



Vulnerability Reduction of Technology-Based Business Research in the Last Four Decades: A Bibliometric Analysis

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Abstract

Natural and man-made disasters have increased the attention of practitioners and researchers to vulnerability. Identifying business vulnerability is one of the basic elements of strategic analysis and public policy. The purpose of this paper is to explore evolutionary pathways to reduce the vulnerability of technology-based businesses. The intellectual structure of this subject was examined using both bibliometric co-occurrence and co-citation analyses. We focused on 629 articles published between 1981 and 2021. This article identifies four specific areas, namely business performance, small business vulnerability, sources of sustainability in business, and adaptation policy assessment. A novel framework was developed based on the most prominent papers identified in co-citation as well as the highly cited papers. The proposed model includes drivers, vulnerability appearance, and vulnerability reduction. This study examines the basis of research concepts, themes, and communities in reducing the vulnerability of technology-based businesses. This article identifies business vulnerability as one of the relevant areas to disaster economics and sustainability studies.

Keywords: absorptive capacity, adaptive capacity, bibliometric analysis, business vulnerability, transformative capacity, vulnerability reduction strategy.

Introduction

Today, businesses are facing tremendous threats and challenges because of high economic, social, geographical, political, technological, and, environmental risks, such that all over the last decade, surviving and flourishing against and through troubling times (e.g., recession, natural disasters, armed global conflicts) has been one of the main considerations faced by businesses (Azusa & Hiroyuki, 2013). Natural and man-made disasters, such as the recent outbreak of COVID-19, have grabbed the attention of practitioners and researchers to vulnerability (Sharma et al., 2021). COVID-19 is the “Black Swan” which makes businesses vulnerable to unnatural external forces (He & Harris, 2020) (Kamalipoor et al., 2022). In a post-pandemic world, some of the entrepreneurs with great management skills may also be feeling particularly vulnerable. During COVID-19, entrepreneurs have been facing unprecedented setbacks. They grappled with extreme levels of vulnerability (Branzei & Fathallah, 2021). Terrible and frequent recent natural disasters have made studying catastrophic events very important and emergent, particularly for speeding business recovery and risk alleviation. These are known as principal research fields. Thus, it's of grave

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importance to explore factors alleviating risks and making businesses prepared to respond to crisis-caused challenges effectively (Morrish & Jones, 2020). Businesses may be disrupted by direct damage to property, the reduction or loss of support for critical infrastructure development, or the impact on social systems (such as human resources and customers). This business disruption may manifest as a reduction (or loss) in production and sales, or a temporary or permanent closure (Nocera & Gardoni, 2019). Vulnerability is a weakness in the organization that opens the way for threats to enter (Goel & Chen, 2008).

Organizations and businesses play a key role in social, economic, and ecological systems' dynamics (Orhan, 2016). The survival of the business after a disaster plays a vital role in the long-term well-being of society (Lee, 2019). Thus, one can facilitate business recovery by identifying domains that make survival harder and exacerbate business vulnerabilities. Through learning from past experiences of the impacted businesses, one can mitigate business vulnerability against future events and disasters, decrease shutdown frequencies, and improve sustainability (Sydnor et al., 2017). It should be mentioned that vulnerability varies according to environmental, economic, institutional, social, demographical, and cultural aspects (Li et al., 2015). Identifying business vulnerability is one of the basic elements of strategic analysis and public policy (Cowan & Wright, 2016). Marshall et al. (2015) believed that developing policies for relieving after-mass business is not the only important issue, but rather a policy development, planning, and backup operation to encourage businesses to take part in pre-disaster planning should be focused on. Moreover, the most vulnerable businesses need to be identified, too. Thus, mid-and long-term planning is of grave importance for re-equilibrium and economic recovery (Nicola et al., 2020).

Berrouet et al. (2018) also suggested that some concepts such as vulnerability, sensitivity, threat, exposure, and adaptive capacity are not homogeneously defined and are sometimes inconsistent, leading to confusion, instability, and inability to compare different studies taken place in different areas. They stated that vulnerability analysis requires a change in conceptual and methodological approach and call for the creation of a new framework for vulnerability assessment. Although the vulnerability has been discussed extensively from various spatial-temporal dimensions, there is no universally accepted model or theory (Jamshed et al., 2017). As a growing field, "business vulnerability to disasters and crises" is increasingly attracting scientists and researchers from practical and theoretical worlds, while how to define business vulnerability to disasters is an open question (Song et al., 2016). As vulnerability has been inserted into scientific discussions only in recent times, a clear definition is still missed (Lo et al., 2019). Branzei and Fathallah (2021) stated that vulnerability is a dark side of resilience that remains largely untold. Since disasters and crises impact organizations' and businesses' ability to realize their objectives, they consider them controversial and complicated affairs to deal with (Tarrant, 2010); thus, this issue is a real challenge, the evaluation of the characteristics and related theoretical framework of which is of grave necessity. While more researchers are interested in vulnerability assessment methods, they should be modified and integrated before being used in policies (Rana & Routary, 2018).

Technology-based businesses have played a major role in the economic growth of many countries and have been strongly encouraged as a source of competitive advantage as well as job creation (O'Regan & Sims, 2008). However, environmental shocks affect the performance of technology businesses and reduce their demand, and although environmental shocks are a challenge for any business, such a challenge is especially serious for high-tech entrepreneurial businesses. Few technology-based businesses can achieve superior performance after environmental shocks (Colombo, 2020).

Exploring the previous research using the bibliometric method, we found that research and attention to the category of vulnerability has a long history and has been paid more attention

in social and natural sciences and less in management and entrepreneurship, especially in technology-driven business. There is no sufficient bibliographical research (BR) regarding this issue. In addition, little research on business vulnerability has often been done with a climatic approach, and other factors that lead to vulnerability have been neglected. Therefore, the first and most important achievement of this research is the development of a framework to reduce the vulnerability of technology-based businesses, which significantly impacts the continuity and sustainability of technology-based businesses.

Because the term business vulnerability has great potential for bringing together diverse disciplines, this research has scientific contributions to areas related to disaster planning and management (Venkateswaran *et al.*, 2014), disaster risk reduction (Zhou *et al.*, 2015), and resilience (Sheffi, 2005) via identifying drivers, vulnerability appearance, and vulnerability reduction. We contribute to the literature on business vulnerability by analyzing co-citation, co-occurrence of keywords, theme evolution, and future study directions. Eventually, the research acknowledges the theoretical contribution and the limits of the present study, and recommends further study directions.

Aiming at fixing the aforementioned shortcomings, the main purpose of this study is to identify the antecedents of business vulnerability and strategies to reduce business vulnerability. Accordingly, the following questions are proposed:

- 1) What is the main structure map of business vulnerability concerning its subfields relationships?
- 2) What is the thematic visualization of the business vulnerability?
- 3) What are the business drivers for vulnerability?
- 4) What are the elements of business vulnerability?
- 5) What strategies can reduce vulnerability?

To answer research questions, bibliographic research was conducted through analyzing the co-citation and co-occurrence of keywords. Web of Science Database's records (timeline: 1981-2021) was analyzed using Citespace, GunnMap2, and VOSviewer. Then, a vulnerability reduction model was designed. To our best knowledge, this research is one of the scarce efforts that try to look comprehensively at business vulnerability and its logical basics from the BR viewpoint.

The rest of the article is structured as follows. The second section describes the overview of vulnerability. The third section presents the research methodology. The fourth section offers the results. Finally, the paper discusses results and gives in the proposed future research directions.

