Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

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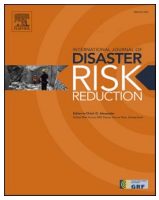

A reflection on the impact of the COVID-19 pandemic on Australian businesses: Toward a taxonomy of vulnerabilities

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ABSTRACT

The extant literature paints a grim picture of the COVID-19 impact on businesses around the world. However, in neither case has there been an attempt to evaluate the disproportionate impacts of the pandemic on the operation of different business sectors. To remedy this situation, this study utilises a cluster analysis to develop a taxonomy of vulnerabilities based on the industry-specific vulnerability indicators for 83 business sectors in the economy of Australia. The proposed taxonomy groups businesses into three clusters, labelled as vulnerable to business to people (B2P), vulnerable to business networking, and vulnerable to external factors. The differing vulnerability of businesses to the recent pandemic raises a fundamental question about how best to build resilience to reduce vulnerabilities. Built on the vulnerability characteristics identified in the taxonomy, this article suggests factors that contribute to the resilience of businesses in each cluster. Further, the present paper develops a novel validation method to demonstrate the goodness of the clustering results. Business leaders and government officials might draw considerable assistance from the taxonomy of vulnerabilities presented herein to build more resilient businesses to crises.

1. Introduction

The year 2020 witnessed a global outbreak, known as the COVID-19 pandemic, which plunged the world economy into the worst contraction on record since the Great Depression [1]. Many businesses have been teetering on the edge of a pandemic crisis over the past two decades. The 2003 SARS outbreak in southwest China and Hong Kong attacked the global IT supply chain and forced many electronic manufacturing plants to shut down [2]. The economic loss of the 2015 MERS outbreak extended beyond its origin in the Middle East and caused a substantial loss in the tourism-related industries around the world [3]. Deleterious effects of previous outbreaks on the economy were well known prior to the recent outbreak. However, the COVID-19 pandemic has presented unprecedented challenges not only to the lives of people but also to business operations around the world [4,5]. What is unique about the recent pandemic is the breadth and diversity of its impacts on businesses [6].

Much of the research on the impacts of the COVID-19 pandemic on firms and businesses is currently under development. Some efforts have recently been made to determine the changes and adjustments that businesses have to undertake in order to respond to the pandemic [7,8]. A theme within the existing literature is to examine few vulnerability indicators such as home confinement and social distancing that affect the functionality of different firms and businesses [9,10]. However, while the disproportionate impact of the pandemic across business sectors is widely recognised [11], research on this topic rests on a narrow range of vulnerability indicators and therefore is not perceived as realistic to classify businesses based on the key firm-specific characteristics that make some businesses more vulnerable to the pandemic. Indeed, building resilience in businesses to respond rapidly during this time of volatility requires a thorough understanding of where the vulnerabilities are for various business sectors. This study fills a significant gap in evaluating and classifying a variety of factors that disproportionally contribute to the vulnerability of businesses to the pandemic. In this vein, we develop a taxonomy of vulnerabilities based on the industry-specific vulnerability indicators across different sectors of the economy in Australia.

Our first step is to identify the key business vulnerabilities manifested through the COVID-19 pandemic. We procure data from an industry research company IBISWorld dataset (www.ibisworld.com), which has been created to determine the impact of the recent pandemic on 83 business sectors in the economy of Australia. The focus on a diverse set of business sectors allows us to draw a conclusion on a wide range of the firm-specific vulnerability characteristics and hence to

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enhance the generalisability of our findings in Australia. In the second step, we conduct a cluster analysis to group these sectors into meaningful groups of businesses that are different in their vulnerability to the recent outbreak. The third step develops a taxonomy of vulnerabilities based on the vulnerability characteristics of businesses in each cluster. Finally, our empirical strategy uses the proposed taxonomy to offer suggestions to strengthen the resilience of businesses in each cluster in the current context of the COVID-19 pandemic.

Two theoretical contributions can be made from this study. First, this article links the industry-specific vulnerability characteristics, identified in the proposed taxonomy, to the concept of business resilience. This link provides a better understanding of the vulnerability of business sectors to the recent pandemic and subsequently sets a basis for theory development in business resilience research. In fact, the link between the proposed taxonomy and the notion of business resilience enables researchers to understand more situation-specific resilience research. This, in turn, allows researchers to develop and test the theory in a given business environment [12]. Second, cluster validation as an important component of cluster analysis presents a conundrum, as it is computationally time-consuming [13]. Rooted in entropy theory, this work generates, for the first time, a novel cluster validity index (presented in Appendix A) that quantifies the validity of the clustering results in an efficient and parsimonious way. The proposed index conforms to the intuition of cluster validation because it measures the heterogeneity of clusters that can be interpreted as the extent of variability within and between clusters.

This paper proceeds as follows. The next section outlines the view of the extant literature on the impacts of the current pandemic on businesses across the world. The "Materials and methods" section provides the descriptions of data and statistical analysis used in this research. The paper then develops a taxonomy of vulnerabilities based on the industry-specific vulnerability characteristics of business sectors across Australia. The "Implications for practice" section covers the practical implications of this work. Conclusions, limitations, and future directions for research are discussed in the end. Finally, Appendix A presents the evaluation of the validity of the cluster analysis.

2. The literature viewpoint of the COVID-19 impacts on businesses

A year after coronavirus was officially declared as a pandemic, the academic literature is witnessing the growing torrent of studies about the impact of pandemics on the functionality of businesses and organisations. Broadly classifying, the literature on this topic follows two main streams of research. The first stream concentrates on the impacts of the outbreak on the people aspect of the business, and the second stream studies changes to business processes during and after the pandemic.

2.1. COVID-19 and people in businesses

This stream of research places people at the centre and focuses on various attributes such as roles, collaboration, attitude, and behaviour in the context of the COVID-19 pandemic. The studies in this category treat people as the key elements of businesses in the fight against the pandemic. Subsequently, an attempt is made to investigate how behavioural and attitudinal attributes of business leaders and employees, the culture of collaboration during the pandemic, and the new social norms affect businesses and vice versa.

Business lead managers and owners: The literature has acknowledged the central role of business leaders and owners to the challenge of COVID-19 [14]. Filimonau et al. [15] studied the organisational commitment of senior hotel managers during the pandemic by taking into account the interdependencies between organisational capital, corporate social responsibility, and organisational resilience. Contreras et al. [16] discussed the emergence of a new type of leadership, called e-leadership, in the pandemic working environment where remote working is embraced by many organisations. The findings of the study highlighted the necessity of applying changes in the hierarchical forms of leadership, the development of intercultural competencies for effective communication with team members, and the technology competencies of managers and employees.

Social Capital and collaboration: Since the pandemic began, there has been growing realisation regarding the importance of social capital to succeed through the crisis [17–19]. The literature has also suggested the inter-organisational learning through knowledge sharing between business partners as a key success factor in mitigating the negative effects of the crisis [20]. Furthermore, researchers and practitioners alike stressed the significance and importance of collaborative endeavours between business partners, employees, and customers to prepare for and recover from the COVID-19 pandemic [21–23].

Behavioural attributes: The restrictions imposed by many countries along with the fear of contagion have significantly influenced consumers' sentiment and behaviour. Goolsbee and Syverson [24] examined the effect of consumers' behaviour on the pandemic economic slowdown, concluding that the fear of infection results in a higher rate of drop in consumer visits compared with government-imposed restrictions. Akhtar et al. [25] investigated the consumers' psychological reactance to the imposed restrictions due to the pandemic. The study evaluated the correlation between perceived choice confidence and consumers' reactance. In terms of behavioural economics in times of pandemic, Gómez et al. [26] suggested that people's behaviour should be viewed from three different perspectives: 1) employees' mental health, 2) potential innovativeness when working in isolation, and 3) personal growth.

