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The vulnerability of Technology-based Business during COVID-19: An indicator-based Conceptual Framework

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1 **The vulnerability of Technology-based Business during COVID-19: An indicator-**
2 **based Conceptual Framework**

3
4 **Abstract**

5 **Purpose**

6 COVID-19 has affected most business activities, including technology-based business.
7 The higher the business vulnerability rating, the greater the impacts. After identifying
8 three dimensions of vulnerability (exposure, business sensitivity, and response capacity),
9 this research determined the potential components and indicators of the vulnerability of
10 technology-based businesses.

11 **Design/methodology/approach**

12 *Using the indicator approach*, a comprehensive vulnerability model was developed
13 for assessing the vulnerability of the technology-based business against COVID-19.

14 **Findings**

15 In this study, COVID-19, as a biological threat and an exogenous shock, was
16 considered the exposure dimension. Business characteristics, job characteristics, business
17 owner-manager demographics, product, and supplier characteristics were identified as the
18 sensitivity dimension, while resources, human capital, technological capitals, social
19 capitals, institutional capitals, infrastructures, management capacity, and supply chain
20 capabilities were defined as the adaptive business capability or response capacity. To
21 determine vulnerability and response capacity against exogenous shocks and a pandemic
22 crisis, our framework can act as a useful checklist for managers and owners of
23 technology-based businesses.

24 **Originality/value**

25 Research on the COVID-19, especially in the technology-based business, is still at the
26 emergent stage. This study is a pioneering effort to review the literature on business
27 vulnerability and provide a framework to reduce business vulnerability using the
28 indicator-based approach.

29
30 **Keywords:** Business Vulnerability; Exposure, Business Sensitivity; Business Response
31 Capacity; Indicator-Based Approach

1. Introduction

Detecting business vulnerabilities is one of the main pillars of strategy and public policy (Cowan & Wright, 2016). Business's vulnerability to crises and disasters, as a growing field, has been concentrated on by researchers and academics, both from theoretical and experimental points of view (Song et al., 2016). Such interest was largely driven by escalating business vulnerabilities; both external, such as legislative and environmental vulnerabilities, and internal, such as financial and internal business-process vulnerabilities (Eltantawy, 2016). Crises and disasters may heavily affect businesses' various aspects, including direct physical impact, human impact, interruption to lifeline services, delays and increased costs for repairs, reduced delivery performance from suppliers, and potential changes in customer purchasing behavior (Dalziell, 2005).

COVID-19 is unique and unprecedented considering its three simultaneous factors: 1) widespread infection 2) mortality high rate, and 3) lacking cure (Krishnamurthy, 2020). Most countries could restrict this pandemic by limiting human activities, which affected economic affairs negatively (Sharma et al., 2020). Researchers and economists agree that COVID-19 has affected all economies heavily, resulted in recession, and has decreased inter-country product, investment, human interaction, and temporary lockdown (Barua, 2020).

COVID-19 is the "Black Swan" that makes businesses vulnerable to unnatural external forces (He & Harris, 2020). The frequency and intensity of recent events have made studying disasters a necessity, in particular for risk mitigation and rapid recovery of businesses (Morrish & Jones, 2020). To accomplish their mission, owner-managers are forced to regularly assess their business vulnerabilities to potential threats and risks, particularly those who work against vision and object accomplish, and thus make themselves ready for adaptation to external and internal environments using the best possible strategies. According to Angeon & Bates (2015), the factors that increase vulnerability during adverse shocks hamper long-term development.

Up to now, 19,265,000 persons are infected with COVID-19, and 885,000 persons have passed the way (Worldometers, 2020). According to the International labor organization (ILO) forecast, 195M person will lose their jobs because of COVID-19 by the 2020 2nd quarter (ILO, 2020). By April 23, 26.5M worker lost their jobs in the US (Lambert, 2020). Also, according to Global Data, COVID-19, in 2020, will affect the

1 high-tech sector more than any other sector. In terms of a 17-section report, Global Data
2 have indicated the short- and long-term impacts of COVID-19. One section is devoted to
3 technology, media and communication, and leading companies. The report claims that
4 these sections will be affected negatively, among which the Information Technology (IT)
5 sector will face the darkest long-term horizon (Global Data, 2020). To save their business
6 against COVID-19, most companies have relied on technology. Meanwhile, its effect on
7 technology-based businesses is delicate since while technology is a widespread sector,
8 the technology-based business isn't affected similarly (Schaefer et al., 2020). While
9 technological entrepreneurship is gaining momentum and technology-based businesses
10 are getting more attention, research-oriented knowledge is still limited (Bailetti et al.,
11 2012). Considering that technology-based entrepreneurship is still an infant, thus many
12 corners of which aren't discovered (Peng & Zhang, 2008). Given that in many countries,
13 technological businesses play a major role in economic growth and are encouraged as a
14 competitive advantage and job creation (O'Regan & Sims, 2008), their sustainability and
15 continuity are important. The business should be sustainable in the face of internal and
16 external perturbations and vulnerabilities. Through learning from past experiences of the
17 affected businesses, one can mitigate business vulnerability against future events and
18 disasters, decrease shutdown frequencies, and improve sustainability (Sydnor et al.,
19 2017).

20 Although vulnerability has been discussed extensively from various spatial-temporal
21 dimensions, there is no universally accepted model or theory (Jamshed et al., 2017).
22 While more researchers are interested in vulnerability assessment methods, they should
23 be modified and integrated into policies (Rana & Routary, 2018). On the other hand,
24 vulnerability is considered an integral element of crises and disasters (Birkmann et al.,
25 2013). The disaster-related literature has disproportionately focused on the vulnerabilities
26 of national and regional analysis units, and the vulnerability of micro-business units has
27 been less focused on (Zhang et al, 2009). Although the vulnerability concept has been
28 embedded in scientific discussions recently, it lacks an accurate clear definition (Lo et al.,
29 2019). Businesses' inadaptability indicates that they are heavily vulnerable to disasters
30 (Davlasheridze & Geylani, 2017). How to define business vulnerability to threats is an
31 open question calling for answers (Song et al., 2016).

1 Reviewing academic and scientific publications with higher impact factors, it was
2 concluded that vulnerability is an ancient issue, mostly considered by social and natural
3 sciences, while has been embodied to a lesser extent in management, entrepreneurship,
4 and, in particular, tech-based business fields. Also, rare business vulnerability research
5 has focused mainly on climate change and other factors affecting vulnerability. Therefore,
6 to reduce these gaps and due to the COVID-19 epidemic virus, our research seeks to find
7 a framework for the vulnerability of technology-based businesses during COVID-19.
8 Creating a conceptual framework that considers the vulnerability of technology-driven
9 businesses with diverse and complex links is essential to identify policymakers in
10 identifying key components of vulnerability.

11 This research's first and foremost contribution is designing a model for reducing tech-
12 based businesses' vulnerability, contributing to business survival and sustainability. The
13 proposed framework provides the policymakers and decision-makers with priceless
14 recommendations regarding vulnerability reduction. Vulnerability assessment is a critical
15 component of disaster risk reduction and sustainability field (Zhou et al., 2015).
16 Therefore, this research contributes to sustainability and disaster literature. Given that
17 vulnerability reduction alleviates potential disturbance and promotes resilience (Sheffi,
18 2005), thus business vulnerability research is linked to resilience literature, which is
19 another contribution of this research. Research objectives are: 1) defining vulnerability
20 and identifying its main dimensions. 2) identifying components related to the
21 vulnerability of tech-based businesses, 3) tech-based business actions to reduce
22 vulnerability, and 4) proposing a conceptual framework for tech-based business
23 vulnerability.

24 This research begins its work with a vulnerability literature review. Section 2
25 contributes to the comprehension of the business vulnerability concept and identifies its
26 dimensions. The research methodology is explained in section 3. Reviewing Literature
27 and covering vulnerability-related issues across previous crises and disasters, an indicator
28 approach is employed. Section 4 identifies various components affecting vulnerability's
29 three dimensions: exposure, sensitivity, and adaptive capacity. Section 5 outlines
30 technological entrepreneurial action to reduce vulnerabilities. A conceptual framework is
31 proposed in section 6, based on results obtained in sections 4 and 5. Section 7 presents

1 the readers with theoretical and practical implications. Undoubtedly, the contributions of
2 this research will pave the way for future research.