Overview of Vulnerability

Vulnerability is a multifaceted and multidimensional phenomenon. There are different definitions and interpretations of vulnerability in the scientific literature (Rana & Routray, 2018). The term "vulnerability" is a derivative of the Latin word "vulnus," i.e., wound. That is, the word vulnerability refers to a wounded soldier who is already injured and vulnerable and is on the verge of death. Merriam Webster dictionary describes vulnerability as the "possibility of physical or psychological injury" (Cuevas, 2011). Many fields including economy, anthropology, psychology, and engineering use the vulnerability concept (Adger, 2006). The first instants of vulnerability application in risk and disaster management were about physical persistence of engineered structures, while recent applications are focused on the characteristics of environmental and social factors (Cardona *et al.*, 2012). One can say that vulnerability is referring to a specific situation in which a public risk may turn into a disaster

(Gaillard, 2010). Disaster occurs when an individual, a society, or an organization is driven away from relative stability or equilibrium.

Vulnerability is defined as the degree to which the ability of an ecological system to maintain the ecosystem functions is affected by the adverse effects of the threats of different types – punctual or continuous, endogenous or exogenous (Berrouet et al., 2018). Vulnerability can also be seen as the gaps and weaknesses in the coping strategies that are adopted by a community (Rana & Routray, 2018). Fussel (2005) believed six elements should be determined to describe a vulnerable phenomenon correctly: 1) time reference (now, future, and long-term); 2) scale (internal, external, internal-external); 3) domain (socioeconomic, biophysical, and mixed); 4) vulnerable system; 5) system's valuable characteristics; and 6) threats.

Yan and Zhou (2010) believe that vulnerability refers to quantitative and qualitative weaknesses of a business, i.e., lacking sufficient stability against any intervention and uncertainty. Song et al. (2016) explain business vulnerability to natural disasters considering geographical location, economic situation, and critical demographic characteristics in terms of responding to natural disasters and define them as made of four factors, namely business capital, labor, critical suppliers, and physical location. Aleksić et al. (2014) stated that vulnerabilities in the organization and business should be constantly examined, because in critical situations they can lead to disaster. They emphasized that the most appropriate way to overcome the vulnerability of the organization and business is to effectively manage the vulnerability in each of the business processes (operational, managerial, and supportive) in order to achieve the long-term sustainability of the business. Businesses' inadaptability indicates that they are heavily vulnerable to disasters (Davlasheridze & Geylani, 2017). Concerning the COVID-19 crisis, Giones et al. (2020) stated that entrepreneurs should take appropriate actions to reduce vulnerability in three stages of the crisis, including pre-crisis, in-crisis, and post-crisis.

Table 1 shows the definitions of vulnerability based on literature review.

Table 1. Definitions of Vulnerability Based on Literature Review

Source	Definition of vulnerability
Lo et al., 2019	Low capital mobility, high capital intensity, and a high proportion of local customers are considered as vulnerabilities of small and micro-businesses.
Nazari Nooghabi et al., 2019	Vulnerability is a dynamic concept that is understood using the three dimensions of exposure, sensitivity, and adaptive capacity.
Thomas et al., 2019	Vulnerability is a function of the degree to which the ecological system is exposed to the threat, its sensitivity, and its adaptive capacity.
Berrouet et al., 2018	Vulnerability refers to the degree of system performance loss in which the system is affected by different types of threats (punctual, continuous, endogenous, and exogenous) and is inversely related to system resilience.
Rana & Routray, 2018	Vulnerability is considered as gaps and weaknesses in the coping strategies adopted by a community.
Hong et al., 2016	Vulnerability implies a weak resistance and low resilience of ecosystems in response to external interference, including natural and artificial factors at a specific spatial scale.
Aleksić et al., 2014	If an undesired event happens, vulnerability depends not only on exposure to an event but also on the degree to which normal system reliability is compromised during harmful events.
Cardona et al., 2012	Vulnerability is related to the background of susceptibility, fragility, weakness, defect, or inability to be exposed to adverse effects.
Cuevas, 2011	Vulnerability has been defined as the measure of the degree to which a system might be harmed in response to a stimulus.
Polsky et al., 2007	A system is vulnerable to the effects of global change, which is not only exposed and sensitive to the effects but also exhibits a limited ability to adapt.
Greiving et al., 2006	Vulnerability is defined as the degree of the fragility of a system (natural or socio-economic) or society against natural and technological hazards.
Dalziell, 2005	Vulnerability indicates the extent to which the system will be affected by an event, and is defined as natural, economic, or social system fragility facing natural risks and technology.
Dalziell & Mcmanus, 2004	The extent to which the society or the organization is easily driven to the new status is their vulnerability level.

Method

Selection of Papers

Choosing the appropriate databases is a critical element one should consider to have the right resources. According to Morant and Soriano (2016), identifying the more appropriate databases for the research is the first step in the bibliometric review. Thus, the Web of Science (WOS) database was selected because of many reasons among which one can point to the fact that it, compared to other databases, searches much more entries and gives in a larger sample (Dias, 2019). Moreover, it uses a great variety of bibliometric studies and covers social, art, and human sciences (Mulet-forteza et al., 2019).

Search keywords were chosen in a specific way such that the database can find the maximum number of the related findings. Keywords were linked using “OR” and “AND,” according to expert recommendations. It should be mentioned that titles, abstracts, and keywords of English review and research papers published between 1981 and 2021 were searched for keywords since scarce studies have been conducted regarding this issue and that gaining the most possible data from journals was the main object. Finally, 629 papers were found.

TITLE: (vulnerability) AND TOPIC: (business) OR TITLE: (business) AND TOPIC: (vulnerability) OR TITLE: (vulnerability) AND TOPIC: (firm) OR TITLE: (firm) AND TOPIC: (vulnerability) OR TITLE: (vulnerability) AND TOPIC: (corporate) OR TITLE: (corporate) AND TOPIC: (vulnerability) Refined by: LANGUAGES: (ENGLISH) AND DOCUMENT TYPES: (ARTICLE OR REVIEW)

Bibliometric Analysis

Groos and Pritchard (1969), in “employing mathematical and statistical methods in the book and other communication tools,” introduced the term “bibliometric.” To identify various patterns of published papers in a specific domain, the bibliometric study analyzes empirical data empirically (De Bellis, 2009), which is used in qualitative analysis of the basic and critical literature (Suominen et al., 2019). To help researchers analyze and determine particular meanings of an issue, this method uses quantitative bibliographic elements, too (Danvila-del-valle et al., 2019). The bibliographic method reduces the bias seen in most traditional and professional surveys (Kovacs et al., 2015). The most common analysis methods used in the bibliography are co-citation, co-occurrence, and co-authorship analysis (Van Eck & Waltman, 2014). Co-occurrence and co-citations were used in this research.

Co-Citation Analysis

Co-citation analysis is the most common and popular bibliographic analysis technique (Ozç, 2015). Co-citation refers to two titles cited simultaneously in another article, and it's assumed there is some relation if they are co-cited in the same document (Small, 1973). If other papers cite these frequently, one can claim that these two references are irregular (Benckendorff & Zehrer, 2013). To reveal a significant mapping across the published data, this method links the published documents (Dzikowski, 2018). According to Chen et al. (2019), to recognize potential scientific knowledge developments, one can check citation of those documents which are not only referenced rapidly but also have intermediate centrality on the co-citation network; it's assumed that every article represents a specific issue and that any co-citation

occurrence reveals the connection between two concepts through the knowledge base of a scientific field.