New social norms: Social norms refer to the rules of belief, attitude, and behaviour that inform people how to construe and act in a given situation [27]. The COVID-19 pandemic has led to a new normal through the adoption of specific behaviours and rules [28] such as social distancing, wearing masks, quarantine rules, and work from home. The recent literature has studied the impact of these social norms on the performance of people in businesses. For instance, Dingel and Neiman [9] evaluated the economic impact of social distancing during the recent pandemic. Based on the results of a survey, the authors identified the feasibility of work from home for various industry sectors in the United State. Popkova et al. [29] investigated how the social distancing conditions during the COVID-19 pandemic have affected, and consequently have changed, the practices of corporate social responsibility of firms. Wang et al. [30] explored the challenges that employees faced when they were working from home during the coronavirus outbreak. The authors further determined the key characteristics of work from home that affect these challenges.

2.2. COVID-19 and business processes

The COVID-19 pandemic has brought the necessity of effective business processes into sharp focus. Consequently, a question of particular interest has preoccupied academic scholars: how has the pandemic unleashed unprecedented changes in businesses? Accordingly, the literature in this stream attempts to answer this question by examining the impact of the outbreak on key areas of business processes such as innovation, digitalization, operational processes, and business management frameworks.

Innovation, technology, and digitalization: Innovation appears in the literature as a crucial requirement for business thriving in the current unprecedented outbreak crisis [31]. Triggered by the pandemic, Morley and Clarke [32] emphasised an urgent need for innovation in social work education by rethinking and reconfiguration of many aspects of the education. Breier et al. [33] observed the positive impacts of business model innovation on alleviating the negative consequences of the lockdown in six hospitality firms in Austria. In times of pandemics, business scholars and practitioners around the globe have shifted their attention towards e-commerce platforms [34]. The recent crisis has

indeed motivated businesses to enhance their digital infrastructure. The extant literature has widely advocated the use of technologies including Internet of Things (IoT), artificial intelligence, and 5G to mitigate the deleterious effects of the pandemic [35,36]. Empirical evidence in the work by Katz et al. [37] confirms the enabling role of digital infrastructure to reduce the negative effects of the pandemic.

Operational processes: A large number of works in business research have studied the significance of changes in operational processes to dissipate the disruptions caused by the pandemic [38]. Based on the empirical data obtained from small hospitality businesses across eight countries, Alonso et al. [39] identified key concerns of business owners associated with the COVID-19 pandemic. The authors have suggested changes and adjustments to the day-to-day activities of businesses to cope with the pandemic. Furthermore, to facilitate business responses to the current pandemic, Rashad and Nedelko [40]; and Leong and Hock [41] posited lean and agile frameworks to move beyond the traditional approaches to supply chain management. In addition, managing more localised suppliers has been advocated in the literature. Many studies have favoured the fact that the localised suppliers can reduce the disruption risks and builds higher organisational reliability [8,42].

Business management frameworks: To address challenges in times of the COVID-19 crisis, some studies encourage businesses to implement the situation-specific risk and resource management framework. In particular, the literature has drawn attention to the backup supply resources that enable firms to acquire their required resources in a short period of time [43]. Additionally, the literature has given notes to the development of a customized risk management framework based on the capability and unique characteristics of firms in order to support businesses during this challenging time [44].

2.3. Analysis of the reviewed literature

The findings of the reviewed literature can be outlined as follows.

1) The recent pandemic has not affected all businesses equally. The existing studies do not capture the differing susceptibility of businesses to the pandemic. In its current state, the literature has predominantly studied the impact of the pandemic on people and business processes without examining the varied impact of the pandemic on different business sectors. There is, therefore, the need for an indicator-based approach to compare the differing impact of the pandemic on the performance of different firms.
2) While a body of work exists for evaluating the impact of the COVID-19 pandemic on the functionality of businesses as well as the suggestions to mitigate the detrimental effects of the outbreak, the knowledge of business vulnerabilities is not sufficiently consolidated. The extant literature either does not specify any indicator of vulnerability at all or is confined to a single vulnerability indicator (for example, social distancing).
3) As the literature review reveals, a great deal of recent studies on the impact of the pandemic has undertaken qualitative research. These studies have mainly provided a qualitative perception of the COVID-19 impact on businesses. The development of quantifiable indicators based on empirical data is a blind spot that has not been addressed to date.

3. Materials and methods

3.1. Variables and measures

The data for our research was obtained from the official website of an industry research company IBISWorld (www.ibisworld.com), which is sourced from IBISWorld's Industry Wizard, IBISWorld's Business Environment Database, Business. gov.au, and the Australian Bureau of Statistics. The report classifies the level of vulnerability to the COVID-19 pandemic for 83 business sectors in the economy of Australia. These sectors are further classification of 19 industry in which they operate. Table 1 reports these 19 divisions and their constituent 83 business sectors. As reported by this table, 15 out of 83 (18%) businesses in the dataset operate in the manufacturing industry (C division), followed by 10% in the transport postal and warehousing sector (I division) and 8% in the information media and telecommunication field (J division). The remaining businesses are distributed across 16 other divisions.

We define the term "vulnerability" as the susceptibility of a business to suffer a loss of functionality when it is exposed to a disturbance arising from internal and external risks [45]. In this vein, business vulnerability is viewed as a concomitant of a disturbance or crisis [46]. Thus, this research takes into account the mutual conditioning of vulnerability and crisis. More specifically, we analyse the vulnerability of a firm based on its exposure to a crisis as well as the susceptibility factors that lead to a drop in the performance of the firm in the face of a crisis.

We utilise seven indicators of business vulnerability indicated in the data source. These vulnerability indicators allow the identification of factors that affect the performance of business sectors during the pandemic. More specifically, these indicators show how vulnerabilities are generated and indicate the risks that businesses face during the pandemic. The choice of the vulnerability indicators is driven by the following factors.

- Government restrictions during the pandemic including home confinement, social distancing, and business classification as essential/non-essential
- Sector-specific factors including reliance on workers and suppliers as well as importing and exporting activities
- Macroeconomic changes due to the pandemic such as changes in the GDP growth and number of travellers

Set out below the seven vulnerability indicators are briefly described.

Work From Home (WFH) Capacity: Some businesses may lend themselves more easily to work remotely, whereas others may struggle with remote working during the outbreak. Home confinement has increased the vulnerability of some businesses and consequently has made certain occupations such as blue-collar workers more vulnerable to this crisis [47]. Many businesses such as food services, healthcare, manufacturing, and transportation have not been able to operate remotely, thereby rendering them more vulnerable during the pandemic.

Social Distancing: The health ramifications of the COVID-19 pandemic have resulted in imposing social distancing restrictions on business operations. While many firms have responded to these restrictions by modifying their workplaces, many other businesses that are heavily reliant on face-to-face communications have been significantly disrupted in their operations [10].

Essential Business: The lockdown policies implements by governments across the world have had disproportionate impacts on businesses. Some businesses in a particular industry such as agriculture and food processing are deemed essential and have been allowed to remain, while others such as hospitality businesses have been mainly banned [48].

Key External Drivers (KED) Exposure: The KED exposure measures the impacts of macroeconomic indicators on businesses amid the COVID-19 pandemic. The examples of macroeconomic indicators are GDP growth, the number of travellers to a country, exchange rates, and consumer disposable income. The impacts of these factors on businesses vary based on the firm-specific characteristics including liquidity, size, and growth [49].

Trade Exposure: This variable is concerned with the impact of international trade exposure on the performance of firms in the wake of the COVID-19 pandemic. The underlying concept is the fact that disruptions in importing or exporting activities and the complexity of managing global operations during the pandemic can be detrimental to trade-

Table 1
The studied divisions and business sectors in Australia.