3 4 **2. Literature review of vulnerability**

5 Vulnerability is a concept used in many fields, from economics to psychology,
6 anthropology, and engineering (W. Neil Adger, 2006). The initial tries appeared in risk
7 and disaster management; they were concentrated on engineered structures' physical
8 resistance, while current works considered vulnerability with characteristics of social and
9 environmental processes (Cardona et al., 2012). The "vulnerability" construct indicates
10 to what extent an organization may be impacted by an event and is defined as how much
11 a natural, economic, or social system is fragile against natural and technological threats
12 (Dalziell, 2005). Vulnerability cannot be regarded independently from hazards. Thus
13 vulnerability is seen as a relative and specific term that always implies vulnerability to a
14 particular hazard (Greiving et al., 2006). Also, Cuevas (2011) defined vulnerability as the
15 extent to which a system is harmed in response to a stimulus. Gallopín (2006) said that
16 vulnerability means a system's tendency to be affected by harm or potential change or
17 transformation. Many researchers (Turner et al., 2003; Lo et al., 2019; Aleksić et al.,
18 2014; Adger, 2006; Polsky et al., 2007; Smit & Wandel, 2006) consider vulnerability as
19 a tri-dimension system: **exposure**: to what extent or degree to which systems are exposed
20 to hazard and perturbation, **sensitivity**: to what extent or degree to which a system is
21 affected or modified, and **adaptive capacity**: systems capability to adapt to changes and
22 response perturbation.¹

23 Yan and Zhou (2010) defined vulnerability as a business weakness in quantitative and
24 qualitative aspects or lacking sufficient capabilities to stand any intervention and
25 uncertainty. Perhaps business vulnerability results from the negative impacts, which may
26 affect business responsiveness and its ability to overcome potential barriers (Andrade et
27 al., 2012). The vulnerability construct is defined as a condition that affects a firm's goal
28 accomplishment dependent upon negative consequences of disturbance (Svensson, 2004).
29 Zhang et al., (2009) presented business vulnerability in four dimensions: labor, supplier,
30 capital, and customer. Also, to define business vulnerability to natural disasters, Song et
31 al., (2016) considered geographical location, economic situation, and critical

1 -Based on this definition, we worked on our article.

1 demographic characteristics in terms of tolerating natural disasters. They divided them
2 into four groups: business capital, labor, critical suppliers, and physical location.

3 The existence of potentially vulnerable points makes the business vulnerable to
4 internal and external threats (Nyanchama, 2005). COVID-19 outbreak, as a global crisis
5 that has affected the globe socially and economically (Giones et al., 2020) has affected
6 technology-based businesses, exploiting their weak points. Dark forecasts, which predict
7 the higher frequency of and more intense natural disasters, focus on local economic
8 activities because small businesses are vulnerable to such events and affect all over the
9 country, given small businesses' role in job creation (Davlasheridze & Geylani, 2017).

11 **3. Methodology**

12 According to the literature review, to analyze business vulnerability, various metrics
13 were used. To make theoretical concepts operational in the context of vulnerability
14 assessment, three approaches are used for highly diverse systems, as well as spatial and
15 temporal measures: 1) participatory; 2) simulation-model-based; and 3) indicator-based
16 approaches (Nguyen et al., 2016). We used an indicator-based approach in this research.

17 Indicator-based methodologies are increasingly used in research and studies while
18 being used to support decision-making in terms of disaster risk mitigation (Papathoma-
19 köhle et al., 2019). The indicator approach is useful for monitoring trends and identifying
20 conceptual frameworks (Gbetibouo & Ringler, 2009). It is adopted to create more useful
21 knowledge of the socio-economic and biophysical factors affecting vulnerability (Hebb
22 & Mortsch, 2007).

24 **3.1. Application of the methodology**

25 *3.1.1. Reviewing hazards threatening technological businesses*

26 At this stage, by reviewing the existing literature on crises and disasters that have
27 occurred, and the literature on vulnerabilities, one can be aware, to some extent, of the
28 factors that lead to the vulnerability of technology businesses. In this regard, articles
29 related to business vulnerability, improving businesses in times of crisis, as well as
30 articles related to the COVID-19 crisis in the WoS, Scopus, and Google Scholar databases
31 were studied. The criterion for selecting articles was thematic relevance to the present
32 study.

3.1.2. Identifying and classifying vulnerability indicators

By studying the existing literature, indicators of business vulnerability were identified. Then, the indicators were classified into three dimensions of vulnerability (exposure, sensitivity, adaptive capacity) using experts' opinions.

3.1.3. Weighting to indicators

In the indicator approach, there are two options for weighing indicators. The first option assumes that all vulnerability indicators are of equal importance and therefore gives them equal weights. In the second option, different weights are considered for the indicators. In line with the second option, many methodological approaches have been proposed to compensate for the weight differences of the indicators. Some of these approaches include expert judgment, correlation with previous catastrophic events, and fuzzy logic (Deressa et al., 2008). Given that this study identifies the components of vulnerability and not their ranking, we considered the same weights for the indicators in this study.

3.1.4. Presenting a proposed model

Finally, by reviewing the existing vulnerability models as well as the indicators identified in the vulnerability literature, a proposed framework was presented.

Insert Fig 1 here

4. Results: Vulnerability Dimensions

According to the literature review, the exposure dimension is caused by environmental-ecological driving forces (Gallopín, 2006; Smit & Wandel, 2006; Greiving et al., 2006; Polsky et al., 2007; Rossignol et al., 2015; Füssel, 2007), social driving forces (Smit & Wandel, 2006; Greiving et al., 2006; Polsky et al., 2007; Füssel, 2007), economical driving forces (Greiving et al., 2006; Füssel, 2007), technological driving forces (Dalziell, 2005; Rossignol et al., 2015, Robertson et al., 2020; Merino, 2016), biological natural driving forces (Dzigbede et al., 2020). COVID-19, in this research, was described as a natural biological threat, and an exogenous shock and other dimensions (social, economic, and technological) won't be discussed. Two other vulnerability dimensions (sensitivity and response capacity) were divided into the

1 following components, respectively: 1) sensitivity: business characteristics, job
2 characteristics, owner-manager demographics, product and supplier characteristics, 2)
3 response capacity: resources, human capital, technological capital, social capital,
4 infrastructure, institutional capital, management capacity, and supply chain capabilities.

6 **4.1. Dimension 1: Exposure**

7 Component 4.1.1: Biological Natural Driving Forces - Pandemic Events (COVID-19)

8 Social distancing, isolation, personal insularity, and travel restriction because of
9 COVID-19 prevalence faced all economic sectors with the labor shortage and deleted
10 many jobs (Nicola et al., 2020). Supply drained and consumption/investment declined led
11 to demand downfall because of the global economic shutdown in anticipation of infection
12 control (Seetharaman, 2020). COVID-19, as a devastating crisis, has affected the global
13 economy (Eggers, 2020) just like previous pandemic infections, including SARS (Pine &
14 Mckercher, 2004) and Flu (Rassy & Smith, 2012), while reviewing SARS and Flue data
15 since 1918, brings us some ideas and information regarding COVID-19 pandemic events,
16 giving weight to the differences, including the following is of grave importance, and will
17 prevent from simple comparison: global prevalence, not being specific to low-middle
18 earning countries, lowering profit rate to its historical minimum, more integration across
19 the world, imposing double effects on supply change, supply and demand decline
20 (Fernandes, 2020). Also, technology-based businesses were affected by these natural
21 biological factors and their exogenous shock. According to Price Waterhouse Coopers
22 (PWC), they experience some difficulties in terms of crisis management, crisis response,
23 workplace, and employees, supply chain and related activities, financial reports, tax and
24 charges, and customers since they didn't give any point to business uncertainty caused by
25 infection continuance (PWC, 2020). COVID-19, unfortunately, is evolving continuously,
26 the effects of which are unprecedented in terms of speed, intensity, and scope (Yang,
27 2020).