Co-Occurrence Analysis

Just as keywords reveal some information regarding document content, keyword matrix analysis can be used to find the research subject, conceptual-structural blocks, changing boundaries, and concept development (Zupic & Čater, 2015). A keyword analysis is created based on counting their co-occurrences, i.e., the number of articles in which both keywords occur simultaneously (Whittaker, 1989). Assessing the strength of keywords' co-occurrence relations, keyword review discovers and represents keywords interrelations (Lee & Su, 2010). However, keyword analysis is unstable because of term evolution over time (Leydesdorff, 1997). Using keyword co-occurrence, researchers can map and measure business vulnerability development. Given that every bibliographic method has its strengths and weaknesses, using various methods for conducting bibliometric research has become a norm in discovering research trends of a specific field (Chang et al., 2015). Therefore, to map a bibliographic plan, both co-occurrence and co-citation analyses were employed, the results of which are discussed later in this article.

Theme Evolution

To comprehend a theme thoroughly and rapidly, and to discover evolution pathways, the method used for uncovering theme evolution through reviewing a great deal of data is critical for specialists and researchers, such that theme evolution study across scientific literature has grown in importance in recent times (Ye et al., 2015). The theme evolution method can recognize keywords' developments through various periods (Wu et al., 2016).

Software

To review technology-based businesses, three software packages were used, namely CiteSpace, VOSviewer, and GunnMap2. Citespace, developed by the Korean scientist Chaomei Chen in 2004, is Java-based software with various capabilities, including visualizing and analyzing text trends using co-citation. CiteSpace illustrates a matrix consisting of institutions, contributing countries, cited journals, and authors (Chen et al., 2019). Matrices assist us in recognizing and visualizing core thinking societies to business vulnerability research evolution. VOSviewer software offers popular bibliographic analysis purposes, including co-authorship, co-occurrence, bibliographic coupling, and co-citation analysis. VOSviewer is used extensively in citation-based analyses (Baier-fuentes et al., 2019), and is useful for reviewing mutual relations between clusters (van Eck & Waltman, 2010). VOSviewer can analyze keywords co-occurrence and co-citation, thus making it possible to interpret themes related to business vulnerability. It was chosen by the researchers because of some reasons. This software can reveal the significance of intra-network relations and identify extant clusters automatically. To represent documents' universal distribution, GunnMap2 (<http://lert.co.nz/map>) was employed, too.

We used VOSviewer software for co-citation and co-occurrence keyword analysis. CiteSpace was used for the timeline view and GunnMap2 was used to show the global distribution of papers.

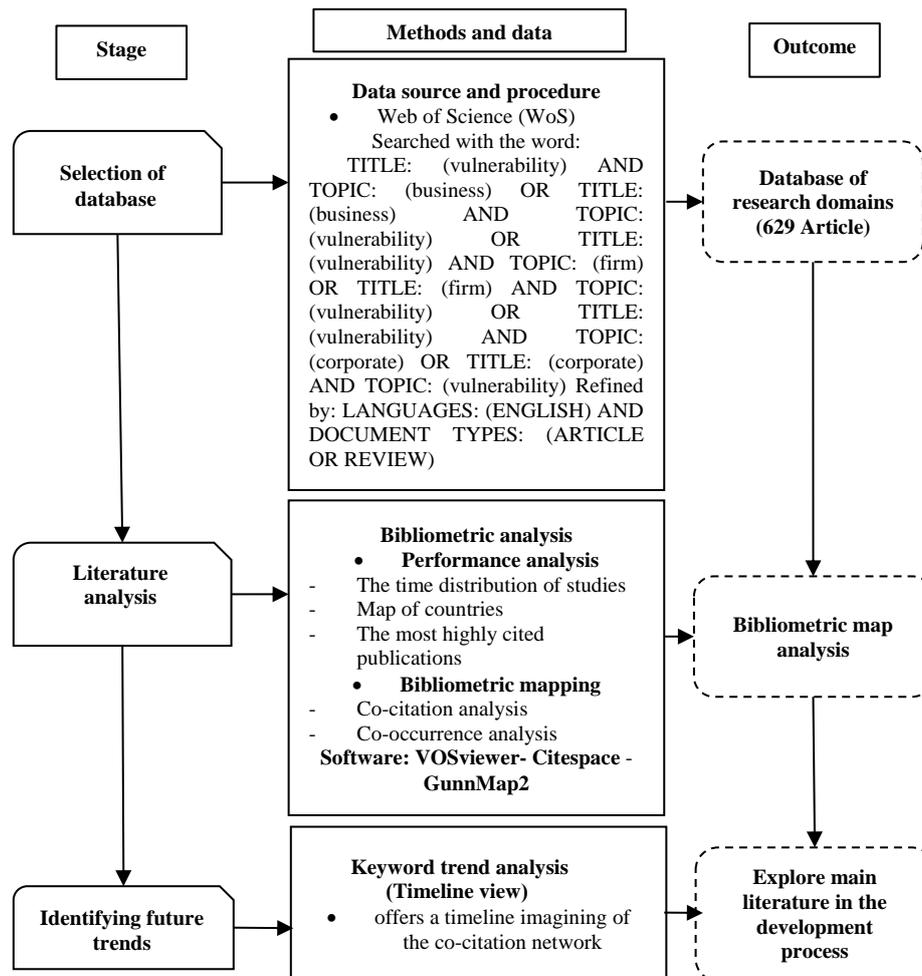


Figure 1. Methodological Approach

Results

The Time-Based Distribution of Studies

Using bibliometric analysis of the WOS database, this section determined the annual citation and distribution of papers published regarding business vulnerability between 1981 and 2021 (Figure 2). To this end, we analyzed the yielded total studies (TS: 629) and total citation (TC: 9435) records. Figure 2 indicates that the number of business vulnerability researches is growing and the annual citation rate is increasing gradually. Time-based distribution (Figure 2) is divided into three periods: 1) 1981-2004: the number of studies is relatively low, i.e., business vulnerability couldn't attract a great deal of scientific attention; 2) 2013-2005: gradually, more studies have been published during this period; and 3) 2014-2021: the number of published studies has increased significantly, such that it can be argued that business vulnerability has been focused on by a greater number of researchers.

Map of Countries Based on the Number of Citations

USA had the greatest number (N=218) of publications between 1981 and 2021. The UK, claiming the second rank, published 87 papers. Australia, China, Canada, South Korea, Italy, Germany, India, and France ranked third to tenth, respectively. As it is evident, these countries have published more papers in the business vulnerability research (Figure 3).