Code	Business Sector	Code	Business Sector
A	**Agriculture, Forestry & Fishing**	**I**	**Transport Postal & Warehousing**
A01	Agriculture	I46	Road Transport
A02	Aquaculture	I47	Rail Transport
A03	Forestry & Logging	I48	Water Transport
A04	Fishing, Hunting & Trapping	I49	Air & Space Transport
A05	Agriculture, Forestry & Fishing Support Services	I50	Other Transport
B	**Mining**	I51	Postal & Courier Pick-up & Delivery Services
B06	Coal Mining	I52	Transport Support Services
B07	Oil & Gas Extraction	I53	Warehousing & Storage Services
B08	Metal Ore Mining	**J**	**Information Media & Telecommunications**
B09	Non-Metallic Mineral Mining & Quarrying	J54	Publishing (except Internet & Music Publishing)
B10	Exploration & Other Mining Support	J55	Motion Picture & Sound Recording Activities
C	**Manufacturing**	J56	Broadcasting (except Internet))
C11	Food Product Manufacturing	J57	Internet Publishing & Broadcasting
C12	Beverage & Tobacco Product Manufacturing	J58	Telecommunications Services
C13	Textile, Leather, Clothing & Footwear Manufacturing	J59	Internet Service Providers, Web Search Portals & Data Processing Services
C14	Wood Product Manufacturing	J60	Library & Other Information Services
C15	Pulp, Paper & Converted Paper Product Manufacturing	**K**	**Finance**
C16	Printing (including the Reproduction of Recorded Media)	K62	Finance
C17	Petroleum & Coal Product Manufacturing	K63	Insurance & Superannuation Funds
C18	Basic Chemical & Chemical Product Manufacturing	K64	Auxiliary Finance & Insurance Services
C19	Polymer Product & Rubber Product Manufacturing	**L**	**Rental, Hiring & Real Estate Services**
C20	Non-Metallic Mineral Product Manufacturing	L66	Rental & Hiring Services (except Real Estate)
C21	Primary Metal & Metal Product Manufacturing	L67	Property Operators & Real Estate Services
C22	Fabricated Metal Product Manufacturing	**M**	**Professional, Scientific & Technical Services**
C23	Transport Equipment Manufacturing	M69	Professional, Scientific & Technical Services (Except Computer System Design & Related Services)
C24	Machinery & Equipment Manufacturing	M70	Computer System Design & Related Services
C25	Furniture & Other Manufacturing	**N**	**Administrative & Support Services**
D	**Electricity, Gas Water & Waste Services**	N72	Administrative Services
D26	Electricity Supply	N73	Building Cleaning, Pest Control & Other Support Services
D27	Gas Supply	**O**	**Public Administration & Safety**
D28	Water Supply, Sewerage & Drainage Services	O75	Public Administration
D29	Waste Collection, Treatment & Disposal Services	O76	Defence
E	**Construction**	O77	Public Order, Safety & Regulatory Services
E30	Building Construction	**P**	**Education & Training**
E31	Heavy & Civil Engineering Construction	P80	Preschool & School Education
E32	Construction Services	P81	Tertiary Education
F	**Wholesale Trade**	P82	Adult, Community & Other Education
F33	Basic Material Wholesaling	**Q**	**Health Care & Social Assistance**
F34	Machinery & Equipment Wholesaling	Q84	Hospitals
F35	Motor Vehicle & Motor Vehicle Parts Wholesaling	Q85	Medical & Other Health Care Services
F36	Grocery, Liquor & Tobacco Product Wholesaling	Q86	Residential Care Services
F37	Other Goods Wholesaling	Q87	Social Assistance Services
G	**Retail trade**	**R**	**Arts & Recreation Services**
G39	Motor Vehicle & Motor Vehicle Parts Retailing	R89	Heritage Activities
G40	Fuel Retailing	R90	Creative & Performing Arts Activities
G41	Food Retailing	R91	Sport & Recreation Activities
G42	Other Store-Based Retailing	R92	Gambling Activities
H	**Accommodation & Food Services**	**S**	**Other Services**
H44	Accommodation	S94	Repair & Maintenance
H45	Food & Beverage Services	S95	Personal & Other Services

dependent businesses [50].

Labour Intensity: The industry reliance on workers can be an indicator of the potential vulnerability of businesses to the recent outbreak. This can be attributed to the restrictions imposed by the government to slow the spread of COVID-19. In particular, many foreign workers across the world have been incapacitated due to government restrictions [51]. For example, the travel restrictions imposed by the Australian government have led to labour shortages to fulfil the agricultural industry's need.

Supply Chain Exposure: A robust and resilient network of suppliers is a key ingredient for business continuity in the times of the COVID-19 pandemic. In calling for a resilient business that can stay on top of challenges during the pandemic, substantial emphasis has been placed on the significance of a reliable supply chain network [52,53].

In the available dataset, a set of linguistic variables is used to indicate the level of vulnerability of a given business sector to the COVID-19 pandemic. The linguistic variables are represented as very high, high, medium, low, and very low. In the next step, we operationalise the vulnerability indicators by turning these linguistic variables into measurable variables. In doing so, a five-point scale, ranging from 1 to 5, is adopted. This five-point scale indicates the vulnerability of businesses to a given indicator where 1 denotes a very low vulnerability to the indicator, whereas 5 implies the highest vulnerability. Since space does not permit, rather than providing a detailed list of operationalised variables, we present Fig. 1 to illustrate the operationalisation of the vulnerability indicators for various business sectors.

3.2. Descriptive statistics

Table 2 provides descriptive statistics for the business vulnerability indicators. As shown in this table, labour intensity (mean = 3.88) is the greatest contributor to the vulnerability of Australian businesses to the COVID-19 pandemic. Other important vulnerability indicators are WFH capacity (mean = 3.81), supply chain exposure (mean = 3.73), and essential business (mean = 3.67). Among the vulnerability indicator, KED exposure (mean = 1.40) is the least important indicator. We observe a relatively high diversity in the vulnerability of businesses to trade exposure (SD = 1.34), whereas business sectors exhibit a low variation in terms of offering essential or non-essential services during the pandemic (SD = 0.72).

In terms of the percentage of businesses that are vulnerable to different vulnerability characteristics, 49.40% of businesses in Australia have shown a high level of vulnerability (VS = 4) to the WFH capacity. A high percentage of businesses (43.37%) have also experienced a high

