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Statistical analysis of small business survival under the shock of multiple COVID-19 waves: A case study from Wuhan, China

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The long-term viability of small businesses in the aftermath of multiple pandemics and consequent lockdowns has a crucial impact on the sustainable economic and social development of any region across the world. Thus, in order to investigate what has been the major impact of COVID-19 pandemic within local small businesses and to identify which main factors helped small businesses to survive none as well as multiple lockdowns, data were obtained from 382 small businesses in the main urban area of Wuhan, China, *via* two rounds of field investigations and surveys in July 2020 and July 2022. This paper presents the results of the field investigations and the surveys completed and describes the Bayesian methods applied to quantitatively explore the impact of different variables on the probability of each business to remain active and open even after experiencing none or multiple lockdowns. Results obtained show that the difference between survival rates associated with businesses hit by no pandemic outbreak with those hit by one or several waves is negligible. Furthermore, owners who had higher confidence in their abilities since the beginning or they implemented an accurate evaluation of their strategies to run their businesses since the start of the pandemic, demonstrated to have a higher probability to keep their business alive with none as well as additional waves of the pandemic. Reduction of employees, transition of operations and promotion activities online as well as rent subsidies and tax reduction were identified as crucial actions that enhanced the probability to maintain alive businesses that experienced at least one lockdown. Globally, there was no clear policy approach at the start of the pandemic, however this study clearly determines that in future governments should provide timely support to small businesses in regions experiencing more severe impacts of the pandemic, and this should consist of a mix of grants, loans, and temporary tax cuts since initial stages.

KEYWORDS

business, economy, COVID-19 pandemic, probability, bayesian method, Wuhan China

1 Introduction

COVID-19 pandemic has been one of the worldwide health emergencies with the fastest transmission speed and the widest range of influence in the 21st century, which seriously threatened the safety of people's lives and hindered the sustainable development of mankind (Raghavan and Demircioglu, 2021). As of July 2022, COVID-19 has infected more than five hundred forty million people and killed more than six million people across two hundred

countries. In addition to harming people's lives and health, COVID-19 has also posed a serious threat to the economic development of several countries (Sarkodie and Owusu, 2021). According to Eurostat, Gross Domestic Product (GDP) in the Eurozone fell by 3.8 percent in the first quarter of 2020, the steepest decline since data were first recorded in 1995 (Fernandes, 2020). The United States economy also experienced a sharp decline which shrank by 1.2 percent in the first quarter of 2020 (Bai and Quayson, 2021). The COVID-19 pandemic has also severely damaged China's economy, with the year-on-year GDP growth rate plummeting to 2.3 percent in 2020 (Zou and Huo, 2020).

Small businesses play an important role in the national economy and contribute more than 50 percent of GDP in China (Yuan, 2013). Business is often affected immediately by sudden global events such as COVID-19 pandemic because spending is more likely to be shunned in times of high risk or uncertainty (Appel and Hardaker, 2021). According to China's National Bureau of Statistics, after the outbreak of the pandemic, the total consumption of social retail goods in China fell by 20.5 percent year-on-year in the first quarter of 2020. The profits of small, medium and micro enterprises (MSME) in China fell by more than 30 percent year-on-year throughout 2020 (Susanti, 2021). According to the *Measures for the Division of Large, Medium, small and Micro Enterprises in Statistics (2017)* issued by the National Bureau of Statistics of China, the business size of different sectors can be divided into large, medium, small and micro based on their revenue and number of employees (Yang and Cai, 2016). For example, the business size for retail sector can be divided into four categories: Large business (revenue ≥ $29.5 million, and employees ≥300), medium business ($738.8 thousand ≤ revenue < $29.5 million, and 50 ≤ employees <300), small business ($14.8 thousand ≤ revenue < $738.8 thousand, and 10 ≤ employees <50), micro business (revenue < $14.8thousand, and employees <10). The small business in the current study refers to small and micro businesses, which are a vital component of MSMEs.