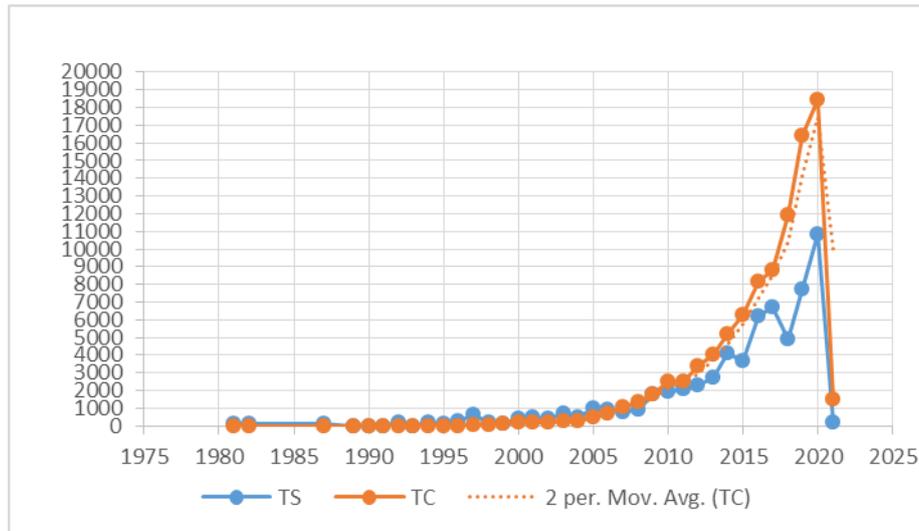


Figure 2. The Time-Based Distribution of Studies



Figure 3. Map of Countries Based on the Number of Citations

The Most Highly Cited Publications

Identifying the most cited publications in the business vulnerability field is a great guide to ranking the writers and a good foundation for deeper analysis. The most cited publications and citation frequencies between 1981 and 2021 are shown in Table 2. Among the most cited publications, Bacon (2005) has the most attention across the vulnerability field. Bacon (2005) has linked the development of international markets of coffee to farmers' living and points out the main factors causing the coffee crisis. Using organic networks and fair trade are two alternatives that provide small producers with appropriate opportunities, making farmers less vulnerable. Manova (2013) discussed how financial vulnerability influences firms' international affairs, and argued that credit constriction and financial market weakness lead to choosing more heterogeneous firms (than domestic producers), turning to local producers (only for export), and export volume. Cruz et al. (2010) is the third study in Table 2. In terms of family-owned firms, they have studied chief executive officer's (CEO) vulnerability. They expressed that smaller family ownership increases a family CEO's risk-bearing and, hence, decreases their willingness to become even more vulnerable to the possibly opportunistic behavior of the top management team (TMT). Details of the most highly cited documents in the last forty years are presented in Table 3.

Table 2. The Most Cited Publications

Rank	Publication	Source	Citation
1	World Development	Bacon (2005)	381
2	Review of Economic Studies	Manova (2013)	290
3	Academy of Management Journal	Cruz et al. (2010)	247
4	Journal of Marketing	Smith & Cooper-Martin (1997)	185
5	Journal of Production Economics	Wagner & Neshat (2010)	181
6	International Journal Of Human Resource Management	Tzafrir (2005)	138
7	Mitigation and Adaptation Strategies for Global Change	Scott et al. (2008)	141
8	Journal of Financial Economics	Raddatz (2006)	140
9	International Journal of Management Reviews	Linnenluecke (2015)	135
10	Disasters	Zhang et al. (2009)	103
11	Journal of International Business Studies	Murray & Coeurderoy (2015)	96
12	Global Environmental Change	Hoffmann et al. (2009)	87
13	IEEE Transactions on Software Engineering	Telang & Wattal (2007)	87
14	Natural Hazards and Earth System Science	Papathoma & Dominey-Howes (2003)	84
15	Natural Hazards	Van Der Veen & Logtmeijer (2005)	79
16	Ecosystems	Marshall et al. (2013)	77
17	Academy of Management Executive	Insinga & Werle (2000)	76
18	American Journal of Sociology	Luders (2006)	74
19	Journal of Banking and Finance	Buyukkarabacak & Valev (2010)	73
20	Management Science	Kannan & Telang (2005)	68

Table 3. Overview of the Highly Cited Papers in Business Vulnerability

Source	Motivation	Theories	Research methods	Analysis
(Bacon, 2005)	This article examined the impact of global coffee market-related factors and coffee prices on farmers' vulnerabilities.	Livelihood vulnerability	Quantitative and Qualitative method	Used Structured closed-ended interview questions and multiple visits, and reviewed the internal documents
(Manova, 2013)	This article indicated that financial frictions have a significant impact on international flows.	The intersection of international trade and finance	Quantitative method	Used model-consistent estimation
(Cruz et al., 2010)	This article indicated that the smaller family ownership increases a family CEO's risk-bearing and hence decreases his or her willingness to become even more vulnerable to the possibly opportunistic behavior of the TMT.	Agency theory	Quantitative method	Data were collected through telephone surveys, archived documents, and three face-to-face interviews; regression analysis was used.
(Smith & Cooper-Martin, 1997)	The paper provides a conceptual framework using both products and target components for targeting strategy, and examines consumer vulnerability.	Consumer vulnerability	Quantitative method	Data were collected through two cases and the review of the literature; statistical hypothesis testing was used
(Wagner & Neshat, 2010)	This article displays a new method for measuring and managing supply chain vulnerabilities about supply chain vulnerability drivers.	Supply chain risk management	Quantitative method	Used a questionnaire form and statistical hypothesis testing
(Graebner, 2009)	This article shows that the imbalance of trust between buyer and seller leads to vulnerability of both.	Theory of trust asymmetries	Quantitative and Qualitative method	Data were collected through semi-structured interviews, telephone calls, e-mails, and archival data. Data analysis was performed through a process model.

Table 3.

Source	Motivation	Theories	Research methods	Analysis
(Raddatz, 2006)	Developing the financial system in sectors that require high liquidity will reduce production fluctuations.	Financial development and growth	Quantitative method	regression structural equations were used
(Tzafir, 2005)	This paper provides a framework for reducing vulnerabilities arising from management trust.	Social exchange theory	Quantitative method	Used a questionnaire form and statistical hypothesis test
(Scott et al., 2008)	This article examines the vulnerabilities of the tourism industry to climate change.	Climate change vulnerability	Qualitative method	Past and future weather data were used and scenarios were written based on them
(Linnenluecke, 2015)	This article uses a systematic approach to identify five currents of research on resilience.	Business resilience	Systematic review	Studied articles related to resilience
(Martin et al., 2017)	Improper management of customer data leads to customer vulnerability and affects the company's performance.	Customer data vulnerability/ Gossip theory	Qualitative method	Used the Stata Module Tetrad
(Zhang et al., 2009)	This article examines the vulnerability of businesses to natural disasters and introduces capital, labor, suppliers, and customers as dimensions of business vulnerability.	Disaster research / Business vulnerability assessment	Systematic review	Studied previous literature on the economic effects of disasters
(Murray & Coeurderoy, 2015)	This study emphasizes that reducing the vulnerability of young companies to allocate intellectual capital is of particular importance in the initial selection of foreign markets.	Theory of institutional, internationalization, and entrepreneurial	Qualitative method	Used a panel survey and rank-ordered logistic regression model
(Hoffmann et al., 2009)	This article proposes the factors of companies' adaptation to climate change and thus examines the vulnerability of companies.	Adaptation theory	Quantitative method	Used econometric analysis

Structures of the Field: A Document Co-Citation Analysis

Business vulnerability co-citations are shown in Figure 4, in which a relatively understandable net can be seen. The minimum number of citations was set to seven; accordingly, 39 papers were identified. Then, they were grouped in three clusters, to which specific colors were assigned. The most cited papers were Zhang et al. (2009), Smit and Wandel (2006), Webb et al. (2000), Webb et al. (2002), and Turner et al. (2003), respectively. An overview of the most cited papers regarding business vulnerability between 1981 and 2021 is presented in Table 4.