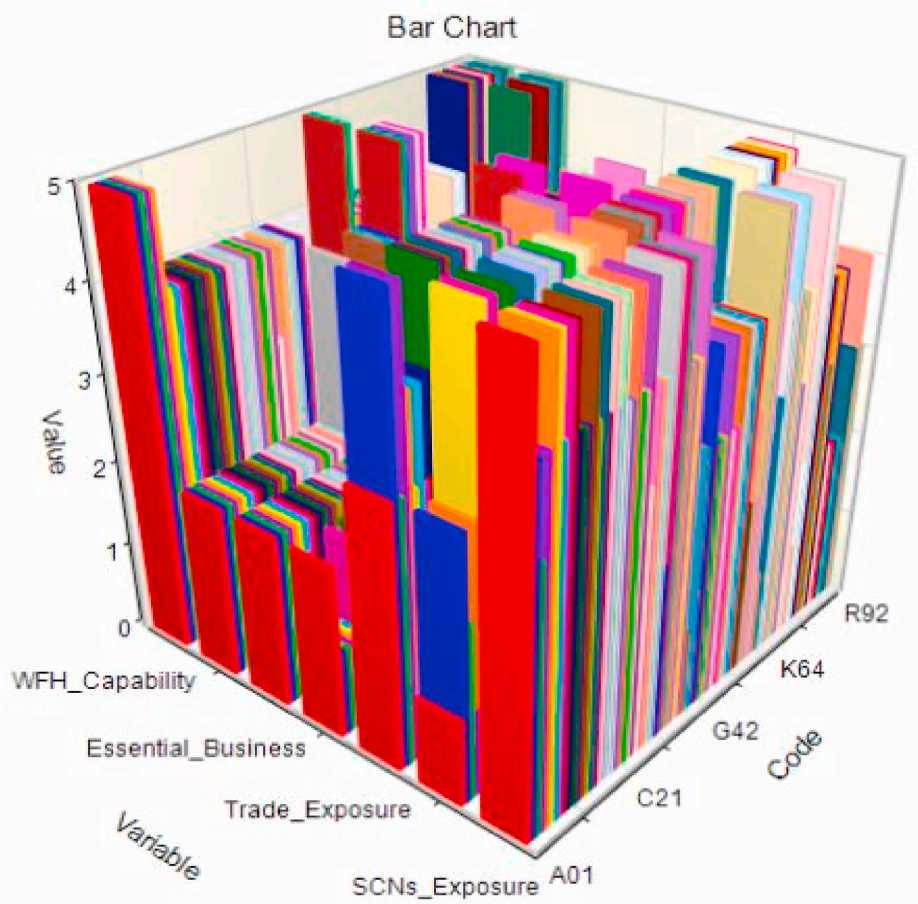

Fig. 1. Operationalisation of business vulnerability indicators for business sectors.

Table 2
Descriptive statistics of the business vulnerability indicators.

Vulnerability Indicator	N	Mean	SD	VS (Percentage Distribution)				
				1	2	3	4	5
WFH Capability	83	3.81	0.97	4.82	2.41	21.69	49.40	21.69
Social Distancing	83	2.67	1.19	7.23	56.63	10.84	12.05	13.25
Essential Business	83	3.67	0.72	1.20	78.31	7.23	13.25	0.00
KED Exposure	83	1.40	0.88	78.31	9.64	8.43	1.20	2.41
Trade Exposure	83	3.31	1.34	16.87	3.61	34.94	20.48	24.10
Labour Intensity	83	3.88	1.15	6.02	4.82	21.69	30.12	37.35
Supply Chain Exposure	83	3.73	1.06	3.61	10.84	18.07	43.37	24.10

Notes: SD: Standard Deviation; VS: Vulnerability Score (1 = very low, 2 = low, 3 = medium, 4 = high, 5 = very high).

level of vulnerability to SCNs (VS = 4). With regard to the labour intensity, 30.12% and 37.35% of business sectors in Australia exhibit high (VS = 4) and very high (VS = 5) levels of vulnerability respectively. On the other hand, 1.20% and 2.41% of businesses account for, respectively, a high (VS = 4) and a very high (VS = 5) degree of vulnerability to the KED exposure. 79.51% of Australian businesses are deemed as essential businesses (VS = 1 and VS = 2), allowing them to operate during the COVID-19 pandemic.

3.3. Cluster analysis

Cluster analysis as an exploratory statistical analysis is used in this research to group 83 business sectors presented in Table 1. By doing so, each sector is grouped based on the maximum similarity within a group and maximum dissimilarity between groups. We employ the Partitioning Around Medoids (PAM) algorithm as the most well-established approach for cluster analysis [54]. The gist of PAM algorithm is to find a set of representative objects, known as medoid, in the sense that the average dissimilarity between a medoid and all other variables within the cluster is minimum. In line with this, we measure the degree of similarity/dissimilarity between data points by means of the Euclidian distance. Since PAM identifies the clusters through medoids, it generates less sensitivity to outliers compared with other clustering algorithms such as K-mean and fuzzy clustering. Additionally, the results of PAM are independent of the order of presentation of patterns [55].

Cluster analysis is performed in two steps. First, we construct a dendrogram to decide on the number of clusters. Second, we proceed with classifying observations using the PAM algorithm. Using the dendrogram, we decide on the number of clusters based on the homogeneity of groups as well as the percentage of increase at each subsequent stage of clustering. Fig. 2 depicts the dendrogram constructed in the first step of the cluster analysis. As shown in Fig. 2, by selecting three

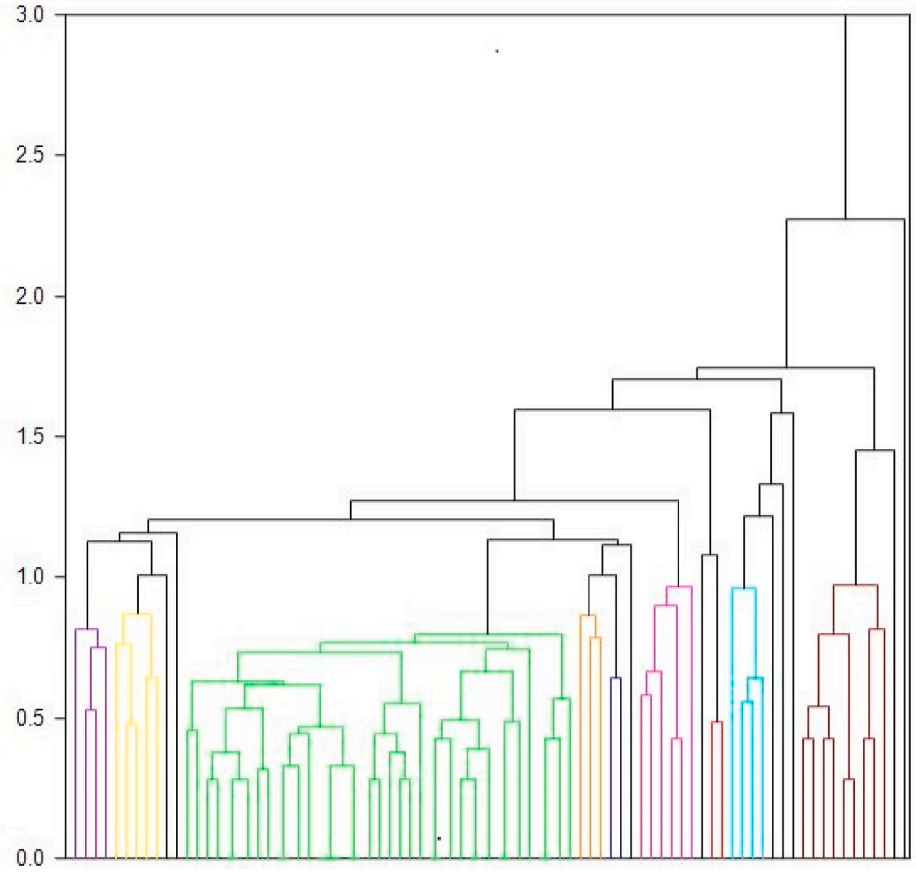

Fig. 2. Dendrogram constructed in the first step of cluster analysis.

clusters, the samples are divided into much more homogeneous groups than does five clusters. Thus, we set the number of clusters to 3 for the PAM algorithm.

In the second step, we use the PAM algorithm to assign the business sectors to three clusters, such that the degree of vulnerability of businesses within each cluster is similar to one another with respect to the vulnerability indicators. This can be done by defining the medoid of each cluster. The clusters are then created by assigning each business sector to the closest medoid. Fig. 3 plots the final medoids of clusters. It should be noted that the medoid of clusters for vulnerability indicators are the corresponding mean values. Table 3 presents the results of the cluster analysis.

Table 3
The results of cluster analysis using the PAM algorithm.