28 **4.2. Dimension 2: Sensitivity**

29 Component 4.2.1: business characteristics

30 A business character impacts business function against crisis (Sydnor et al., 2017).
31 Some business characteristics are intangible and are critical for many modern businesses,
32 including tech-driven and knowledge-driven businesses, such that any shortage and

1 outage makes them vulnerable. Intangible characteristics are brand, organizational
2 culture, routines, and laws of the important strategic and functional layers (Yan & Zhou,
3 2010). Business size is discussed extensively as one of the characteristics (Davlasheridze
4 & Geylani, 2017; Eggers, 2020; Orhan, 2016; Polsky et al., 2007; Song et al., 2016;
5 Sydnor et al., 2017). While smaller businesses are more flexible and their decision-makers
6 have closer relationships with their customers and stakeholders such that they have access
7 to the market's valuable information, in particular through crises, they face resource
8 scarcity, including human and financial problems, or even demand decline because of
9 new competitors. Thus, they will be more vulnerable to internal and external events. So
10 one can claim that the smaller the business, the more vulnerable it will be to a crisis like
11 COVID-19 (Eggers, 2020). Compared to the larger companies, smaller businesses
12 experience greater losses and point to positive dimensions, including irregularity in crises,
13 of small businesses in developing countries like Singapore. They could implement
14 recovery strategies after the earthquake because they had their contingency plans.
15 However, larger businesses are struggling with negative aspects, including a large volume
16 of business activity, more machinery/tools, and greater expenditure in terms of salary
17 (Khan & Sayem, 2013). Eggers (2020) counts new businesses as more vulnerable than
18 older businesses because of lacking confirmed business model, depending on not-totally
19 known colleagues, and a low rule-observance index. Also, other characteristics include
20 the number of business locations (Song et al., 2016); economic sectors to which
21 businesses belong/ industry sector/ type of business/ capital intensity (Song et al., 2016;
22 Orhan, 2016; Sydnor et al., 2017; Khan & Sayem, 2013; Lo et al., 2019); sales previous/
23 financial condition before the disaster/ Monthly average income of the firm (Sydnor et
24 al., 2017; Orhan, 2016; Khan & Sayem, 2013); legal ownership structure/ occupancy
25 tenure (Sydnor et al., 2017; Orhan, 2016); source of business: inherited-personally
26 initiated (Khan & Sayem, 2013) are discussed as the important business characteristics
27 which may be considered to vulnerability.

28

29 Component 4.2.2: Owner/Manager/Primary Decision-Makers Demographics

30 Vulnerability is embedded in the socio-economic trajectories of their primary decision-
31 makers. Multiple vulnerabilities may arise if the decision-maker's socio-economic
32 conditions are associated with climate-sensitive business characteristics (Lo et al., 2019).

1 According to the literature review, owner gender (Lo et al., 2019; Song et al., 2016;
2 Sydnor et al., 2017), education level (Lo et al., 2019; Orhan, 2016; Sydnor et al., 2017),
3 experience, race, ethnicity (Sydnor et al., 2017), manager/supervisor competencies (Yan
4 and Zhou, 2010), and previous disaster experience (Orhan, 2016) are among important
5 factors affecting vulnerability. In experimental models, some are the control, dependent,
6 or independent variables. Some studies claim there is a negative relationship between the
7 female gender and technology entrepreneurial initiative formation (Zapata-Huamaní et
8 al., 2019); according to the OECD, perhaps females are less interested in high-technology
9 than males, while they have a greater tendency to service businesses (OECD, 2012).
10 Facing crises, compared to males, female owners prefer to shut down the business, and to
11 reopen after the crisis disappears. Also, more educated owners continue their efforts and
12 don't shut the business down, compared to less educated (Sydnor et al., 2017). According
13 to Yan and Zhou (2010), more educated and knowledgeable managers/owners seem to
14 have the quality and efficiency of transferring tacit knowledge to mitigate the business
15 vulnerability, and, thus, a more sustainable business. Given that education level and
16 business preparedness are positively related, thus one can claim that businesses with less-
17 educated owners/managers should gain more knowledge regarding their vulnerability to
18 crises. Also, previous disaster experiences may increase the willingness to engage in
19 preparedness activities, particularly in the long term (Orhan, 2016).

20

21 Component 4.2.3: Job Characteristics

22 *4.2.3.1: Job complexity*

23 The complexity of the system is one factor studied by the researchers. Failure is
24 inevitable, whenever the system is complex enough (Robertson et al., 2020). Because of
25 web complexity, portal websites, telecommunication, and e-commerce websites have
26 reported the highest rate of vulnerability across the IT sector, while large and complex
27 systems become more unreliable and more vulnerable through the crisis (Egan, 2007).

28

29 *4.2.3.2: Interaction between elements of a system*

30 Interaction between elements of a system makes it more vulnerable in crises, such that
31 damage to any element will create a cascade of damages. Also, when new systems are
32 connected, new systems' vulnerability has culminated in the overall vulnerability, and

1 complexity grows. Thus better management and vulnerability mitigation is accomplished
2 through understanding interaction points and inter-technology/service/system relations
3 (Egan, 2007).

4 5 Component 4.2.4: Supplier/Product Characteristics

6 Repeated and uncommon crises disturb the supply chain and make them more
7 vulnerable to disturbance and greater losses, which can be mitigated through the
8 management of vulnerability-causing factors, including globalization, decentralization,
9 outsourcing, product/process complexity, litigation, sole sourcing, just-in-time
10 manufacturing (Stecke & Kumar, 2009).

11 Spekman (1988) focused on supplier/product characteristics to strategic vulnerability
12 levels. He considered: product (cost of the service contract, ease of maintenance design,
13 reliability of the product, case of operation, impact on energy utilization, contribution to
14 productivity, warranties); service (amount of pre-purchase information, service response
15 time, dependability, the competence of the salesperson, vendor's image); experience
16 (experience with a vendor, preferences established by users in the organization, reputation
17 of the supplier, ability to keep a delivery promise); price (price/performance, low price,
18 the total cost of the product); avail (suppliers financial condition, geographic proximity,
19 technical support available, breadth of product lines). Also, Orhan (2016), and Khan &
20 Sayem (2013) focused on the market for the product (regional/local) among the factors
21 affected by the crises.

22 23 **4.3. Dimension 3: Response capacity**

24 Response capacity stands for a great set of resources, many of which are to a group or
25 nation's socio-technical and economic development level, that may be turned into either
26 adaptive or mitigative capacity (IPCC, 2007a). Adaptive and mitigative capacities have
27 nearly the same determinants but they differ in their application (Winkler et al., 2007).
28 Mitigative capacity reflects the ability to mitigate the intensity of the natural (and other)
29 disaster (IPCC, 2007a). The adaptive capacity of a system or society indicates its ability
30 to regulate its traits or actions to adapt better to external situation changes (H. M. Füssel
31 & Klein, 2006).

1 Mitigative capacity depends on viable technological options for decline emissions,
2 policy instruments, institutional structure and the derivative allocation of decision-
3 making authority, the availability and allotment or tools required to ensure their adoption,
4 and the associated opportunity cost of allocating those resources to mitigation, human
5 capital resources, social capital, and the ability of decision-makers to manage information
6 (Yohe, 2001). Adaptive capacity reduces exposure or sensitivity to stresses, whereas
7 mitigative capacity reduces the intensity of the stress itself (Winkler et al., 2007).

8 Lacking adaptability capacity is an indicator of high business vulnerability to natural
9 disasters (Davlasheridze & Geylani, 2017). Adaptive capacity plays a critical role in the
10 ultimate vulnerability because it defines the size of the effect to a great extent (Moreno &
11 Becken, 2009). Various capital (financial, social, human, knowledge, etc.) affect business
12 vulnerability and resilience (Marshall & Schrank, 2014).