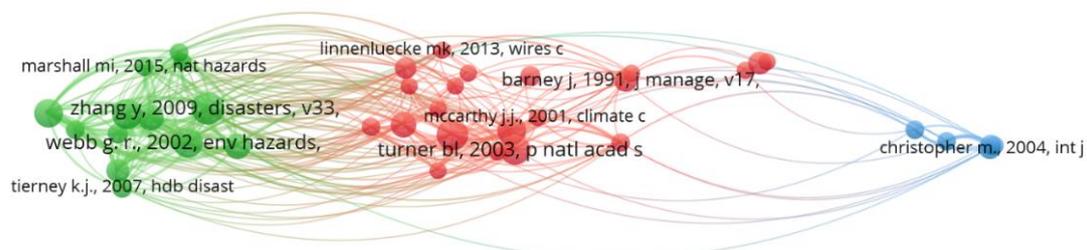
**Figure 4.** Co-citation Analysis

Table 4. Clusters From Cited References

Cluster A: 21 items: Basics and fundamental theories vulnerability					
	TC		TC		TC
Smit & Wandel, 2006	21	Dimaggio & Powell, 1983	9	Füssel & Klein, 2006	7
Turner et al., 2003	19	Adger, 2005	8	Füssel, 2007	7
Adger, 2006	18	Hoiling, 1973	8	La et al., 1998	7
Gallopín, 2006	14	Adger & Kelly, 1999	7	Linnenluecke et al., 2013	7
Barney, 1991	12	Adger, 2000	7	Mayer et al., 1995	7
Jensen & Meckling, 1976	12	Adger et al., 2005	7	McCarthy, 2001	7
Berkhout et al., 2006	10	Blundell & Bond, 1998	7	Strauss, 1998	7
Cluster B: 13 items: Factors affecting vulnerability and business improvement strategies					
Zhang et al., 2009	24	Runyan, 2006	14	Marshall et al., 2015	8
Webb et al., 2000	20	Tierney, 1997	11	Stafford et al., 1999	8
Webb et al., 2002	19	Cutter et al., 2003	9	Danes et al., 2008	7
Dahlhamer & Tierney, 1998	17	Tierney, 2007	9		
Alesch et al., 2001	14	Chang & Falit-Baiamonte, 2002	8		
Cluster C: 5 items: Supply chain vulnerability					
Christopher & Peck, 2004	10	Sheffi, 2005	8	Wagner & Bode, 2006	8
Kleindorfer & Saad, 2005	9	Sheffi, 2005	8		

Cluster 1. Basics and Fundamental Theories Vulnerability

Cluster 1 included 21 papers, which are focused on the basics and fundamental theories of vulnerability. Specifying the dimensions of vulnerability, researchers in this cluster proposed a conceptual framework for vulnerability assessment. The researchers identified the dimensions of the vulnerability in exposure, sensitivity, and adaptive capacity. They agreed that there was an internal connection between these dimensions. Some related articles were discussed in Table 5.

Cluster 2. Factors Influencing Vulnerability and Business Improvement Strategies

Cluster 2 included 30 papers focused on business vulnerability and business improvement strategies. Researchers in this cluster introduced the characteristics of business and the factors that make them vulnerable to crises. Researchers also described what small businesses can do to improve and recover in times of crisis. In this cluster, authors focused more on small businesses and businesses exposed to natural disasters such as floods and earthquakes. Table 5 shows the results of some articles in this cluster.

Cluster 3. Supply Chain Vulnerability

Cluster 3 includes five papers. They are about the vulnerability concept and factors contributing to supply chain vulnerability. Due to the high vulnerability of today's supply chains to disruption, measuring and managing supply chain vulnerabilities has become very important. Now, more than ever, supply chain managers must manage supply chain risk and vulnerability to prevent costly disruptions and their negative consequences. Researchers have studied supply chain vulnerabilities in different ways. Including supply chain vulnerabilities as a conceptual, analytical, or normative recommendation on how to manage supply chain vulnerabilities (Wagner & Neshat, 2012). In Table 5, the articles are discussed and the authors' opinions are reviewed.

Table 5. Overview of Clusters

Cluster 1. Basics and fundamental theories vulnerability	
Smit & Wandel, 2006	Authors presented a conceptual framework for assessing vulnerability and argued that there is an eternal interaction among exposure, sensitivity, and adaptive capacity. Stressing on the evaluation of participatory vulnerability, they believed this approach makes it possible to identify factors other than climate, political, economic, institutional, and technological streams.
Turner et al., 2003	Authors proposed the following as the elements of the vulnerability evaluation framework: disturbances and stressors, being exposed to danger, the sensitivity of the coupled system to exposure, system resilience, system recovery after receiving a response, nested scales, hazard scales' dynamics, coupled systems, and their responses.
Adger, 2006	The author reviewed the analytical frameworks of vulnerability change and enumerated vulnerability approaches: 1) vulnerability to famine and food insecurity, 2) vulnerability to threats, 3) human ecology, 4) stress –vulnerability reduction model, 5) vulnerability to climate change and diversion, 6) sustainable livelihood and vulnerability to poverty, 7) vulnerability of the social-environmental system.
Gallopín, 2006	To environmental-social systems, the author surveyed vulnerability terminology, including sensitivity, response capacity, exposure, adaptation capacity, and resilience. The author did not consider vulnerability as an absolute negative characteristic and argued that one can view a change positively only if it leads to positive development.
Füssel & Klein, 2006	To evaluate vulnerability, authors introduced alleviated vulnerability along with adaptive capacity, and introduced adaptation and alleviation approaches to vulnerability reduction.
Cluster 2. Factors influencing vulnerability and business improvement strategies	
Zhang et al., 2009	Authors divided business vulnerability dimensions into four groups: 1) capital, 2) labor, 3) supplier, and 4) customer.
Webb et al., 2000	According to authors, small businesses and fewer resources make the business unprepared for the disasters.
Webb et al., 2002	Authors showed that the long-term recovery of businesses depends on many factors, including the industrial section, history, financial situation, market area, physical injury, obliged closure, work disruption, and owner's understanding of the vast economic space.
Dahlhamer & Tierney, 1998	Authors mentioned business characteristics, disaster's direct and indirect impacts, external assistance, and experience as the predictors of business recovery.
Runyan, 2006	The author argued that small businesses suffering from the following problems are considered vulnerable: lacking planning, cash flow scarcity, financial crises unmet, having problems in receiving federal help, and infrastructure crisis.
Marshall et al., 2015	Authors showed that firms controlled by females, minorities, and veterans are extra vulnerable to disasters. Older and more experienced businesses, larger firms with more employees, businesses that have faced a greater number of crises, and service businesses are better than other firms in terms of failure risk.
Cluster 3. Supply chain vulnerability	
Christopher & Peck (2004)	Authors pointed out three categories of risks related to supply chain vulnerabilities, which are: 1) internal risks of the company, 2) risks related to supply and demand, and 3) environmental risks. In addition, authors introduced the following four dimensions as the main pillars of supply chain resilience: 1) supply chain (re) engineering, 2) supply chain collaboration, 3) agility, and 4) creating a supply chain risk management culture.
Sheffi, 2005	The author framed firms' disruption and dynamics in eight steps: 1) preparation, 2) destructive event, 3) primary response, 4) primary impact, 5) full impact, 6) recovery-related preparation, 7) recovery, and 8) long-term effect.
Kleindorfer & Saad, 2005	Authors pointed to operational risks, natural-disaster-caused risks, terrorism, and political instability, which contribute to disrupting normal supply chain operations.
Wagner & Bode, 2006	Authors considered demand risk, supply risk, and disastrous risk as the main risks threatening the supply chain. According to authors, customer dependence, supplier dependence, supplier concentration, single sourcing, and global sourcing are the main characteristics of supply chain driving and intensifying supply chain vulnerability.