Cluster	No.	Business Sectors
1	24	S95,R92,R91,R89,P82,H45,R90,H44,P80,Q87,I48,I49,O76,P81, J60,Q86,G 39,J55,G41,Q85,G40,N72,G42,I47
2	33	C19,C15,C18,C22,C13,C17,C24,C12,C20,C11,C23,C14,B10,F34, I52,J58,B06,O77,F37,F35,D28,Q84,C25,F33,B08,C16,F36,C21, I50,A02,I53,A05,B07
3	26	L67,L66,O75,D27,M70,K64,M69,E30,K63,D29,K62,A03,A01,J57, I46,S94,J59,A04,E31,E32,I51,N73,J56,D26,B09,J54

Fig. 3. Graphical presentations of medoids of the three identified clusters.

4. A taxonomy of vulnerability of business clusters

This section is intended to interpret the three clusters identified in the preceding section. Further, we assign a label to each cluster that describes the vulnerability characteristics of the cluster. Table 4 reports the 83 business sectors that have been grouped within the three identified clusters. The size and name of clusters have been also presented in Table 4.

4.1. Cluster 1: vulnerable to business-to-people (B2P)

24 out 83 business sectors (29%) are grouped into the first cluster. The representative examples of business sectors in this cluster are retail trade, accommodation& food service, education & training, and Art &recreation services. These businesses are highly reliant on person-to-person interactions and exhibit a very low capacity for working from home. The businesses within this cluster rely on workers to perform their operations and the social distancing measures greatly affect their functionalities. Thus, we call this group of businesses *vulnerable to B2P*. Business sectors in this cluster are mainly considered as non-essential businesses with a cluster mean of 4, rendering the businesses vulnerable to closing their operations in the case of tight restrictions imposed by the government. In terms of the reliance on international trade as well as the exposure to SCNs, this cluster exhibits a medium level of vulnerability (cluster mean of 3 for SCNs exposure). The radar chart, shown in Fig. 4, visualises the percentage of businesses in each division that are classified under this cluster. The points plotted on the perimeter of the chart represent the main divisions in the economy of Australia and the radial depth indicates the percentage of businesses in these divisions. As expected, all businesses of divisions G (retail trade), H (accommodation and food services), P (education and training), and R (arts and recreation services) are grouped under this cluster.

Fig. 5 illustrates the vulnerability of business sectors against the three indicators of business vulnerability, namely social distancing, WFH capacity and labour intensity. As shown in this figure, the first cluster occupies a region of the chart enclosed in the circle, which is distinguished by the high group mean values of the three indicators of business vulnerability discussed above. In fact, the colours in Fig. 5 (in the online version of this article) reflect the level of vulnerability to the vulnerability indicators. The red colour of the enclosed region shares a strong emphasis on the vulnerability of businesses to the people-related vulnerability indicators represented by the three axes of the chart.

4.2. Cluster 2: vulnerable to business networking

This cluster is the largest cluster and includes 33 (40%) of the 83 business sectors such as manufacturing and wholesale trade. The exposure to SCNs and the reliance on international trade play key roles in differentiating the members of this cluster from the other two clusters. With the cluster mean values of 4, this cluster experiences high vulnerability to the exposure to SCNs and international trade. Therefore, we label the firms within this cluster *vulnerable to business networking*. In addition, the group mean value of 2 positions the firms within this cluster as essential businesses, thereby rendering them less susceptible

Table 4
The clusters' labels and their constituent business sectors.

Cluster	No.	High Vulnerability to	Label
1	24	WFH capacity Social Distancing Essential Business	Vulnerable to B2P
2	33	Trade Exposure Labour Intensity SCNs Exposure	Vulnerable to business networking
3	26	KED Exposure SCNs Exposure	Vulnerable to external factors

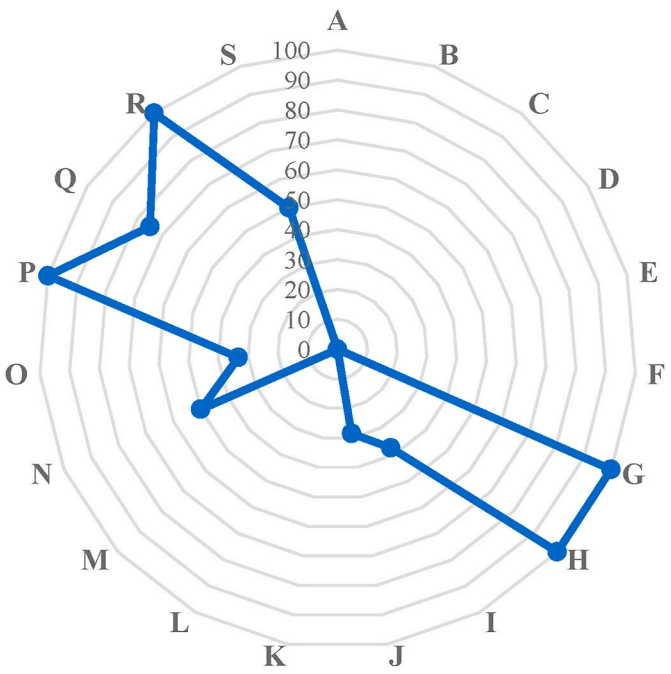

Fig. 4. Radar chart showing the percentage of businesses in the first cluster.

to closure. Note that the second cluster is also vulnerable to labour intensity as many businesses in this cluster are reliant on workers. Fig. 6 plots the percentage of businesses in the 19 divisions, which have been grouped under the second cluster. As shown in this figure, 100% of businesses in divisions C (manufacturing) and F (wholesale trade) are clustered in this category. The fact that these two divisions rely heavily on interactions within SCNs as well as importing and exporting activities makes this an unsurprising result.

The area enclosed by the circle in Fig. 7 represents three key characteristics of the second cluster. The same colour of the enclosed region in this figure (in the online version of this article) indicates the same range of values for vulnerability indicators. As can be observed, the mean values of labour intensity, SCNs exposure and trade exposure in the enclosed region are 4. This indeed illustrates the high vulnerability of businesses in this cluster to these three vulnerability indicators, from which two indicators are related to the network of national and international relationships with suppliers and trades.

4.3. Cluster 3: vulnerable to external factors

The third cluster, which we label as *vulnerable to external factors*, consists of 26 business sectors. The representative examples of businesses in this cluster are construction, finance, real estate services, and professional, Scientific &technical services. With the cluster mean value of 4, the businesses in this cluster represent a high vulnerability to SCNs exposure. Moreover, the group mean value of this cluster for the KED exposure is 2, which is higher than the other two clusters. In fact, the businesses in this group are characterised by relatively high exposure to the macroeconomic drivers such as cost of raw material, the Australian GDP growth, and consumers' disposable income. Fig. 8 graphs the percentage of business sectors that are classified into the third cluster. A glance at this figure reveals that 100% of businesses within the four divisions that are mainly deemed as non-essential businesses with a high degree of exposure to macroeconomic factors are grouped in this cluster. These four divisions are E (construction), K (finance), L (rental, hiring and real estate services), and M (professional, scientific and technical services).

