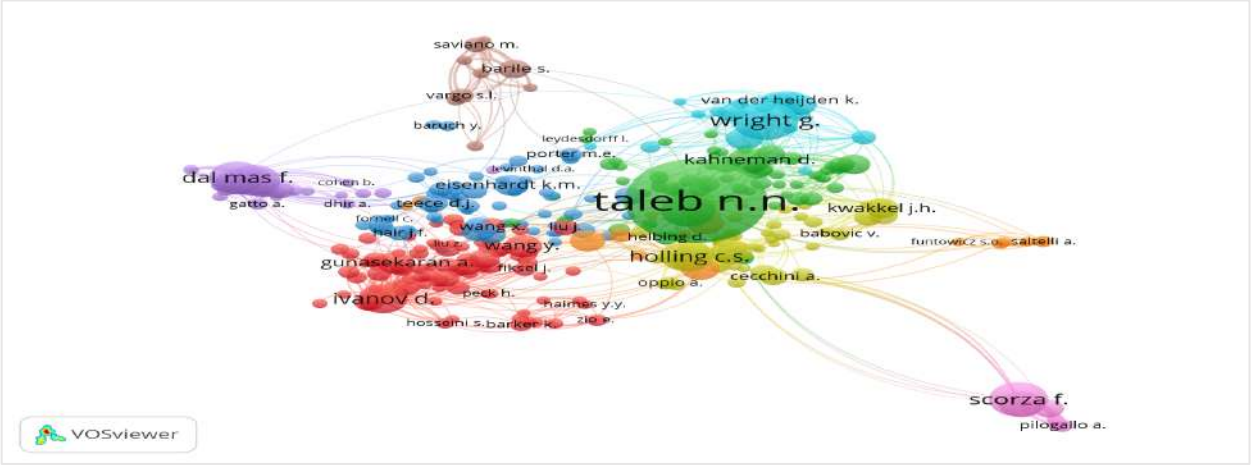

Figure 6: Co-citation by authors
Source: Bibliometric data from Scopus

Key Occurrence Analysis

This section describes the keywords, co-occurrence, or co-word analysis conducted on the concept of antifragility. The keyword analysis highlights the dynamics of the conceptual structure of the subject area (Zupic & Čater, 2015). The analysis entails the frequent keywords found in the titles, abstracts and keyword parts of the published documents found in the bibliometric data (Aria & Cuccurullo, 2017; Verma & Gustafsson, 2020). The keywords analysis conducted reveals the fundamental concepts that have been explored on antifragility and their interrelationships. The keyword co-occurrence visual map was obtained using the Vosviewer tool using the authors' keywords as the unit of analysis. The map shows ten influential keywords distributed in three clusters, with 31 links and 103 total link strengths between the documents [Figure 7]. The results demonstrate that resilience, COVID-19 and antifragility concepts are strongly interrelated to the common keywords recently found in most search engines, especially during the COVID-19 pandemic. Other keywords; uncertainty, complexity, risk management, scenario planning, innovation, digital transformation, and sustainability are also topical issues influencing the current research activities [Table 5].