MSMEs accounts for more than 90 percent of the total number of enterprises in China, contributing more than 50 percent of tax revenue and providing 80 percent of jobs in urban areas (Li and Huang, 2021). In addition, MSMEs contribute nearly 70 percent of patented inventions and more than 80 percent of new product development in China (Li and Huang, 2021). MSMEs also play a significant role in building urban space and improving urban vitality and attractiveness (Kim and Yun, 2021). As an important component of MSMEs, the survival and development of small businesses under the strike of any pandemic could closely affect many aspects of any region, such as economy, society, scientific and technological innovation, and urban vitality (Parker, 2006; Blanchard and Tolbert, 2012; Lee, 2018; Kalogiannidis, 2020; Tuymuratovich, 2021; Vinberg and Danielsson, 2021).

In the context of non-crisis, it is found that many factors may affect the value or performance of MSMEs, such as cash flow (Deng and Zhao, 2022), production mode (Xu and Zhou, 2021) and technological innovation (Ban and Liu, 2022). To date, previous studies have been conducted in the context of the COVID-19 pandemic focusing on the operating status of MSMEs, while others have been completed to investigate the vulnerability of businesses and the impact that the pandemic had on them (Bartik and Bertrand, 2020; Hatab and Lagerkvist, 2020; Shakil and Munim, 2020; Bai and Quayson, 2021; Huang and Liu, 2021; Khan and Niazi, 2021; Nguyen, 2021). The abovementioned studies were conducted across a wide range of regions, including the United States, Europe, Pakistan, and Vietnam, etc.; rare studies have explored the situation and experience of China. In addition, most of the abovementioned studies were carried after the first wave of the pandemic (late 2019) to observe the short-term survival and development of businesses during this initial timeframe, however, survival and adaptation of a business after any crisis is a long process (Marshall and Schrank, 2014) and therefore results produced may have note been extremely accurate because a business's short-term survival after the pandemic did not necessarily ensure its long-term viability. Only an extremely limited number of studies investigated the long-term survival of businesses that survived the pandemic. Moreover, existing studies mainly qualitatively summarizes the impact of the pandemic on businesses and their response measures to the pandemic through literature analysis, questionnaire surveys and interviews (Shakil and Munim, 2020) and to author's knowledge there is a lack of research indicating, *via* quantitative methods, if actions under-taken by businesses were indeed effective for their medium and long-term sustained operation after the pandemic.

Thus, important questions can arise: 1) What is the performance of businesses that survived the first wave of pandemic under the impact of subsequent waves of pandemic? 2) Can these initially surviving businesses achieve sustained operation under the impact of the subsequent pandemic? 3) What factors will affect the sustained operation of these small businesses under the shock of pandemic? 4) What measures can small business take to effectively increase the probability of their sustained operation under the shock of pandemic? 5) What is China's experience in promoting sustained business operation after the pandemic? These are all crucial questions to be asked to address the issues that have been overlooked by previous studies, therefore this study focused on small businesses in Wuhan, China, and carried out medium and long-term tracking for small businesses that survived the first wave of the pandemic (that started at the end of 2019) in order to observe and evaluate their operating status 2 years later. The Bayesian model was adopted to identify key factors affecting the sustained operation of small businesses after the first wave of the pandemic (e.g., owner characteristics, business characteristics, pandemic damage, response measures and external supports). The conclusion of the current study has important significance for promoting the medium and long term sustained operation of small businesses after the crisis induced by a global pandemic, and can help to improve the ability of business operators and managers to cope with any similar future crisis, with the intent to promote economic prosperity, social stability, and sustainable development.

The paper is organized as follows: Section 2 presents an overview of factors influencing the short-term survival or long-term sustained operation of small businesses after the pandemic; section 3 discusses the research methods and the process of data collection; section 4 incorporates the results and the key findings and finally, section 5 combines the discussion of the findings and draws the conclusion.