The segment enclosed by a circle in Fig. 9 represents businesses in this cluster with the relatively high vulnerability indicators for the

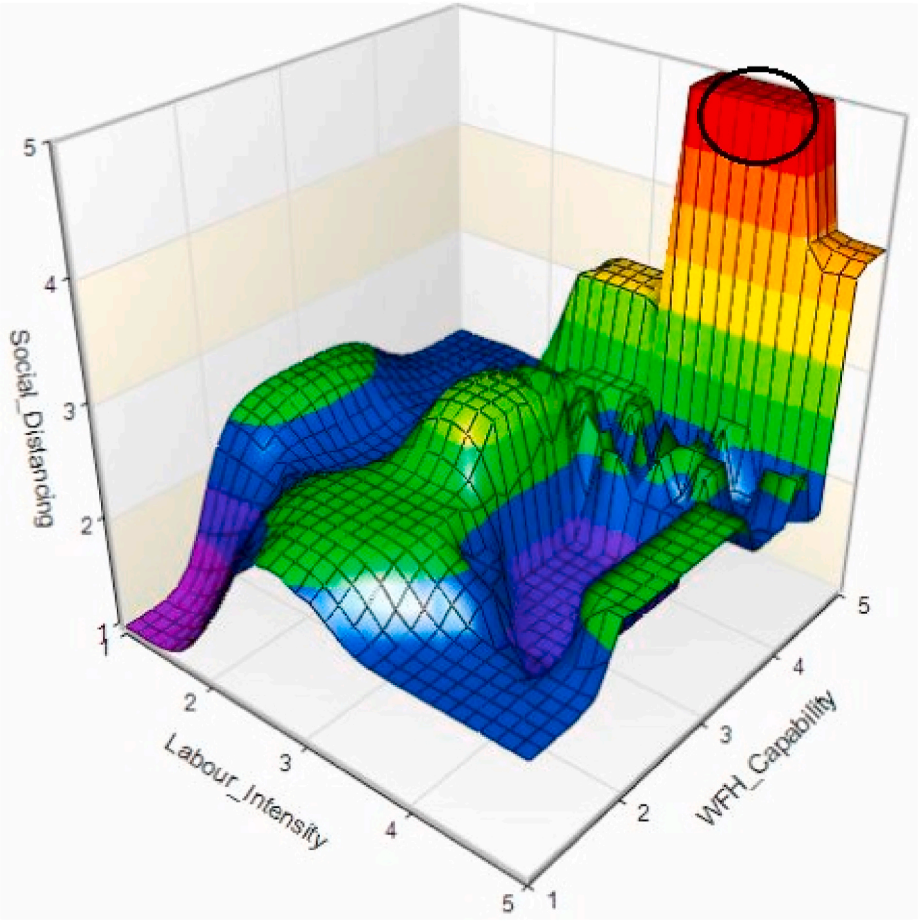

Fig. 5. Surface plot of business sectors against three vulnerability indicators: social distancing, WFH capability, and labour intensity.

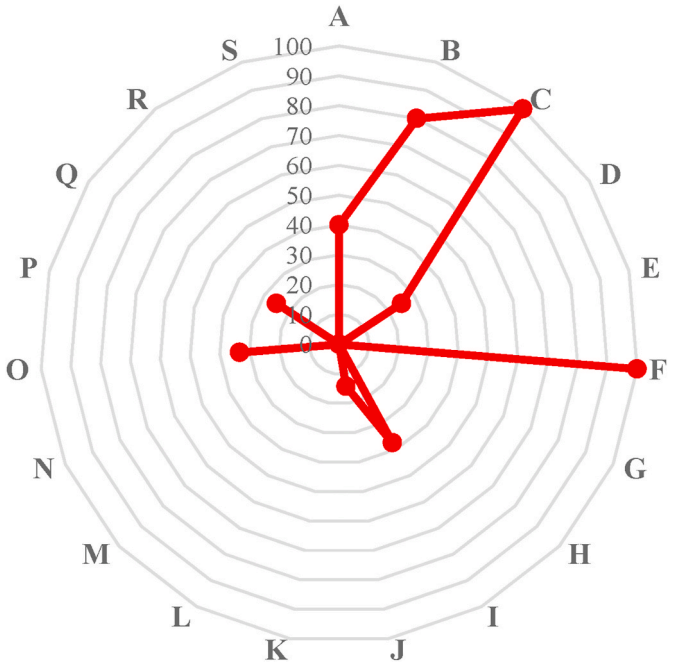

Fig. 6. Radar chart showing the percentage of businesses in the second cluster.

essential business, SCNs exposure and KED exposure. As can be seen in this figure, the corresponding mean value of the KED exposure is 2, which is clearly above the mean value of 1 corresponding to the KED exposure for the businesses in the first and second clusters. The vulnerability indicator combinations that lie on the surface plot but outside the enclosed region become more dissimilar to the key characteristics of this cluster as they move further away from the enclosed circle.

5. Building business resilience to vulnerability

In the highly uncommon and unique situation of the COVID-19 pandemic, building resilience in businesses to succeed through the current crisis is of great importance. Built on the vulnerability characteristics identified in the proposed taxonomy, this section suggests factors contributing to the resilience of businesses in each cluster. Table 5 outlines recommendations that assist businesses within different clusters to respond to the pandemic.

Contributing factors for building resilience in cluster 1: The first stream of business enablers includes the factors that allow firms to bolster their resilience to B2P vulnerability. In this context, the awareness of the business owners, customers, and employees to disruptive changes is a key success factor to enhance resilience [56,57]. This can be achieved through staff training [58], information sharing within firms (Mandal, 2017), and establishing repositories of knowledge obtained from previous disruptions [59]. Furthermore, as the literature review revealed, the COVID-19 outbreak has confirmed the revolutionary role of digitalization and technology in the way businesses engage with customers during the pandemic [60]. In fact, the social distancing measures have pushed businesses to adopt new technologies to successfully serve their

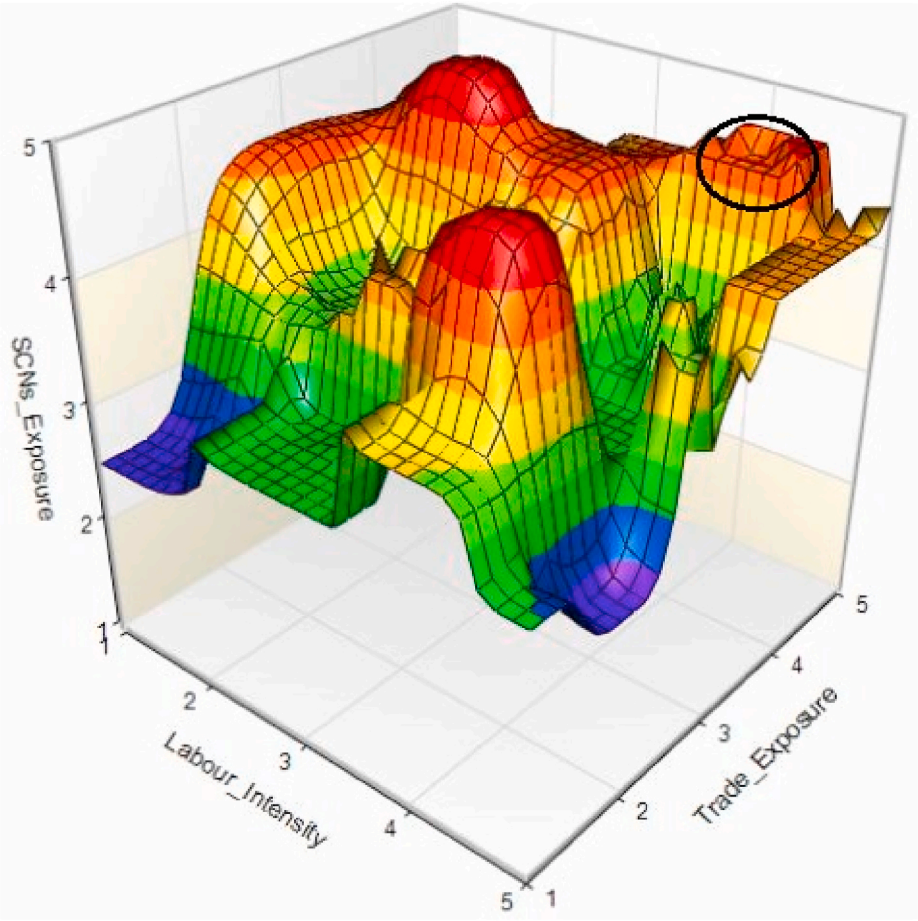

Fig. 7. Surface plot of business sectors against three vulnerability indicators: SCNs exposure, labour intensity and trade exposure.