Co-occurrence Keyword Analysis

According to Waltman et al. (2009), network visualization is an effective and novel method for the visual representation of bibliometric analysis, since it enables researchers to recognize and interpret research boundaries. Keywords are words or terms which reflect the publication's content (Xiang et al., 2017). To pinpoint research points of vulnerability, keywords co-occurrence was examined using VOSviewer. The co-occurrence threshold was set at five, and 126 cases were visualized (Figure 5). In Figure 5, the occurrence of keywords is shown by a circle. The bigger the circle, the more the keywords are used in business

Cluster 2. Risk Assessment

Given the following identified keywords, the second cluster was named “risk assessment”: risk, risk management, prediction, prevention, vulnerability analysis, risk analysis, risk assessment. Liu et al. (2011) described the relationship between risk, hazard, and vulnerability as $R = HV$, where **R** refers to risk, **H** to hazard, and **V** to vulnerability. This means that risk is a function of hazard and vulnerability. Thus, one can claim that risk literature pays attention to vulnerability, too.

Cluster 3. Small Business Vulnerability

The third cluster was named “small business vulnerability” given the identified keywords: vulnerability, resilience, adaptive capacity, recovery, survival, small business, earthquake, natural disasters, and natural hazards. This cluster included threats and disasters as the vulnerability factors. The resilience approach and adaptive capacity for vulnerability reduction and business improvement have been studied in this cluster.

Cluster 4. Sources of Sustainability in Business

The following words were seen in the fourth cluster: business, innovation, sustainability, perspective, corporate social responsibility, absorptive-capacity, technology, companies, resource-based view, entrepreneurship, competitive advantage, sustainable development, enterprises, microfinance, opportunities. Thus, the cluster was named “sources of sustainability in business.”

Cluster 5. Adaptation Policy Assessment

The fifth cluster was named “adaptation policy assessment” because of the existence of the following words in this cluster: adaptation, management, perceptions, policy, mitigation, vulnerability assessment, migration, adaptive capacity, social vulnerability, mitigative capacity. Adaptation was recognized as one of the main approaches to vulnerability reduction.

Table 7. Core Topic Recognized

Clusters	Keywords	Topic
Cluster 1 47 items Red color	performance, strategies, market, growth, productivity, firm, industry, investment, trade, behavior, knowledge, financial performance, information, corporate governance, emerging markets, quality, ownership, costs, dynamics, size, credit, organizations, firm performance, decision-making, diversification, financial vulnerability, fraud, social-responsibility, shocks, corruption, trust, consumer vulnerability, competition, disclosure, failure, big data, power, commitment, constraints, debt, globalization, volatility, ownership structure, social media, evolution, privatization, monetary-policy	Business performance
Cluster 2 24 items Green color	impact, risk, systems, risk management, crisis, security, demand, networks, prediction, game theory, health, integration, supply chain management, cybersecurity, communication, information security, vulnerability analysis, attacks, prevention, risk analysis, risk assessment, internet, women, business process	Risk assessment
Cluster 3 19 items Blue color	vulnerability, resilience, adaptive capacity, recovery, survival, small business, earthquake, natural disasters, flood, disaster, community, gender, culture, work, exposure, employment, tsunami, disaster recovery, scale	Small business vulnerability
Cluster 4 18 items Yellow color	governance, business, innovation, sustainability, perspective, corporate social responsibility, absorptive-capacity, challenges, technology, companies, resource-based view, entrepreneurship, competitive advantage, sustainable development enterprises, microfinance, opportunities, responsibility	Sources of sustainability in business
Cluster 5 16 items Purple color	adaptation, climate change, management, perceptions, policy, tourism, future, mitigation, weather, agriculture, variability, insurance, vulnerability assessment, migration, capacity, social vulnerability, adaptive capacity, mitigative capacity	Adaptation policy assessment

4.6. Thematic Visualization

To reflect the development pathway and current situation of all clusters and to review literature evaluation, the timeline visualization of the co-citation network was developed (Figure 6). The clusters are shown in the horizontal timeline of the timeline view in CiteSpace. According to the publication date, clusters are represented from left to right.

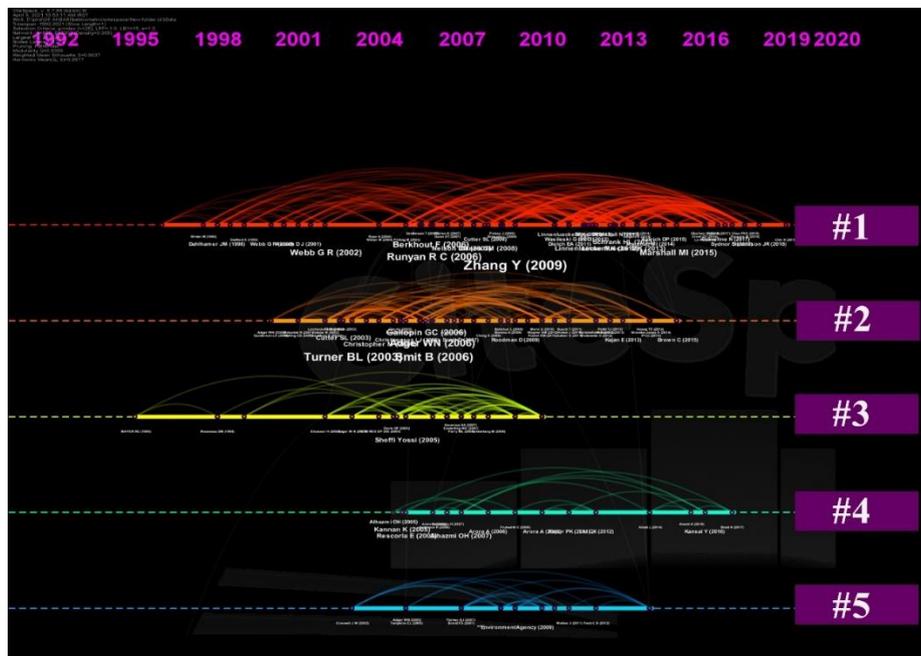


Figure 6. The Timeline Visualization of the Co-Citation Network

Cluster 1

This cluster covers papers published between 1996 and 2019 and includes 83 sources. In this cluster, the similarity index was 0.934, i.e., the cluster is highly robust. Cluster's core themes are turning points of business sustainability and recovery. The following concepts were distinguished in this cluster: small business survival, business disaster recovery, small business vulnerability, community business, firm survival, management strategies, resilience, vulnerability, recovery, and adaptive capacity. Pertaining to this topic is the findings of Lo et al. (2019a) who concluded that the greater the social capital is, the more the measures will be taken for the sake of adaptability. In addition, Lo et al. (2019b) identified factors contributing to business vulnerability and claimed that focusing on the following concepts through crises will make business recovery swifter and easier: capital dynamics, business size, capital ownership, capital intensity, easiness of employee replacement, dependence on critical infrastructure, inter-business dependence, and market diversification. Li et al. (2019) indicated that the following factors have significantly influenced the sustainable performance of a firm after the earthquake: financial conditions before the disaster, average post-disaster every month earnings, obtaining money from entourage, the gender of business owners, and government funding.