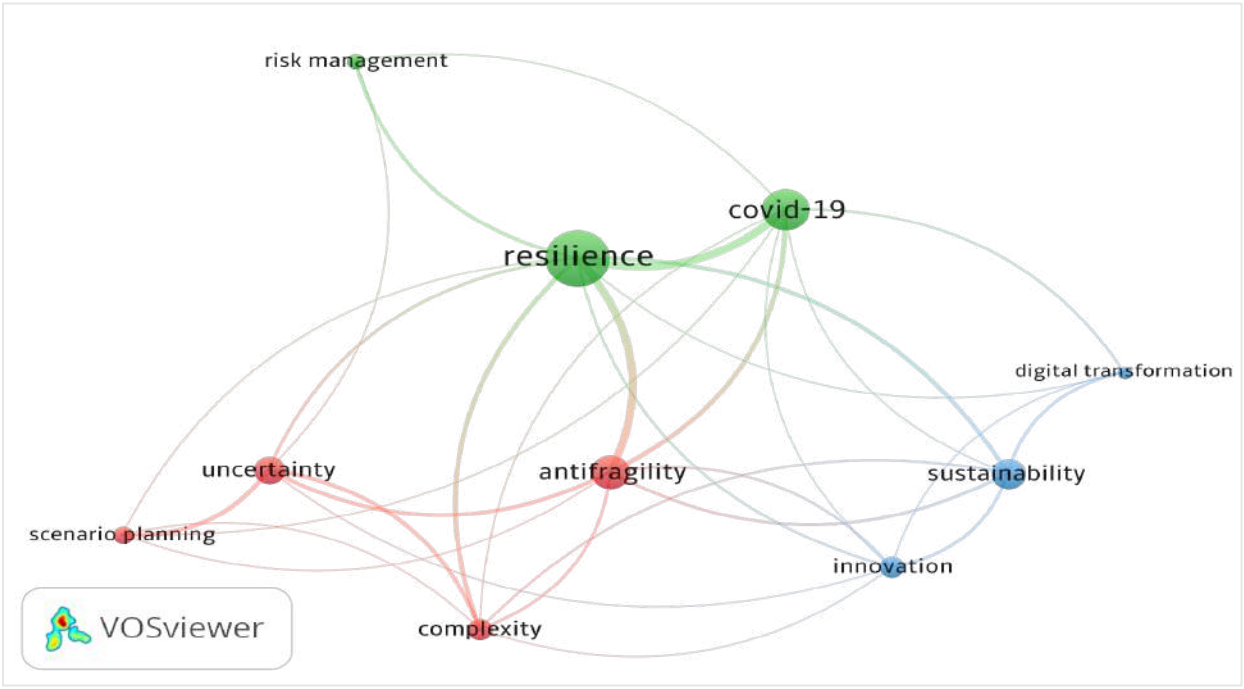

Figure 7: Keyword analysis of documents
Source: Bibliometric data from Scopus

Table 5: **Keyword analysis**

Words	Occurrences
Resilience	**102**
COVID-19	**61**
Antifragility	**48**
Uncertainty	**38**
Sustainability	**34**
Complexity	**28**

Innovation	**28**
Scenario Planning	**23**
Risk Management	**17**
Digital Transformation	**16**

The keywords were clustered based on three distinct colours; green, red, and blue, as follows: Cluster 1 [*antifragility, complexity, scenario planning, and uncertainty*]; Cluster 2 [*COVID-19, resilience, and risk management*]; and Cluster 3 (*digital transformation, innovation and sustainability*).

Findings and Discussion

The keyword clusters were used to form the appropriate research themes on antifragility. This was followed by an extensive perusal of sampled publications from the bibliometric data to understand the subject themes. The scope of antifragility literature is spread across diverse disciplines. Hence the relevant journal articles were prioritized to contribute to the growth of the antifragility literature in the business management context. The following is a comprehensive description of the keywords and suggested subject themes. The research themes were developed to form the theoretical foundation for future studies.

Building Antifragile Capabilities

The keywords in cluster 1 publications established how firms enhance their business operations amid disastrous occasions in the dynamic business environment; characterized by accelerating uncertainties and complexity. The previous literature establishes the strategies firms use to enhance their operations amid disastrous occasions. For instance, Nikookar et al. (2024) identified five approaches to building antifragile capabilities: mindfulness, transformative learning, plasticity, bricolage, and collaboration. According to Juan et al. (2022), collaboration and flexibility enhance resilience and antifragility in the supply chains. Sagala and Őri (2024) found that collaborative networks among business firms are a significant strategy to enhance antifragility. Recently, Lotfi et al. (2023) developed a robust stochastic optimization approach to manage risks and uncertainties in health waste chain networks. Corvello et al. (2023) identified antifragility abilities in SMEs: entrepreneurial orientation, operational dexterity, slack financial resources, fastness, creativity, creativity, and context insightfulness. Ramezani and Camarinha-Matos (2019) argue that firms can manage disruptive scenarios through coping strategies such as readiness, response, and recovery; and capabilities such as being flexible, convex, agile, redundancy, visible, creative and financial power. The authors also suggest that collaborations in business networks are a potential approach to disruptive scenarios.