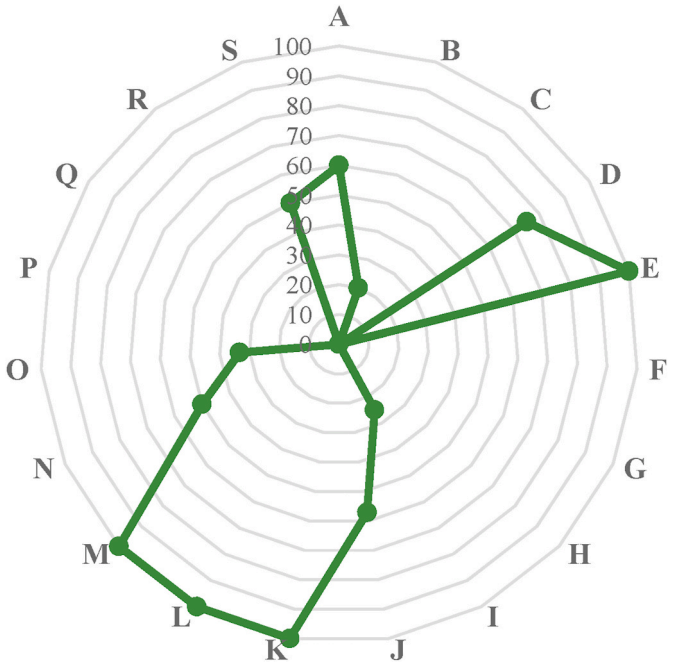

Fig. 8. Radar chart showing the percentage of businesses in the third cluster.

customers facing home confinement during the era of COVID-19.

Contributing factors for building resilience in cluster 2: The COVID-19 pandemic has encouraged a new viewpoint of business networking and supply chain management for survival in the turbulent conditions of the outbreak. It is now recognised that particular notes must be given to restructuring SCNs [61,62]. This can help businesses suffer a lower degradation in their functionality due to international trade and supply chain disruptions. Appealing options for restructuring SCNs are the reduction in the chain of administrations (Shareef et al., 2020), increasing resourcefulness through the availability of heterogeneous resources [63], diversity of suppliers [64], reconfiguration, renewing, and realigning resources [65]. Moreover, cross-sector business collaborations hold a great potential to address the challenges faced in the global pandemic [66]. The business literature offers several examples that such collaborations have assisted firms with rapid recovery from disruptions [67].

Contributing factors for building resilience in cluster 3: The development of a situation-specific risk management structure can assist businesses with managing the external risks that are resultant of the unprecedented conditions caused by the recent pandemic [68]. The risk management process can be implemented through three consecutive steps. 1) Risk identification through which key external risk categories are identified [61]. 2) Risk analysis that aids in poritising key external risks by defining a set of assessment criteria [69]. 3) Risk mitigation strategies in which a range of options for mitigating the external risks are developed [70]. Moreover, collaborative relationships and interactions between businesses, government, and nonprofit organisations can facilitate resilience to the current crisis [71,72]. Businesses and governments are mutually demanding supports to reduce the economic turmoil caused by the pandemic. While governments impose restrictions on the operation

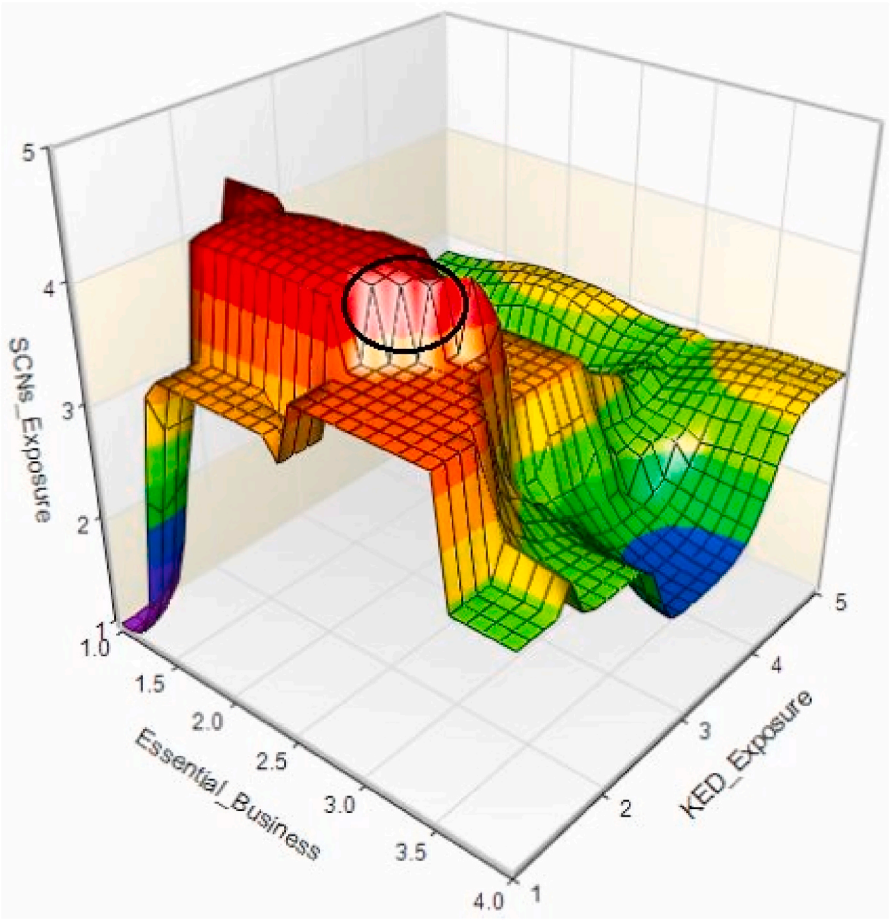

Fig. 9. Surface plot of business sectors against three vulnerability indicators: SCNs exposure, essential business and KED exposure.

Table 5
Recommendations for boosting the resilience of businesses in different clusters.

Cluster	Business Sectors	Representative Industry	Recommendations
1	S95,R92,R91, R89,P82,H45, R90,H44,P80, Q87,I48,I49, O76,P81,J60, Q86,G 39,J55,G41, Q85,G40,N72, G42,I47	– Retail trade – Accommodation& food service – Education & training – Art &recreation services	1. Increasing awareness through training, information sharing repositories of knowledge from previous disruptions 2. Digitalization and technology
2	C19,C15,C18, C22,C13,C17, C24,C12,C20, C11,C23,C14, B10,F34,I52, J58,B06,O77, F37,F35,D28, Q84,C25,F33, B08,C16,F36, C21,I50,A02, I53,A05,B07	– Manufacturing – Wholesale trade	1. Reconstructing SCNs 2. Increasing resourcefulness 3. Diversity of suppliers 4. Reconfiguration, renewing, and realigning resources 5. Cross-sector business collaborations
3	L67,L66,O75, D27,M70,K64, M69,E30,K63, D29,K62,A03, A01,J57,I46, S94,J59,A04, E31,E32,I51, N73,J56,D26, B09,J54	– Construction – Finance – Real estate services – Professional, Scientific &technical services	1. A situation-specific risk management structure 2. Collaborative relationships between businesses, government, and NGOs

of, particularly, non-essential businesses, they can offer businesses various forms of supports.