2 Key factors affecting the survival of small businesses

As previously mentioned, numerous studies have qualitatively summarized the damage of the pandemic to businesses or their response measures to the pandemic based what found in literature or

gained by questionnaire surveys and interviews (Shakil and Munim, 2020; Saif and Ruan, 2021). Other studies have also quantitatively identified the key factors affecting the survival of small business after the first wave of COVID-19 (Katare and Marshall, 2021). Overall, the following variables have been selected to be the most relevant ones when assessing the performance of small businesses under the impact of any pandemic.

2.1 Owner characteristics

For owner characteristics this study includes gender, education, age, experience and expectation. To date, studies developed on the impact of owner characteristics on small businesses' survivals were conducted after natural disasters and several were completed during the global COVID-19 pandemic. Evidence indicated that small business survival or recovery in the aftermath of a natural disaster were associated with owners' education, experience, and expectations (Asgary and Anjum, 2012; Khan and Sayem, 2013; Marshall and Niehm, 2015). Helgeson and Aminpour (2022) determined that female-owned businesses were more likely to go bankrupt after the pandemic, while Katare and Marshall (2021) reported that owners' age and education could be the main drivers to affect the performance of small businesses during the pandemic. In the context of COVID-19, there is evidence that owner' enhancement of employee empowerment can help motivate employees' innovative work and organizational learning readiness, which has a direct impact on the sustainable economic performance of enterprises (Faulks and Song, 2021). During the COVID-19 pandemic, entrepreneurial leadership had a significant impact on employees' perception of crisis and their working status, which affected the sustainable economic performance of enterprises (Alsharif and Shu, 2021). Therefore, owner characteristics may have played a significant role in the sustained operation of small business during the COVID-19 pandemic.

2.2 Business characteristics

For business characteristics, this study includes business type, size, primary market, and financial condition. Gregurec and Tomičić Furjan (2021) demonstrated that business type was associated with business performance under the shock of pandemic. Many studies determined that small businesses were less likely to survive pandemic shocks than large ones (Shafi and Liu, 2020; Grondys and Lusarczyk, 2021; Yue and Korkmaz, 2021). Katare and Marshall (2021) found that business with smaller market coverage had higher probability of suffering financial problems, which reduced their likelihood of survival in a pandemic. The variations of business characteristics imply different competitiveness and access to pandemic relief resources implemented on purpose for governments to support local and national businesses, and unfortunately this usually leads to different survival outcomes (Vinberg and Danielsson, 2021).

2.3 Business operation

For business operational problems due to COVID-19, this includes closure duration, raw material supply, customer loss, employee loss and cost increases. Several studies have qualitatively highlighted the business operation problems during the pandemic crisis based on questionnaires, mainly including raw material supply, customer loss, employee loss and cost increases (Ratnasingam and Khoo, 2020; Grondys and Lusarczyk, 2021; Taneo and Noya, 2021). These operational problems can affect a business to survive or recover from the pandemic (Carracedo and Puertas, 2021; Katare and Marshall, 2021). There is evidence that longer is the duration of the closure and lower is the total amount of income generated by the sale of goods or services related to the company's primary operations, thus reducing the probability of a business surviving a crisis (Webb and Tierney, 2002; Sydnor and Niehm, 2017).

2.4 COVID-19 response measures

For COVID-19 response measures, this includes employee reduction, technological innovation, online transformation, pandemic prevention resource reserve, multi-point location and purchase of commercial insurance. Several studies have reported the online transformation (Raghavan and Demircioglu, 2021), the technological innovation (Ratnasingam and Khoo, 2020; Caballero-Morales, 2021), the employee reduction (Siuta-Tokarska, 2021) and the pandemic prevention resource reserve applied by governments (Hatab and Lagerkvist, 2020) as response to the pandemic. However, only a limited number of studies have quantitatively examined the impact of these measures on post-pandemic performance of small businesses. For example, Katare and Marshall (2021) found that increasing a business's online social media presence can reduce revenue loss and on the contrary, enhance the possibilities of recovery after a pandemic. In addition, there is evidence that a business operating at multi-point locations can expect higher probability of survival after such crisis (Sydnor and Niehm, 2017).