13
14 Component 4.3.1: resource unavailability/ scarcity/inability to replace/intense
15 dependency to scarce resources

16 Previous studies (Eggers, 2020; Mieke et al., 2016; Robertson et al., 2020; Adger &
17 Kelly, 1999) have indicated that resource scarcity is one-factor affecting business
18 vulnerability to crisis. The vulnerability of any group is determined by the availability of
19 resources and, crucially, by the entitlement of individuals and groups to call on these
20 resources (Adger & Kelly, 1999). The negative effect and sensitivity of the community
21 to a crisis depend on the affected resources (Wongbusarakum & Loper, 2011). Across
22 businesses, resource scarcity appears on two levels: 1) no supply, and 2) reduction of
23 supply (Mieke et al., 2016). He also considers the inability to replace the consumed
24 resources as another source of vulnerability. All production and service technological
25 systems depend on viable environmental conditions. User services are condemned to
26 failure in case of unviable environmental conditions and resource unavailability
27 (Robertson et al., 2020).

28
29 Component 4.3.2: technology capital

30 Technology is among those important factors determining a business failure or
31 survival in the face of COVID-19 (Sharma et al., 2020). Technology is one determinant
32 of adaptive capacity to increase resilience and reduce the vulnerability of social systems

1 (Merino, 2016; Robertson et al., 2020; Moreno & Becken, 2009; Thornton et al., 2006;
2 Winkler et al., 2007).

3 Literature review, following technological items, makes the businesses more
4 vulnerable:

5

6 *4.3.2.1: New technology/emerging technologies*

7 Emerging technologies, in particular, those in the beta-test stage are vulnerable to
8 failure. Employing new technologies brings about emergent vulnerabilities, or at least
9 prepared the context for unknown consequences, because of mutual unpredictable
10 dependencies. Relying quickly on a novel and emerging technologies makes the larger
11 system, which depends on them, more vulnerable. If the emergent technology tests aren't
12 completed, making more usage of and depending heavily on them will intensify
13 vulnerability (Egan, 2007). However, using new technologies for higher preparedness for
14 various crises such as COVID-19, hard-working is important (Yang, 2020).

15

16 *4.3.2.2: Technology development/redundancy*

17 Systems' new vulnerabilities exist alone with technology evolution (Baek & Kim,
18 2019). Technology redundancy, as a viable approach to resolving exogenous forces-
19 caused challenges, may make businesses more vulnerable (Egan, 2007).

20

21 *4.3.2.3: Technology maladaptation*

22 Technological shortages make adaptability limited. Thus the more technological
23 challenges, the less the adaptability potential (Cuevas, 2011). Technological adaptation
24 has consisted of two main components: 1) changing the current technologies' structure,
25 and 2) implementing new technologies. Technological adaptation performed
26 inadequately, threats may enlarge (Merino, 2016).

27

28 *4.3.2.4: Technology migration*

29 Technology migration is considered one of the technological vulnerabilities and failure
30 points (Robertson et al., 2020).

31

32 *4.3.2.5: Reverse salient*

1 Through crises, the infrastructure of the large technical system becomes critical
2 quickly, Since comprehensive experimenting with services/technologies intended to
3 resolve reverse salient is impossible because of the simultaneous existence and
4 appearance of invention possibility and the need for a social-technical solution (Egan,
5 2007).

6 7 Component 4.3.3: Management Capacity

8 Managerial measures are one of the adaptive capacity determinants (Egan, 2007;
9 Moreno & Becken, 2009; Polsky et al., 2007).

10 11 *4.3.3.1: Enterprises' strategic plans*

12 Enterprises' strategic plans impact business vulnerability greatly (Yan & Zhou, 2010).
13 Crisis management should be an integral part of the strategic planning processes that
14 companies adopt. To reduce their vulnerability to shocks, business owners need to
15 integrate crisis management with strategic planning processes, prepare detailed
16 contingency plans, define decisional roles and responsibilities, and retain a degree of
17 flexibility. Otherwise, the business is more vulnerable to shocks (Evans & Elphick, 2005).

18 19 *4.3.3.2: Types of vulnerability management*

20 If the management cannot mitigate vulnerability effectively, damages can't be
21 identified, evaluated, resolves, and confirmed effectively (Baek & Kim, 2019). According
22 to (Gartner, 2019), the following make businesses more vulnerable: 1-existence of
23 unreported vulnerabilities; 2-trying to fix all identified vulnerabilities; 3-ineffective
24 communication; 4-insufficient remediation resources; 5- fixing only "high" and "critical"
25 vulnerabilities; 6- conceding broad or eternal exceptions; and 7- mitigation without
26 previous planning can be disastrous.

27 28 *4.3.3.3: Lacking the ability to decide against uncertainties*

29 Entrepreneurs have to make decisions in uncertain conditions since the environment is
30 full of dynamic and uncontrollable forces, and global changes create uncertainty because
31 of which one can act risky (Alvarez et al., 2018). Because businesses are affected by
32 natural forces, including floods and earthquakes, they have to make themselves adapt by

1 making the right predictions; the entrepreneur, as the owner and manager, should have
2 the ability to decide against uncertainty (Knight, 1942). Uncertainty affects managers,
3 founders, and the board of directors' decision-making, and according to Mintzberg,
4 anyone who doesn't understand uncertainty in management can't comprehend managerial
5 decision-making (Alvarez et al., 2018). Prevalence of new diseases, such as COVID-19,
6 as a phenomenon that intensifies uncertainty, makes effective decision making of grave
7 importance, in particular for mitigating losses caused by uncertainty, since, as noted
8 (Teece & Leih, 2016), risk-based decision-making is unreal and simple given difficulties
9 of the global economy. Transformational leadership, behavioral integration, and
10 comprehensiveness in the decision-making process among members of the top
11 management team increase the capacity of small entrepreneurial companies to adapt to
12 environmental changes (Friedman et al., 2016), which absent these factors will reduce
13 their sustainability and performance.

14

15 Component 4.3.4: Financial Capital

16 *4.3.4.1: lack of diverse revenue sources and Flexible business model*

17 If successful companies take their usual path without changing their business model
18 according to the environment, they will experience failure inevitably (Doz & Kosonen,
19 2010). While imposing great challenges on all businesses, the COVID-19 crisis gives the
20 organization a new chance to develop new business models, survive, and decrease
21 physical contact to the highest possible level through digitalization (Seetharaman, 2020).
22 Studying business models of fourteen big and prominent firms in the computer and
23 telecommunication sector, Hacklin et al (2018) identified the business model's continued
24 change as one of the success factors of Apple, such that it adapts itself to its environment,
25 which is full of tension. He continues that some firms try to implement several parallel
26 models along with the main business model. They will face some challenges; some may
27 fail since the firm cannot utilize them synergically because the models are operated in
28 separate firms. In such cases, success requires learning and experimentation.
29 Implementing parallel models according to previous plans is risky and increases
30 complexity, utilizing common resources will be more difficult, and, finally, the
31 organizational function will be hurt (Hacklin et al., 2018). Thus, firms and businesses

1 should change their business model according to the environmental conditions and crises
2 and consider all aspects of trying to use parallel and secondary models.

3 4 *4.3.4.2: Lack of financial resources for adapting technology and development*

5 Financial resource availability has been a component of adaptive capacity for investing
6 in developing the primary warning system, adoption-related operations, and technologies
7 (Moreno & Becken, 2009). Creativity and providing customers with novel proposals
8 require financial resources (Eggers, 2020). Emphasizing financial capital and the
9 importance of technology adaption (whether technological systems structure change or
10 implementing new patterns), and also as one factor determining the adaptive capacity of
11 social systems to crises and disasters, Merino (2016): even if technological adaption is
12 possible, it will be ineffective economically without financial resources.