Cluster 2

This cluster covers the period between 2000 and 2015. In sum, 65 sources were identified in this fifteen-year cluster. The similarity index of this cluster was 0.971, i.e., the cluster is highly

robust. Cluster's core themes are turning points of factors contributing to vulnerability reduction. The following concepts were distinguished in this cluster: assessing the vulnerability, risk assessment, vulnerability; climate change, vulnerability mitigation strategies, effects, measuring, disaster, threat, vulnerability management, economic sectors, and mitigation strategy. For example, Hyman (2014) has reviewed vulnerability dimensions to reduce coastal tourism vulnerability, including exposure, sensitivity, and adaptation capacity. Kurniawan et al. (2017) argued that alleviating vulnerability factors promotes supply chain productivity. They cited supply chain vulnerability drivers as global resources, lean management, and high dependence on suppliers and customers. Their research, supply chain perspective, supply chain flexibility, and supplier development were considered vulnerability reduction strategies with a positive effect on supply chain efficiency. Considering sensitivity, Willroth et al. (2012) have indicated vulnerability reduction factors. They have pointed to social media, income diversity, education, and income in terms of sensitivity. They believed that enhancing sensitivity would increase adaptability and decrease vulnerability.

Cluster 3

This cluster covers the 1995-2010 period. Fifteen sources are identified in this fifteen-year cluster. This cluster was robust enough too, given its similarity index of 0.991. Cluster's core themes are turning points of adaptability. The following terms were more prominent in this cluster: climate change, firm strategy, adaptation, adaptive response, vulnerability, adaptation strategies, environmental policy, uncertainty, and firm relocation.

Cluster 4

This cluster covers the 2005-2017 span. Sixteen sources are identified in this twelve-year cluster. In this cluster, the similarity index was 0.997, so it was highly robust. Cluster's core themes are turning points of assessment of software vulnerability. The following terms highlighted the cluster's more prominent approach: empirical analysis, vulnerability disclosure, evaluation, software vulnerabilities, modeling software patch management, selection, vulnerabilities, cybersecurity, information systems, security, and risks.

Cluster 5

This cluster begins in 2003 and concludes by 2017. Fourteen sources were in this eleven-year cluster. The similarity index of this cluster was 0.991, i.e., it was highly robust. Cluster's core themes are turning points of factors contributing to the social ecology system. The following terms highlighted cluster's more prominent approach: resilience, flood event, flood impacts, small businesses, social-ecological resilience, disasters, vulnerability, shock, capacity to cope, maladaptive resilience, impacts, social-ecological system, and re-conceptualizing societal-environment interaction.

5. Discussion and Conclusion

A small action in the right direction and at the right time before the disaster will play an important role by saving countless lives and assets. It should also be noted that disasters, as they can be a negative threat, can in some cases lead to positive results for a particular system (Rus et al., 2018). A novel framework was developed based on the most prominent papers

identified in co-citation and the highly cited papers. The proposed model has consisted of three sections: drivers, vulnerability appearance, and vulnerability reduction (Figure 7).

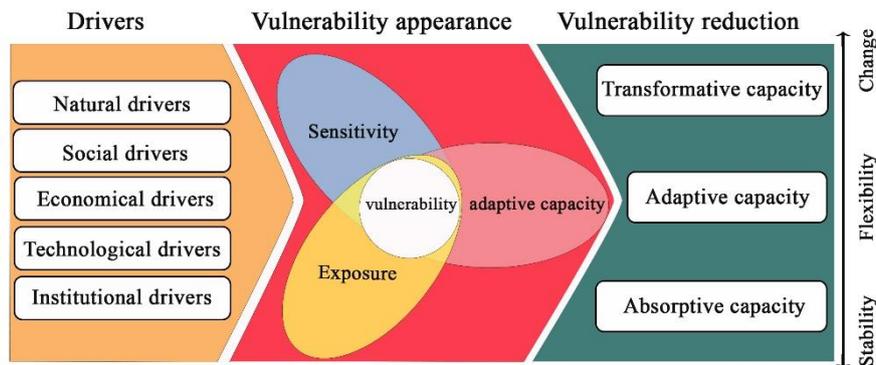


Figure 7. Conceptual Framework

Drivers

Many diverse factors, including natural and unnatural threats, make trade vulnerable. Climate change, technologies, and other social and demographic processes make human and social systems always exposed to surprises and sensitive to unpredicted consequences. These factors were drivers in this research. The drivers are divided into several groups:

- Natural drivers (Füssel, 2007; Gallopín, 2006; Smit & Wandel, 2006), including climate change, earthquake, volcano, flood, tsunami, drought, global epidemics, and COVID-19
- Social drivers (Füssel, 2007; Greiving et al., 2006),
- Technological drivers (Dalziell, 2005; Robertson et al., 2020; Rossignol et al., 2015)
- Economical drivers
- Institutional drivers (Adger, 2006; Birkmann, 2005).

Vulnerability Appearance

Literature review showed that most researchers consider the following as the main factors of vulnerability. First, exposure to threat and hazard, i.e., the nature and scale of environmental evolutions to which the system is exposed (Dabson et al., 2012; Füssel & Klein, 2006; Gallopín, 2006; Turner et al., 2003). A system is invulnerable only if it is exposed to no disruption (Smit & Wandel, 2006). Second, sensitivity to threat, i.e., the level of preparedness (Dabson et al., 2012) or the extent to which a system is affected /modified by inside or outside disruption or because of a combination of disruptions, and can be an overall transformation of the system in terms of disruption variance. Sensitivity is an intrinsic characteristic and is independent of response and exposure. Sensitivity exists before the occurrence of disruption (Gallopín, 2006). The third factor is adaptive capacity. Adaptive capacity plays a vital role in determining the ultimate vulnerability since it determines the final effects greatly (Moreno & Becken, 2009). Adaptation capacity indicates the capacity of the system to adapt to change and to respond to disturbances (Dabson et al., 2012; Gallopín, 2006; Liu et al., 2011). Füssel and Klein, (2006) define adaptation capacity as the capability of a system to adjust to changes and possible losses, modify the system's features and activities, adapt to external changes, take opportunities, and deal with consequences.

Vulnerability and its determinants are changing and evolving. Exposure and sensitivity are inseparable dimensions of any system and depend on the system features and characteristics

of the drivers. Generally, the more the system is exposed to drivers and threats, the more vulnerable it will be. On the contrary, the more adaptable the system, the less the system vulnerability (Smit & Wandel, 2006).

Vulnerability Reduction

Four strategies can be considered for vulnerability reduction, according to the vulnerability domain (Sheffi, 2005) and literature review (Béné et al., 2012).

Situation 1. The probability of event occurrence is low, and consequences are negligible, so the business is least vulnerable. “Business as usual” is the best strategy for such a business (Figure 8, situation 1).

Situation 2. Using absorptive capacity, i.e., the capability to absorb the effects of events using pre-defined coping responses, is the second strategy (Cutter et al., 2008). Turner et al. (2003) identify coping response, as an element of resilience that reduces vulnerability, as a good option for responding to disasters. According to Ghedini and Ribeiro (2009), businesses choosing coping response strategy employ current resources to adapt to and manage unfavorable conditions or prepare for a prominent event. Thus, absorption capacity can be considered as the capacity to take deliberate protective measures and deal with known shocks and stressors. It is the capacity to “go back” after the shock. It includes prediction, planning, dealing with shocks, and recovery from short-term stressors. It means ensuring stability, since its main objective is limiting shocks’ negative impact on individuals, households, societies, businesses, and authorities (Oxfam, 2017). This strategy is appropriate for situation 2 because the probability of occurrence is high and the event is almost comprehensively known (Figure 8, situation 2).