Scenario planning has been underlined as one of the techniques firms adopt to cope with disruptive uncertainties. Tiberius et al. (2020) provide four scenario techniques: prediction markets, crowdsourcing, and super-forecasting that firms integrate into their operations to manage uncertainties. Bui et al. (2019) suggest that 'survivor syndrome' can be tolerated when scenario planning is prioritized as a form of organizational foresight. In addition, Wright et al. (2019) propose a scenario planning tool, 'intuitive logic' to address the emerging 'wicked problems' that emerge unexpectedly. The principles of risk assessment and risk management have also been applied to mitigate disruptions for decades. Aven (2015, 2016) discusses the appropriate approaches to risk management in the context of adaptiveness, resilience, or antifragility.

Therefore, firms build antifragile capabilities through collaborations, scenario planning, and risk management strategies.

Several firms have used various strategies to build antifragile systems. For instance, Zoom Video Communication Inc. expanded its network capacity to video conferencing during the COVID-19 pandemic and experienced exponential growth, scaling its daily users from 10M to 200M (Aboulezz, 2021). Amazon, an online retailer adopted an innovative business model that has disrupted the norms of traditional retail business, eliminating large chains globally (Krishna, 2023). However, several innovative logistics firms such as Uber and Lyft have failed to adjust to the current volatile business climate (Mehta, 2020). By being innovative and creating disruptive products and services, such firms maintain resilience and antifragility (Corvello et al., 2022). With emerging threats such as cyberattacks, service firms need to build resilient, adaptable, and antifragile business ecosystems to ensure business continuity. Other strategies to build antifragility may include the development of workforce, leadership, and learning processes and programs for firms.

Responsive Antifragility Capabilities

The keywords in cluster 2 documents highlight the effect of unpredictable disruptions such as the COVID-19 pandemic on business operations; and how firms need to build capabilities for antifragility. A few scholars have linked various capabilities to antifragility. For instance, (Corvello et al., 2024; Corvello, et al., 2022) identified three antecedents of antifragility: intellectual capital, absorptive capacity, and slack resources. Similarly, Cucino et al. (2022) found four capabilities: flexibility, creativity, simplicity, and collaboration. These capabilities enable a firm to thrive in a volatile environment. In addition, attributes such as disruption absorption, recoverability, slack resources, disruption orientation, collaborative efforts, operational disruptions, firm size and age, and industry type enable a firm to survive disruptions (Essuman et al., 2020). Similarly, Ramezani and Camarinha-Matos (2020) identified various overlapping capabilities for antifragile systems: agility, adaptability, cohesiveness, convexity, cognitive ability, creativity and imaginary capacity, diversity, efficiency, evolvability, flexibility, elasticity, financial strength, fault tolerance, market positioning, observability, redundancy, simplicity, sustainability, security compliance organizational capability, and visibility. Munoz et al. (2022) argue that firms need to enhance slack resources and capabilities to exploit unexpected opportunities during adversity. Hence, antifragile capabilities may comprise slack resources, capacity, adaptability, and creativity.

Key Drivers for Antifragile Capabilities

The publications in cluster 3 describe the possible factors that stimulate the growth of antifragile systems in business firms. These factors motivate firms to pursue or adopt antifragility. The extensive literature describes the significance and application of digital technologies, innovation, and sustainability principles. For instance, digital transformation has been accelerated in several services, such as healthcare to cope with disruptive events (Baudier et al., 2023; Garcia-Perez et al., 2023). Similarly, Bamel et al. (2023) provide insight into the enablers, barriers, and challenges of disruptive innovations in service firms. Alketbi et al. (2022) found that sustainability performance is interrelated to the strategy and financial performance of the firm. Thus, digital transformation, innovation, and sustainability are key drivers for antifragile systems. To enable firms to embrace sustainability, Peter and Swilling (2014) developed a model that links complexity to sustainability theories for transition to sustainability. Silvestre et al. (2022)

developed a management tool to enhance the strategic integration of sustainability in business organizations. Paoloni et al. (2023) demonstrate how disruptive technologies such as artificial intelligence can be used to enhance business sustainability. Tartaglione et al. (2023) argue that digital technologies are drivers for antifragility. Other factors such as economic stability, market fluctuations, regulatory dynamics, technological developments, leadership styles and intellectual capital may drive firms to embrace antifragility.