13 14 Component 4.3.5: Infrastructure Capital

15 *4.3.5.1: Lack of appropriate infrastructure for digitalization*

16 Digital media usage and distribution grew heavily after COVID-19
17 (WorldEconomicForum, 2020). Digitalization brings about opportunities for social-
18 economical systems, becoming obvious, especially after the crises and the “Stay Home”
19 protocol (Dannenberg et al., 2020). COVID-19 crisis marked digital communications and
20 services as the elements for social resilience and business survival, for which effective
21 and large digital infrastructure is necessary. Moreover, those companies controlling two
22 or more parts of the value chain by the digital infrastructure are in a better position than
23 specialized independent companies. However, businesses, eventually, will experience
24 lower speeds and greater latency, because of higher demand and, because of which, lower
25 bandwidth quality decline. But supply decline caused by digital infrastructure supply
26 chain disturbance and supplier changes and evolutions makes the situation darker because
27 businesses are challenged (Strusani & Hounghonon, 2020). Thus, the lack of appropriate
28 digital infrastructure makes businesses vulnerable.

29 30 *4.3.5.2: Damages caused by open innovations and using platforms*

31 four factors make entrepreneurs and entrepreneurship, which act according to open
32 innovations and use open platforms, vulnerable to changes (Nambisan et al., 2018): 1)

1 business model dependence on platforms and open innovations; 2) access to partner data;
2 3)access to the creative ideas of others, and 4) apply the acquired strategy on platforms

3 4 Component 4.3.6: Social Capital

5 Social capital's role has been considered concerning impact mitigation, adaption, and
6 recovery at individual and collective levels (Meyer, 2018). Social capital facilitates access
7 to various resources through the crisis management cycle; alarming disasters before they
8 occur, information exchange, predicting and procuring tools, financial aids, vulnerability
9 assessment, and other preparedness-related activities. Thus one should consider it as a
10 contributing factor to disaster threats (Han et al., 2019).

11 Social capital is an effective factor, in particular, for implementing research and
12 development as a strategic network-based capital through explorative learning, which
13 affects technology performance and utilization learning, and finally, business
14 performance. Research and development consortiums depend on social capital, given it
15 institutionalizes the mutual common bed over which they interact (Seo, 2020). Research
16 and development coalitions are inevitably vulnerable to many factors, including
17 opportunity seeking, technology shortage, and knowledge protection vs. sharing dilemma
18 which makes costs grow higher (Rauch et al., 2015; Meier et al., 2015; Seo, 2020). The
19 level of discourse-action transition depends on the quality of social networks (Acosta-
20 Michlik & Espaldon, 2008). Social networks should consider this issue.

21 Against COVID-19 and subsequent stressful and uncertain conditions, Social
22 networks can play a key role in terms of emotional support and information support using
23 modern technologies, all of which can facilitate businesses' performance against the crisis
24 (Giones et al., 2020).

25 26 Component 4.3.7: Human Capital

27 Technologist entrepreneurs can create successful intuitions through their human
28 capital, which leads to fundamental innovations (Marvel & Lumpkin, 2007). Human
29 capital is one of the intangible organizational assets, and is referred to the unique and
30 knowledgeable people of the organization; employing these people can differentiate itself
31 (Johannesson & Jorgensen, 2017). By human capital, we mean explicit and tacit
32 knowledge of organization people; they belong to the company and include experience,

1 capabilities, learning capabilities, or knowledge creation ability (Delgado-verde et al.,
2 2016). One can define human capital using indicators, including employee capabilities
3 (individual competencies and skills, organization investment in human capital), employee
4 satisfaction (employee's emotional and sensational expression), and employee endurance
5 (maintaining employees) (Moon & Kym, 2006). Merino (2016) claims academic
6 education, public information, and specialty to be among the important features of human
7 capital. Emphasizing human capital and education level's important role in accepting and
8 developing technology through the crises, they indicate that deciding on solutions or
9 technological responses or choices is impossible without them.

11 *4.3.7.1: Employee unavailability*

12 Firms losing their human resources need a longer time to recover (Khan & Sayem,
13 2013). Employee loss is one of the crisis consequences and includes personal and family
14 problems as a result of a crisis, or they may go to work, and considering that employees
15 are critical for organizational success, operational capacity, and also a business
16 improvement, companies will experience great damages if employee loss occurs or
17 absence (Sydnor et al., 2017). Employee replacement easiness, especially during a crisis,
18 is an important factor affecting vulnerability (Lo et al., 2019). Losing key employees,
19 especially leaders who have specialist knowledge, and lack enough good employees
20 (because of infections, death, injury, etc.) influences organizational responsiveness and
21 aftermath recovery greatly. Organizations should know that employees consider
22 themselves, their families, and friends' security as a priority. Employee availability is
23 plausible only then this need is served (Dalziell, 2005). Failing to serve basic needs will
24 worsen the situation and may continue to collapse (Lazarov, 2020). Since has the public
25 information and specialized experience necessary for technological entrepreneurship and
26 radical innovation (Marvel & Lumpkin, 2007), employing empowered labor will be
27 difficult. Training new employees are time- and money-consuming, especially during
28 crises (Morrish & Jones, 2019).

30 *4.3.7.2: Knowledge, skill, and experience shortage*

31 To accomplish technological entrepreneurship, various kinds of knowledge are
32 required: 1) knowledge of ways to serve markets; 2) knowledge of customer problems;

1 3) knowledge of markets, and 4) knowledge of technology. At the same time, the
2 experience is of grave importance regarding service/ product development for
3 technology-based firms (Marvel & Droege, 2010). Also, Verrest (2013) emphasizes
4 special skills and believes that simpler skills are more vulnerable and that developing
5 special skills requires common education. Regarding COVID-19, Yang (2020) points to
6 the main and important role of specialty in identifying and curing COVID-19 and for
7 politicians and technical elites to distribute and allocate emergency aids. Yang (2020)
8 says lacking the special skills against prevalent conditions leads to more failures.

9 10 *4.3.7.3: Risk-taking/ willingness and ability to change*

11 Willingness to change is one characteristic of adaptive capacity against social systems'
12 failure, i.e., social vulnerability comes into existence when there is no willingness to
13 change (Wongbusarakum & Loper, 2011). Risk attitude and self-sufficiency play an
14 important role in personal adaptation and mitigation of disaster risk (Poussin et al., 2014).
15 Entrepreneurship (e.x. technology-based firms) can search for new opportunities in the
16 face of uncertainty by employing special actions, including risk-taking and Proactiveness
17 (Runyan et al., 2008), thus they can survive crises.

18 19 Component 4.3.8: Supply Chain Capabilities

20 To reduce vulnerability and increase supply chain resilience to disruptions and crises,
21 supply chain capability is essential (Ekanayake et al., 2020). Supply chain faults become
22 evident in the face of sudden disruptions and events, including political and economic
23 crises or biological disturbances (Ponomarov & Holcomb, 2009). COVID-19, as a crisis,
24 disrupted many supply chains (Kirk & Rifkin, 2020; Sharma et al., 2020).

25 26 *4.3.8.1: Supply chain disruption*

27 Since the beginning of the COVID-19 crisis, businesses is facing great challenges,
28 including (Sharma et al., 2020):

29 1- Demand-supply challenges: one of the important challenges some sectors are facing
30 is supply uncertainty. However, technology firms faced demand's sudden rise.

31 2- Resilient supply chain challenges: as COVID-19's power to challenge the supply
32 chain grows, more challenges are revealed regarding the necessity of a resilient supply

1 chain. Using blockchain-based technologies, artificial intelligence, and collaboration
2 between industries and competitors improve supply chain resilience.

3 3- Technological challenges along COVID-19: companies differ in terms of
4 technological preparedness. Security breaches, besides technological preparedness, are
5 one of the common concerns.

6 4- Sustainable supply chain challenges: COVID-19 forced companies to pay more
7 attention to the social, economic, and environmental aspects. Employee welfare and
8 suppliers are important for the company since companies without sustainable approaches
9 cannot fight the virus's impacts.

10 11 *4.3.8.2: Financial disruption across the supply chain and customer network*

12 Financial problems, including supplier bankruptcy, are among the factors disrupting
13 the supply chain (Carvalho et al., 2019), which make businesses vulnerable (Song et al.,
14 2016).