6. Implications for practice

This study offers three key implications for practice. First, in this uniquely challenging environment, much has been discussed about the consequences of the COVID-19 pandemic on the performance of businesses. It is now widely recognised that business owners and managers can effectively respond to the pandemic if they identify the core vulnerability of their businesses. Business leaders in Australia might draw considerable assistance from the taxonomy of vulnerabilities presented herein, which helps them in building a more resilient business to crises. Second, government officials and managers are on the front lines of response and recovery efforts to the COVID-19 outbreak [73]. In many countries including Australia, the governments have acted to support businesses by offering various economic support packages. However, as discussed throughout this article, the economic shock of the pandemic disproportionally affects businesses. It is therefore becoming increasingly clear that different businesses require different types of support to maintain their operations during the pandemic. While some business sectors may benefit from repurposing existing manufacturing capacities to ensure sufficient emergency supplies, others may need the payment schemes to retain their current employees [74]. The results of this work provide government officials in Australia with a snapshot of the specific business needs and expectations. This will facilitate the development and implementation of the governmental initiatives and supports by taking into account the specific needs of businesses in each cluster. Third, as already noted, the COVID-19 pandemic has exposed the vulnerability of businesses all over the world. In this situation,

businesses need a set of capabilities to alleviate the debilitating effects of the outbreak. This article suggests an assortment of contributing factors for building business resilience in the current context of the COVID-19 pandemic in Australia. These factors help business leaders to enhance the preparedness capabilities and to achieve the functionality level of their businesses even stronger than before the occurrence of the pandemic.

7. Conclusions

Within the business sphere, the year 2020 may be remembered as the year when the COVID-19 pandemic left businesses struggling to survive. Although the pandemic has engulfed many businesses all over the world, it has disproportionate impacts on business operations. This article has extended exiting efforts to evaluate the impact of the COVID-19 pandemic on businesses by developing a taxonomy of vulnerabilities based on various vulnerability characteristics of businesses across different sectors of the economy in Australia. Building on these vulnerability characteristics, the suggested taxonomy groups businesses into three clusters, labelled as vulnerable to B2P, vulnerable to business networking, and vulnerable to external factors.

The differing vulnerability of businesses to the recent pandemic raises a fundamental question about how best to build resilience to reduce vulnerabilities. Using the developed taxonomy as our anchor, this article has suggested factors that contribute to the resilience of businesses in each cluster. By developing a novel validation method for cluster analysis (Appendix A), we demonstrated the goodness of the clustering results. The suggested method posits the Shannon entropy to generate an index to measure the heterogeneity of the vulnerability indicators within clusters, which in turn can be interpreted as the measure of similarity within clusters and dissimilarity between clusters.

The limitations of this study can be discussed from methodological and scoping perspectives. In terms of the scope of this work, there exist more business vulnerability characteristics than studied herein and therefore some of the characteristics may not have been included in the dataset available to us. An area of future research should be concerned with incorporating more vulnerability indicators. Additionally, this research is limited to the study of the business sectors in the economy of Australia. Future research might seek to conduct cluster analysis in different countries to enhance the global validity of findings. Methodologically, the lack of data has restricted us to utilise subjective qualitative data rather than objective quantitative information about the vulnerability of business sectors. Although we converted the linguistic variables into the measurable values, the subjective ranking of vulnerability indicators denotes the oversimplification of complex scenarios [75]. We hope that the present study encourages researchers to develop a quantitative assessment and ranking of business vulnerabilities. Further, the open-source data obtained from the official website of an industry research company IBISWorld (www.ibisworld.com) is subject to change and cannot be used to develop a forecasting model. For example, social distancing measures and non-essential business lists may be updated according to government-imposed restrictions.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Cluster validity evaluation

This appendix attempts to test the validity of the developed taxonomy. The key intention is to demonstrate that the clusters are heterogeneous and distinct from one another. In doing so, we propose a novel cluster validity index based on the geometric structure information of the clusters [76]. We use the notion of Shannon (information) entropy as a means of measuring the heterogeneity and homogeneity of the data in clusters. Information entropy can be expressed as:

$$H(j) = -\sum_{i=1}^{n_j} p_{ij} \log_2 p_{ij} \tag{1}$$

where $H(j)$ is the entropy of the set of probabilities $P = \{p_{ij} : i = 1, 2, \ldots, n_j\}$ in cluster j, p_{ij} is the probability that a vulnerability indicator in cluster j belongs to the vulnerability level of i, and n_j is the number of members in cluster j.

Since the clusters are statistically independent, the joint entropy of all clusters is equal to the sum of individual entropies [77].

$$H_T = \sum_{j=1}^{m} H(j) \tag{2}$$

where H_T denotes the joint entropy of all clusters, $H(j)$ is the entropy of cluster j, and m is the number of clusters.

We now construct a cluster validity index based on the fractional differences between H_T and the maximum achievable H_T as follows:

$$CVI = \frac{H_T}{H_{T,max}} \tag{3}$$

where CVI represents the cluster validity index, H_T is the joint entropy of all clusters, and $H_{T,max}$ denotes the maximum achievable H_T where p_{ij} for all vulnerability indicators are equal. $H_{T,max}$ can be obtained from the following mathematical expression [78].

$$H_{T,max} = -\sum_{j=1}^{m} log_2(n_j) \tag{4}$$

where is n_j is the number of members in cluster j, and m denotes the number of clusters.

CVI falls within the range of $[0, 1]$. The higher value of CVI implies the higher homogeneity of the clustering results, and consequently, the higher overlap between the clusters. The lower value of CVI indicates the higher heterogeneity of the cluster results, thereby the more distinct and separated results.

Table 6 shows the number of business sectors within each cluster that belong to various vulnerability scores. Additionally, the entropy value of vulnerability indicators in each cluster, $H(j)$, the maximum achievable entropy, $H_{T,max}$, and the value of cluster validity index, *CVI*, are reported in Table 6.

Table 6
Number of business sectors in each vulnerability score and the resulting cluster validity index

Vulnerability Indicator	Vulnerability Score (VS)					$H(j)$
	5	4	3	2	1	
Cluster 1 ($n_1 = 24$)						
WFH Capability	0	0	4	7	13	1.4284
Social Distancing	11	8	3	2	0	1.7179
Essential Business	0	10	3	11	0	1.4171
KED Exposure	2	1	5	3	13	1.8153
Trade Exposure	1	6	8	2	7	2.0365
Labour Intensity	11	10	3	0	0	1.4171
Supply Chain Exposure	0	6	9	7	2	1.8478
Cluster 2 ($n_2 = 33$)						
WFH Capability	0	0	6	25	2	0.9957
Social Distancing	0	0	2	31	0	0.3298
Essential Business	0	32	1	0	0	0.1959
KED Exposure	0	0	1	3	29	0.6311
Trade Exposure	17	10	6	0	0	1.4620
Labour Intensity	16	12	5	0	0	1.4495
Supply Chain Exposure	13	20	0	0	0	0.9672
Cluster 3 ($n_3 = 26$)						
WFH Capability	4	2	8	9	3	2.1125
Social Distancing	0	2	4	19	1	1.2115
Essential Business	1	23	2	0	0	0.4411
KED Exposure	0	0	1	2	23	0.6219
Trade Exposure	2	1	15	1	7	1.6137
Labour Intensity	4	4	9	4	5	2.2335
Supply Chain Exposure	7	10	6	2	1	1.9934
$H_{T,max} = 58.9545$						
$CVI = 0.4739$						

As can be seen, the resulting cluster validity index is substantially lesser than 1 ($CVI = 0.4739$). This can be attributed to a relatively high heterogeneous distribution of vulnerability indicators within clusters. Put it simply, this is because many businesses in each cluster belong to a given vulnerability indicator rather than being distributed within several indicators. For instance, 23 out of 26 businesses in cluster 3 belong to "Essential Business", and 29 out of 33 businesses in cluster 2 are classified under "KED Exposure". In other words, the relatively low value of *CVI* indicates that business sectors are grouped together tightly with little overlap between the clusters.

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