Situation 3. In this situation, occurrence probability is low, consequences are significant, and business is vulnerable moderately. The adaptive capacity is seemingly the good option. Adaptive capacity is the capacity to take deliberate incremental regulations to respond to predicted or actual changes/developments, leading to greater future flexibility. It does not modify operations or structural identities significantly. There are different incremental regulations (e.g., new methods, method change, diversity, engagement with new social media, etc.) (Béné et al., 2012). Accepting change as ongoing and highly unpredictable is among the main characteristics of adaptive capacity. Thus, adaptive capacity means flexibility and the capability to bring ongoing incremental changes through ongoing regulation, learning, and innovation (Oxfam, 2017). The adaptive capacity facilitates system reorganization, development, and learning against threats (Tierney, 2007). The adaptive capacity is proportional to special situations and differs from system to system (Smit & Wandel, 2006) (Figure 8, situation 3).

Situation 4. In situation 4, the probability of event occurrence is high, while business is vulnerable and needs fundamental change. According to Béné et al. (2012), if the required change is so deep that the adaptability capacity is decreased, incremental change cannot be a good option, and change is critical. The transformative approach changes system’s main structure and operations (e.g., changing orientation: agriculture to the economy). The transformative approach can be a planned process, started by involved parties, or maybe imposed because of social, environmental, or economic conditions. Measures include new technological practices, institutional advances, cultural and behavioral developments, any measure which challenges the status quo, current values, and beliefs. Transformative capacity is distinguished by positive significant changes or society’s measures in terms of reducing future risk and vulnerability (Hasan & Kadir, 2020) (Figure 8, situation 4).

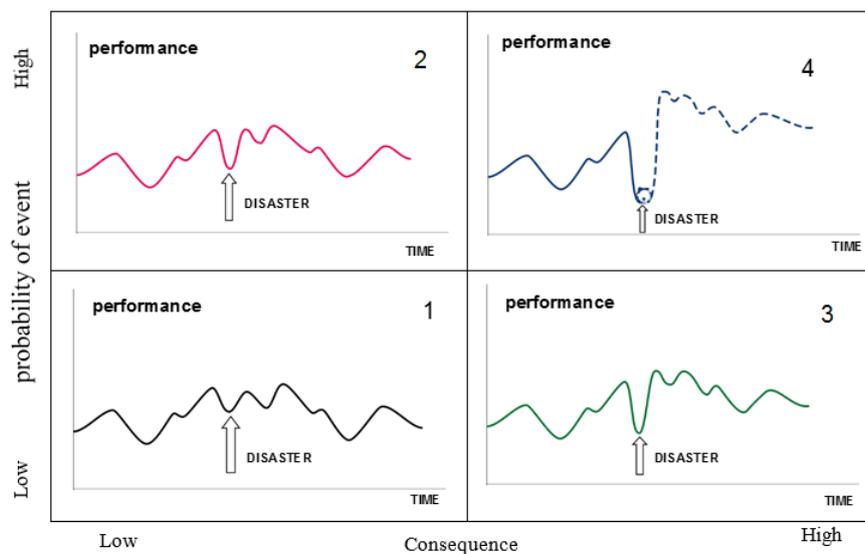


Figure 8. Strategy for Vulnerability Reduction

As we move along the absorption-adaptation-transformation continuum, transaction costs and related hazards increase. The main point is “the greater the change, the higher the transaction cost.” System change is more costly compared to maintaining the status quo or rebuilding it (Béné et al., 2012). As we know, societies with absorption capacity are adaptive and transformative. They also respond to disasters more effectively and have a higher capacity and chance to recover. Thus any system which has higher capacity in all dimensions is intrinsically more robust compared to systems with one capacity or without any capacity (Hasan & Kadir, 2020).

Implications

Although the importance and interest in technological entrepreneurship are increasing and technology-oriented companies have attracted a lot of attention, its research-oriented knowledge is still limited (Bailetti et al., 2012). These businesses are always looking for survival through innovation (Velucchi & Viviani, 2007) and technological entrepreneurial capabilities (Hejazi & Seifollahi, 2019).

Disasters can have a significant impact on all types of businesses, so governmental and non-governmental organizations need to be more supportive of these businesses (Asgary et al., 2012). This study helps reduce the adverse effects of disasters by understanding and identifying the main causes of business vulnerability (Venkateswaran et al., 2014) and helps provide policies for business survival and growth (Davlasheridze & Geylani, 2017). Disaster-related studies contribute to policymakers in local and national planning to increase business resilience, reduce risks in critical situations, and provide workable insights (Skouloudis et al., 2020). Creating a conceptual framework that considers the vulnerability of technology-driven businesses is essential to identify policymakers in identifying key components of vulnerability (Kamalipoor et al., 2022). Therefore, this study helps policymakers, experts, and researchers working in vulnerability reduction sectors.

Business continuity planning is another key measure to help businesses reduce the negative effects of disasters (Venkateswaran et al., 2014). This study also helps managers to measure the likelihood of events and their consequences and have a better understanding of the concept of business vulnerability to disasters. Then, based on this, they can develop and implement four types of strategies to reduce vulnerability so they are better prepared when

dealing with disasters. As a final achievement, this study can be used in any field of natural disasters at the business level.

Limitations and Directions for Future Research

This study, like other studies, has some limitations. The number of samples was one limitation. The search step found only 629 papers in the WOS database because there are few studies on the vulnerability of technology-based businesses. Using a combination of keywords to extract articles from WOS was the second limitation. Using different keywords may change the number and nature of the retrieved papers. Though the WOS database is the most extensive applied database for bibliometric research, it does not cover some publications. This was the third limitation. The search only has reviewed published papers up to 19 Feb 2021, and later papers are not included; this was another limitation.

Future studies may search other databases for other works, including books, notes, book chapters, and conference papers, to gain new insights. Later studies can consider the implications of business vulnerabilities in other languages and discover new issues. Future researchers might use other valid and comprehensive databases like Scopus and compare their results against the results we obtained. To understand this issue more thoroughly, future researchers may employ various imaging software. Their findings may provide additional and interesting information regarding developing business vulnerabilities. Past vulnerability studies have extensively used questionnaires and semi-structured interviews. To identify the vulnerability of technology-based businesses and obtain more comprehensive results, it is better to use both quantitative and qualitative methods. Moreover the system dynamics approach might be considered by researchers.

Future researchers are encouraged to examine the components and indicators of the vulnerability of technology-based businesses in three dimensions: exposure, sensitivity, and adaptive capacity. In addition, identifying the actions of technology entrepreneurs in the dimensions of absorptive capacity, adaptive capacity, and transformative capacity can be a research topic for the future. Given the prevalence of COVID-19 and its effects on businesses, researchers are advised to examine the vulnerability of technology-based businesses in the light of the COVID-19 crisis. Researchers can identify the vulnerabilities of technology-based businesses in their life cycle stages and suggest strategies to reduce vulnerabilities at each stage. Future research could focus on identifying innovative and technological capabilities and examining how these capabilities affect reducing the vulnerability of technology-based businesses.

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