15 16 *4.3.8.3: Consumer behavior-changing*

17 Natural disasters, including earthquakes, storms, and epidemics such as COVID-19,
18 change or modify customer behaviors (Sheth, 2020). Trying to defeat the virus, customers
19 change their behavioral patterns and respond variously to the actions of brands. Future
20 buying decisions are made under the pressure of brands' reaction to COVID-19, such that
21 some consumers shape their perception of a brand according to how they perceive an
22 inappropriate reaction to the crisis. If customers perceive the brand's reaction as self-
23 servicing or don't sacrifice, they will become vulnerable (Kirk & Rifkin, 2020).

24 25 *4.3.8.4: Dependence on supply chain members*

26 To determine to what extent a business can survive without its supplier, Lo et al (2010)
27 used a variable called Inter-business dependence and introduced it as a factor making
28 business vulnerable. A company faces threats if resource control is passed to its partner,
29 such that it perceives itself as dependent on its partner. The fewer the buyer choices, the
30 more vulnerable the business (Spekman, 1988).

31 32 Component 4.3.9: Institutional Capital

1 Institutional capability as one component of adaptive capacity is effective in reducing
2 vulnerability. Institutional capability is represented by the political leadership and
3 governance structure, and disaster prevention systems (Ludena et al., 2015). As stressful
4 or structural factors affect system flexibility and sensitivity, institutions are important,
5 and institutional structures should be created through conscious efforts, which connect
6 vulnerability analysis to decision-making (Turner et al., 2003). Institutions are
7 fundamental determinants of economic behavior (North, 1990) and exchanges (B. O. E.
8 Williamson, 1998), and affect innovation and technological development directly and
9 indirectly (Arabiyat et al., 2019; Rabelo & Bernus, 2015). Institutional Void occurs when
10 the community's institutions act inappropriately (Covin & Miller, 2013), after which
11 there will be weak or no institutional support, this factor brings vulnerability with itself.
12 (Cuevas, 2011; H. M. Füssel & Klein, 2006; Moreno & Becken, 2009; Mortreux &
13 Barnett, 2017; Rana & Routray, 2018; T. Williamson et al., 2012).

14 According to North (1990), human beings have developed institutions to make
15 exchanges disciplined, and mitigate uncertainty; thus, one can conclude that institutions
16 play a greater role in the COVID-19 crisis given its high uncertainty.

17 Regulatory, normative, cognitive, and conducive aspects of an institution are of grave
18 importance for entrepreneurship support, while innovative firms are more interested in
19 conducive and regulatory aspects (Arabiyat et al., 2019; Stenholm et al., 2013).

20 1- Regulatory aspect (business freedom, ease of starting up a business, ease of closing
21 a business, property rights, the orientation of the country's financial system toward
22 entrepreneurship, government policies, and taxes) 2- normative aspect (societal
23 perception of entrepreneurship as a good career choice, the perception of high societal
24 status for successful entrepreneurship, the media attention is given to successful
25 entrepreneurs) 3- cognitive aspect (entrepreneurial intentions, fear of failure, perception
26 of perceived business opportunities, skills for starting a business within the adult
27 population, the percentage of the non-entrepreneurial adult population who knows
28 someone who started a business in the previous two years (networks) 4- conducive (ICT
29 use/ laws, technological adoption, quality of scientific research institutions, university-
30 industry collaboration in R&D, quality of education, availability of venture capital,
31 availability of latest technology).

1 While COVID-19 affects many economic activities, public support programs prioritize
2 and support established organizations. Unfortunately, they seem to prioritize bankruptcy
3 threat mitigation and job loss, and put innovation or entrepreneurship efforts receive less
4 attention (Giones et al., 2020).

6 **5. Technological entrepreneurial action**

7 Entrepreneurial actions are a response to exogenous shocks that lead to the emergence
8 of entrepreneurial opportunities (Klein, 2008). The final response should be selected
9 according to business capabilities. Researchers, generally point to various response and
10 action mechanisms for vulnerability control and reduction. Based on a review of the
11 literature (Ghedini & Ribeiro, 2009; Turner et al., 2003; Winkler, 2007; Yohe, 2001;
12 Füssel & Klein, 2006), these actions are taken to reduce vulnerability:

13 1) Coping response: means the system's capability to employ the existing resources to
14 mitigate and manage bad conditions or to promote preparedness for an adverse event.
15 They include predefined policies, autonomous individual actions, and/or an outcome of
16 self-adaptive procedures or learning approaches.

17 2) Impact response: measures the effect of changes in local and global scales and
18 presents feedback to other parts.

19 3) Adaptation response: If a significant change has occurred, the systems take an
20 adaptive approach. In this approach, predefined policies and procedures are updated
21 according to negative feedback.

22 4) Adjustment response: This approach is the same as the adaptive approach, except
23 that it is used when a minor change in the system has occurred. Adaptation/ adjustment
24 response is a set of predefined procedures to restructure the business after a response.

25 5) Mitigation: Füssel & Klein (2006) state that a mitigation strategy is a human
26 intervention to reduce sources of risk. Focusing on mitigation reduces the impact on all
27 stress-sensitive systems, while the potential for adaptation actions is limited for many
28 systems. However, there are some factors that we cannot reduce and therefore the need
29 to use adaptive policies becomes more. IPCC (2007b) defined it as a technological change
30 and substitution that reduces resource inputs and emissions per unit of output. Although
31 several social, economic, and technological policies would produce an emission
32 reduction, mitigation means implementing policies to reduce stressful components.

1 **6. Discussion: Conceptual Framework**

2 Identifying and mitigating vulnerability elements are the main factors decreasing
3 disaster threats (Greiving et al., 2006). According to the literature review, vulnerability
4 has three dimensions: 1) exposure 2) sensitivity of business elements, and 3) lack of
5 response capacity to effects and outcomes caused by internal and external disruptions.
6 Perhaps the greater the three-dimension overlap, the more business is more vulnerable.
7 Business vulnerability includes social-economical responses to social, technological,
8 human, biological, and environmental threats, such that the business will become
9 vulnerable if it becomes sensitive to threats because of lacking response capacity.

10 To understand the vulnerability process and outputs from quantitative and qualitative
11 viewpoints, vulnerability analysis should be integrated with diverse parameters. In this
12 research, dimensions, components, and corresponding indicators to each dimension were
13 studied using the indicator-based approach. First, potential indicators were identified,
14 then a conceptual framework was developed using a set of factors and connections
15 affecting the vulnerability of technology-based businesses through the COVID-19 crisis
16 (Figure 2).

17 To analyze technology-based business vulnerability according to the specified
18 indicators, first, the threat should be identified. As you may see in Figure 2, technology-
19 based businesses expose to threats, which in turn may affect sensitivity and response
20 capacity: 1) through various economic, social, technological, and political factors, which
21 we call “other exposure” 2) through businesses’ internal activities, and 3) through a
22 pandemic event like COVID-19. Intensity, frequency, scope, duration, and rapidness of
23 events and crises are determinants of exposure level. Exposure impacts business
24 sensitivity and is related to business vulnerability, in other words, the higher the exposure,
25 the higher vulnerability. The greater the response capacity, the less the potential exposure-
26 caused losses. Exposure and sensitivity create potential impacts if they overlap. The
27 potential impacts are direct/ indirect. The response capacity and the potential impacts
28 affect business vulnerability. Response capacity to reduce vulnerability includes two
29 types of capacity, adaptive capacity, and reduction capacity. **Vulnerability is related**
30 **reversely to response capacity, and response capacity is in reverse relation to sensitivity.**
31 Response capacity influences sensitivity according to exposure level. If the business is
32 sensitive to stressful factors and lacks response capacity for the related threat, then it is

1 considered vulnerable. The lower is the response capacity, the higher the vulnerability
2 possibility. An appropriate or inappropriate response to the crisis is associated with
3 response capacity. Vulnerability lowers with an appropriate response, otherwise, it will
4 grow. If businesses are vulnerable to the crisis and fail to take measures to reduce
5 vulnerability, they will eventually collapse.

6 **Insert Fig 2 here**

7
8 Model variables, classified into three groups of dimensions, components, and
9 measures of components, are shown in Table.1 according to the conceptual framework
10 and literature review.