Conclusion

The study conducted a bibliometric analysis to determine the current research outlook, key research themes, and requisite capabilities of antifragility in service firms. The study answers four key research questions: *a) who are the most influential authors in terms of publications on antifragility? b) which are the most cited journals on antifragility? c) what are the main antifragility research themes and trends?, and d) what are the requisite antifragility capabilities?* The study illustrated the current picture of the concept of antifragility within business research with a focus on service firms. The findings reveal that since its inception in 2012, there has been an upsurge in publications on antifragility particularly between 2020 and 2024. This was driven by the unwavering COVID-19 pandemic, which exposed the susceptibility of many business firms across the world. The analysis reveals that most articles and research collaborations were from developed countries, that is, the USA, Italy, the UK, Australia and China. Thus, this signifies that there are still limited research outputs from emerging markets such as Africa. The top-most authors include F. Scorza, B. Murgante, and J. Derbyshire. The citations and co-citation network analysis also revealed the most dominant research documents and sources. The relevant sources on antifragility are published in the International Journal of Services and Operations Management, Journal of Cleaner Production, Industrial Marketing Management, and Journal of Purchasing and Supply Management.

Bibliometric data was used to generate a visual representation of the key research components and themes useful for future research. The study examined the annual research output analyses to identify the country's annual publications, key journals, and influential authors. The citation and co-citation network analyses were performed to determine the scholarly linkages and conceptual structure of antifragility. Keyword analysis was conducted to highlight the conceptual structure of antifragility to form the theoretical foundation for future research. This comprises an analysis of frequent keywords found in the published documents drawn from the bibliometric data to identify the key concepts of antifragility and their interrelationships. The keyword analysis results revealed ten influential keywords distributed in three clusters. The findings of the keyword analysis demonstrated three key clusters that formed three research themes on antifragility: strategies for building antifragility capabilities, responsive antifragility capabilities, and key factors that drive the adoption of antifragility. The most prevalent capabilities include the firm's slack resources, capacity, adaptability, and creativity. The fragmented literature on antifragility discloses that there are empirical and theoretical gaps. First, the existing literature shows there is inadequate research on the influence of antifragility on organizational performance. While there is growing evidence that antifragility enables firms to cope with risks and disruptions, there is a need for more empirical studies on specific ways in which antifragile systems allow firms to attain performance gain in a dynamic and volatile environment. Second, though antifragility has existed for more than a decade, there is limited understanding of its enablers, barriers, and capabilities.

In addition, the general guidance on how firms can effectively measure and monitor their progress on antifragility is not clear.

In conclusion, the extensive bibliometric literature reveals the current disposition of the antifragility concept in business research and its significant practical applications in the business world. Though the antifragility concept is regarded as a potential organizational strategy to respond to environmental disruptions, its theoretical and conceptual structure is still not well understood in the literature, particularly on its intrinsic capabilities. The bibliometric analysis unveils three key research themes, which form the basis for future studies.

Practical Implications

The study develops three key research themes. First, strategies on how firms can build antifragility capabilities include collaborations, focus on scenario planning and risk management. Second, key influential antifragility capabilities comprise the use of slack resources, capacity, adaptability and creativity that are responsive to environmental turbulences. Third, the main drivers of antifragility include digital technologies, innovation and sustainability principles. These research themes offer the firm's top management teams a wide range of real-world understanding of the challenges and opportunities that emanate from disruptions; and how to embrace opportunities that enable them to improve performance during crises.

Theoretical Implications

This study contributes to the field of antifragility by illuminating the theoretical evolution of antifragility research, and its disposition in the modern literature, and suggests future research leads. Generally, the conceptual structure and research themes contribute to the epistemological discourse on the knowledge about the antifragility capabilities, strategies and drivers. Further, the study provides a better understanding of the key journals, influential authors and research collaborations between countries. The citations and co-citation networks reveal the most productive authors and sources that may be useful for future researchers. In addition, this could be one of the first bibliometric analyses and a set of research themes to set the pace for future research studies to further advance the knowledge on antifragility.

Limitations and Direction for Future Research

This study could have some limitations. First, the study focused only on the Scopus database for data extraction and the results and inferences are made entirely based on these articles. Though Scopus is one of the largest databases, there could be several publications not captured. Future studies could consider incorporating other databases such as the Web of Science for richer analyses. In addition, future studies could focus on the key research themes to build the possible theory on antifragility capabilities.

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