11 **Insert Table 1 here**

12 13 **7. Theoretical and practical implication**

14 **Recently, global change and sustainability literature have focused heavily on**
15 **vulnerability (Metzger & Schröter, 2006). Assessing small-business vulnerability to**
16 **disasters helps disaster economy research, establishing a firm foundation for business**
17 **survival and development policies (Davlasheridze & Geylani, 2017). By examining the**
18 **phenomenon of business vulnerability, several main areas such as risk and crisis**
19 **management, resilience, development, and sustainability of businesses have been**
20 **identified as the background of this study. Therefore, this article provides a scientific**
21 **contribution in the above areas.**

22 **Acquiring differential elements of vulnerability is a key precondition for developing**
23 **and implementing policies, which enhance equitable and sustainable development (Vogel**
24 **& O'Brien, 2004). Thus, providing a conceptual framework for vulnerability reduction**
25 **of technological businesses, this research informs and contributes to local, national, and**
26 **regional decision-makers. Also, identified elements are of great help for policies**
27 **developed for vulnerability reduction.**

28 **Also, this research helps business managers in various ways. First, managers can**
29 **employ a research model against all crises and disasters, although the proposed model has**
30 **been developed according to COVID-19 exposure. Second, identified dimensions and**
31 **components can help managers and owners in vulnerability cognition. Third, the**
32 **vulnerability dimensions of many tech-based businesses can be determined, compared,**

1 and ranked, using components of all dimensions of vulnerability. Fourthly, owners and
2 managers can develop various indicators and extend vulnerability factors according to
3 their field proficiency, experience, and all related factors, including context and type of
4 business. Fifthly, this research helps managers and owners to develop strategies for
5 shocks, crises, and various disasters about possible internal and external events. And most
6 important, they can prepare themselves for any crisis.

7 The proposed framework could provide future studies with a useful checklist for
8 developing new approaches to reduce vulnerability and adaptive capacity (mitigative
9 capacity) to shocking events and epidemics.

10 Researchers, planners, policymakers, and decision-makers can seek solutions and
11 recommendations to overcome shortcomings that reduce the vulnerability of
12 technological businesses and can be feedback to the conceptual framework.

14 **8. Conclusion**

15 This research aimed to design and present a model for high-tech businesses' vulnerability, and to determine the dimensions, and components of vulnerability. To
16 quantify or review vulnerability, vulnerability management tools need specific patterns.
17 These patterns should be based on all types of vulnerability (Lowis & Accorsi, 2011).
18 Given that business vulnerability is non-linear and includes many interactions, thus taking
19 dynamic perspectives is necessary (Lo et al., 2019). To identify vulnerability levels, we
20 should determine its dimensions and components, and then we can compare and rank a
21 wide range of businesses. Vulnerability assessment is useful only if it can support
22 decision-making processes in real environments (Ghedini & Ribeiro, 2009).

24 We conclude that analyzing the vulnerability of technology-based businesses should
25 be conducted along four main paths: exposure, business sensitivity, response capacity,
26 and technological entrepreneurial action. Reviewing related literature and a similar
27 situation to the COVID-19 crisis showed informed us that technology-based businesses
28 should always have an eye on environmental dynamics and uncertainty, forecast, and
29 determine what negative outcomes they may bring about. Technology-based businesses
30 have to know their characteristics and components against such crises and consider them
31 as sensitivity components. In this research, we considered Business characteristics, job
32 characteristics, owner/manager demographics, and supplier/product characteristics as the

1 components of the sensitivity dimension. Thus technology-based businesses should
2 determine to what extent they are prepared for crises in terms of various levels, including
3 resources, technology capital, human capital, social capital, economic capital,
4 institutional capital, managerial capital, and supply chain. Then they have to identify their
5 weak points and shortcomings to respond adaptively and effectively. This is the only way
6 they can take to survive and mitigate their vulnerabilities.

7 Although many researchers are interested in vulnerability assessment, they should be
8 modified, and then to be inserted into appropriate policies. Also, since vulnerability is
9 multi-faced and consisted of many components, thus we can't propose an integrated
10 method, so we can add more indicators for vulnerability to reflect local requirements
11 thoroughly (Rana & Routray, 2018). Vulnerability assessment seems focused on
12 quantitative evaluation, while qualitative evaluation is the key to assessing vulnerability
13 comprehensively and notifying general policies. Quantitative assessment of vulnerability
14 requires the ability to provide simple, summary, and standard data. This method needs
15 little interpretation and provides for a multi-case comparison. To resolve vulnerability
16 complexity, governmental solutions based on a quantitative-qualitative mix are required,
17 each of which should be based on participation (Rossignol et al., 2015). In the study a
18 specific indicator or index was not used, while an indicator-based approach with various
19 indicators was employed, thus a better view and perspective on business vulnerability was
20 projected. To assess various businesses' vulnerabilities, we can use some of the identified
21 factors.

22 23 **9. Limitations**

24 This study is not without limitations. Quarantine restrictions and communication
25 limitations during the COVID-19 did not allow us to interview managers and owners of
26 technology-based businesses to give different weights and prioritize the indicators, so in
27 this study, the indicators were identified by reviewing the literature and assumed equal
28 weight. There is a need for future research. Future research is necessary to validate the
29 dimensions. The presented study only identifies the indicators. The validation of the
30 identified findings in a more robust setting with in-depth interviews across a range of
31 cases in different technology-based business contexts would be desirable. A quantitative/
32 qualitative survey on a technology-based business is needed to evaluate the empirical

1 significance of the presented findings based on an indicator-based approach. The
2 comprehensiveness of the cases should be verified by conducting additional focus groups,
3 interviews, and surveys, and additional differentiation dimensions could be identified.
4 And given that cross-sectional designs are not suitable for examining the impact of
5 dynamic changes and discontinuous changes over time on business. It is appropriate to
6 use longitudinal plans to achieve an appropriate model of the vulnerability and ability of
7 businesses to survive. We recommend research on the vulnerability model of technology-
8 based businesses at different levels (individual, group, organizational). Finally, we
9 suggest research in related areas such as business sensitivity, mitigation capacity, and
10 adaptive capacity, as these areas pose similar challenges to the conceptual boundaries of
11 business vulnerability.

12

13

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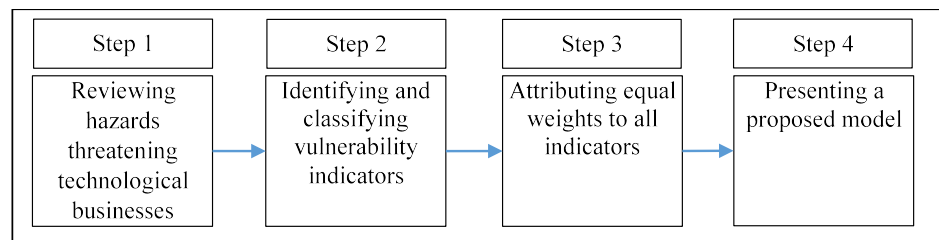
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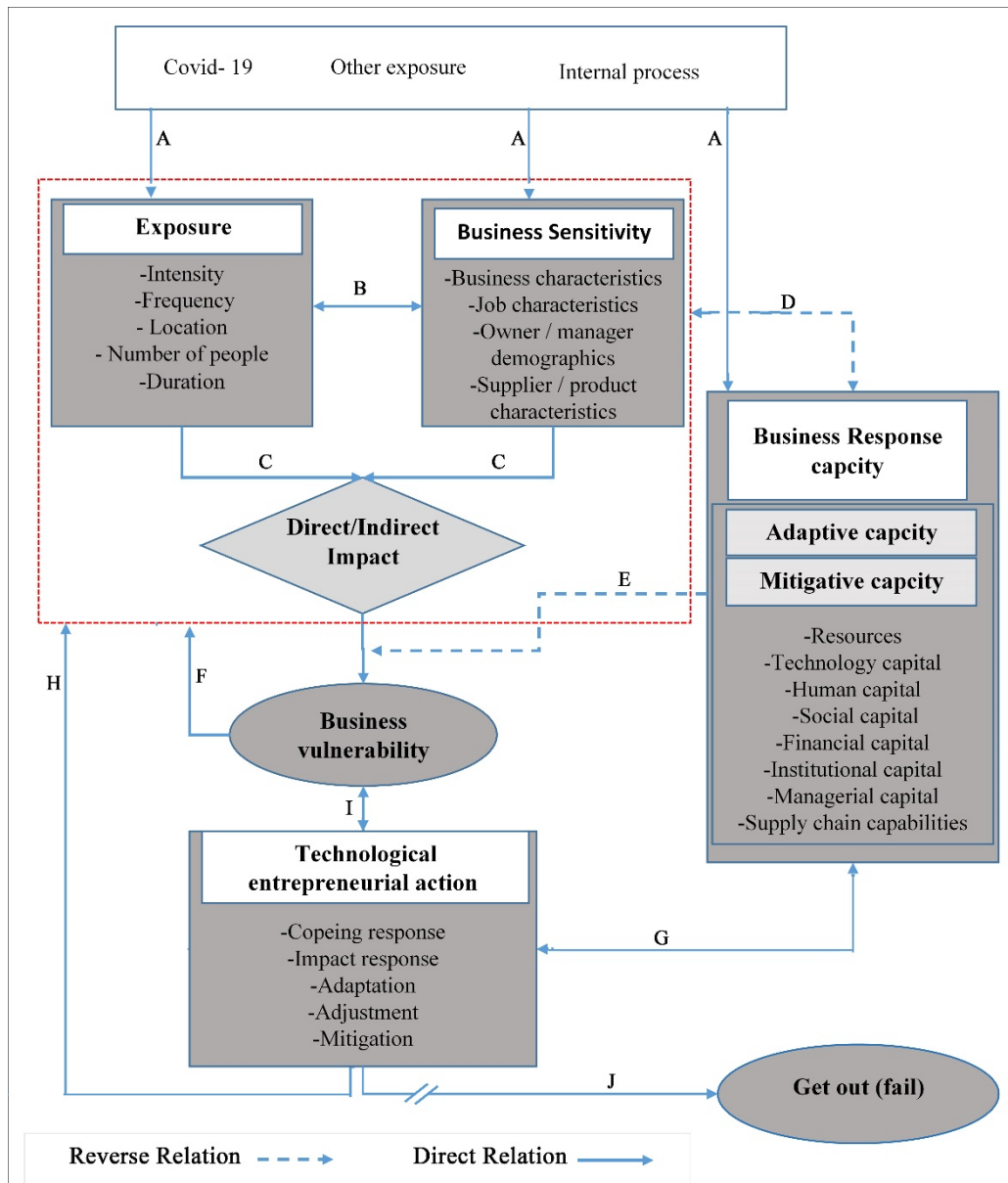
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Figure 1. Methodological approach



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Figure 2. Conceptual Framework

Lines A: hazards directly affect the business component of exposure, sensitivity and business response capacity. The greater the intensity, frequency, scope, duration, and rapidness of hazards, the higher the exposure and sensitivity, and the greater the business response capacity needed to reduce the impact of the hazards.

Line B: The component of exposure and sensitivity are directly related. The more exposure a business has, the more likely it is that the business will become more sensitive. This relationship is two-way. The more sensitive a business is, the more likely it is that the business will be exposed to hazards.

Lines C: Exposure and sensitivity have potential effects if overlapped. Potential effects are direct or indirect.

Line D: Business capacity inversely affects component exposure and sensitivity. The higher this capacity, the less businesses are exposed and the less sensitive the business is to hazards.

Line E: Business capacity inversely affects the direct or indirect impact that results from the overlap of sensitivity and exposure, and determines the severity of the business vulnerability.

Line F: Businesses may have current vulnerabilities. These current vulnerabilities affect vulnerabilities in the future and increase the severity of the vulnerability. Therefore, it is necessary to link the business vulnerability to the red rectangle to take into account the current business vulnerability.

Line G: business response capacity directly affects technological entrepreneurial actions. Businesses decide what to do based on their response capacity. This relationship is two-way. The actions of technology entrepreneurs may increase the business response capacity.

Line H: Technological entrepreneurial actions directly affect the exposure component and sensitivity. These actions, if done correctly, will make the business less exposure or reduce the business sensitivity to hazards.

Line I: Technological entrepreneurial action affect the reduction or increase of business vulnerabilities. This is a two-way communication. The degree of business vulnerability and Business Response capacity determines the actions of entrepreneurs.

Line J: Business will fail if the wrong actions are done and technology entrepreneurs fail to reduce the vulnerability.

1 **Table 1. Dimensions, components, and measures of components**

Determinants of Vulnerability	Vulnerability Indicators	Measures of components
exposure	Biological natural threats: An epidemic event (Coronavirus)	<ul style="list-style-type: none"> • Intensity • Frequency • Location • Number of people • Duration
Sensitivity	Business characteristics	<ul style="list-style-type: none"> • Business size • Business age • the number of business locations • economic sectors to which businesses belong/ Industry sector • sales previous • Legal ownership structure • Source of business • Business brand • Business culture • Business structure • Routines/ laws
	Job characteristic	<ul style="list-style-type: none"> • Complexity of system • interaction between elements of a system • Cascading failer
	Owner/manager demographics	<ul style="list-style-type: none"> • Gender (Male/Female) • Manager's quality/ supervisor's competence • Education

Determinants of Vulnerability	Vulnerability Indicators	Measures of components
		<ul style="list-style-type: none"> • Knowledge • knowledge of ways to serve markets, knowledge of customer problems, knowledge of markets, knowledge of technology
	Social capital	<ul style="list-style-type: none"> • opportunism; technology leakage; and conflict in between sharing and protecting knowledge • quality of social network • R&D consortium performance
	Economic capital	<ul style="list-style-type: none"> • Income diversity - Business model inflexibility • Lack of financial resources for technology adaptation and development
	Institutional capital	<ul style="list-style-type: none"> • Regulatory indicators: Business Freedom, Ease of starting up a business, Ease of closing a business, Property rights, The orientation of the country's financial system toward entrepreneurship, Economic freedom, Government policies, and taxes • Normative indicators: The societal perception of entrepreneurship as a good career choice, The perception of high societal status for

Determinants of Vulnerability	Vulnerability Indicators	Measures of components
		<p>successful entrepreneurship, the Media attention given to successful entrepreneurs</p> <ul style="list-style-type: none"> • Cognitive and individual aspects: Entrepreneurial intentions, Fear of failure, perception of perceived business opportunities, skills necessary for starting a business within the adult population, the percentage of the non-entrepreneurial adult population who personally knows someone who started a business in the previous two years (networks) • Supportive/ conducive indicators: ICT use/ laws, technological adoption, quality of scientific research institutions, university-industry collaboration in R&D, quality of education, availability of venture capital, availability of latest technology,
	<p>Infrastructure capital</p>	<ul style="list-style-type: none"> • Lack of proper infrastructure for digitalization • Business model dependence on platforms and open innovations • Access to partner data • Access to the creative ideas of others • Apply acquired strategy on platforms
	<p>resources</p>	<ul style="list-style-type: none"> • Inaccessibility and scarce resources and irreplaceable resources • High dependence on scarce resources

Determinants of Vulnerability	Vulnerability Indicators	Measures of components
	Managerial capital	<ul style="list-style-type: none"> • enterprises' strategic plans • Inability to make decisions in conditions of uncertainty • Types of management of vulnerability <p>(1-existence of unreported vulnerabilities; 2-trying to fix all identified vulnerabilities; 3-ineffective communication; 4-insufficient remediation resources; 5- fixing only "high" and "critical" vulnerabilities; 6- conceding broad or eternal exceptions; 7- mitigation without previous planning can be disastrous)</p>
	Supply chain capital	<ul style="list-style-type: none"> • Financial disruptions in the supply chain and customers • consumer behavior Changing • Dependence on partners in the supply chain