2.5 Support from national and local authorities

Regarding support from governments or non-governmental organizations (NGO), this includes loans, rent subsidies, and NGO assistance. Many countries have introduced policies to help businesses cope with the pandemic, such as loans, rent subsidies, tax reduction and exemption (Bartik and Bertrand, 2020; Tetlow and Dalton, 2020; Vinberg and Danielsson, 2021). Katare and Marshall (2021) found that small businesses with access to a variety of these types of help can reduce their recover time from the pandemic. Additionally, Lo (2009) suggested that government and non-government assistance have been extremely important for the resilience of local and national businesses after the crisis.

2.6 Summary of the key factors

Table 1 summarizes the factors that may affect business performance under the shock of pandemic based on previous research.

In general, the abovementioned studies explored a range of factors that may influence the performance of business after the crisis. These factors provided an important reference for the current

TABLE 1 Factors that may be related to sustained operation of a business after the pandemic.

Categories	Factors	References
Owner characteristics	Gender	Helgeson and Aminpour (2022)
	Education	Katare and Marshall (2021)
	Age	Katare and Marshall (2021)
	Industry experience	Asgary and Anjum (2012)
	Owners' expectations of business climate	Khan and Sayem (2013)
Business characteristics	Business type	Gregurec and Tomičić Furjan (2021)
	Business size	Shafi and Liu (2020)
	Primary market	Katare and Marshall (2021)
	Owned or leased facility	Wasileski and Rodríguez (2011)
	Pre-pandemic financial condition	Li and Wang (2020)
COVID-19 induced business operational problems	Closure duration	Sydnor and Niehm (2017)
	Raw material supply	Taneo and Noya (2021)
	Customer loss	Ratnasingam and Khoo (2020)
	Employee loss	Grondys and Lusarczyk (2021)
	Pandemic prevention costs increased	Grondys and Lusarczyk (2021)
COVID-19 response measures	Employee reduction	Siuta-Tokarska (2021)
	Technological innovation	Ratnasingam and Khoo (2020)
	Online transformation	Raghavan and Demircioglu (2021)
	Pandemic prevention resource reserve	Hatab and Lagerkvist (2020)
	Multi-point location	Sydnor and Niehm (2017)
Supports from government and NGO	Loans	Vinberg and Danielsson (2021)
	Rent subsidies	Tetlow and Dalton (2020)
	Tax reduction and exemption	Tetlow and Dalton (2020)
	NGO assistances	Lo (2009)

work to construct a model to explore the sustained operation of businesses after multiple waves of COVID-19. However, most of the abovementioned studies focused on the performance of small businesses after the first wave of COVID-19, ignoring the sustained operation of businesses under the impact of subsequent waves of COVID-19. In addition, most of existing studies qualitatively analyzed or summarized the main measures of businesses response to the pandemic but lack further quantitative testing of the effectiveness of these measures for the sustained operation of the businesses during the COVID-19 pandemic. Moreover, existing studies focus on the short-term performance of business after the crisis, ignoring the medium - and long-term perspective on sustained operation of business after the pandemic.

It is of foremost importance to explore the sustained operation of small businesses after multiple waves of the pandemic because such understanding could help owners to carry out effective response measures to improve the probability of survival of their businesses and mitigate the impact of multiple waves of the pandemic.

Thus, this research could provide a reference and fundamental novel knowledge that could be used by policy makers to develop more effective measures to be promoted when small businesses are affected by a pandemic and require dissimilar operations in the medium and long term. Thus, one of the aims of this work is to elucidate the most important tasks that could secure the operation of local businesses during the highly stress period imposed by a pandemic and consequently ensure regional economic prosperity and social stability. Therefore, this study aims to provide further insights regarding 1) what was the operating performance of initial surviving businesses under the impact of subsequent waves of the pandemic and 2) what were the main factors influencing the sustained operation of small businesses experiencing lockdowns induced by multiple pandemic waves.

3 Materials and methods

3.1 COVID-19 pandemic and the study area

Wuhan is the capital of Hubei Province and the main city of central China. The main city of Wuhan is composed of Wuchang, Hankou and Hanyang towns, including seven main urban areas:

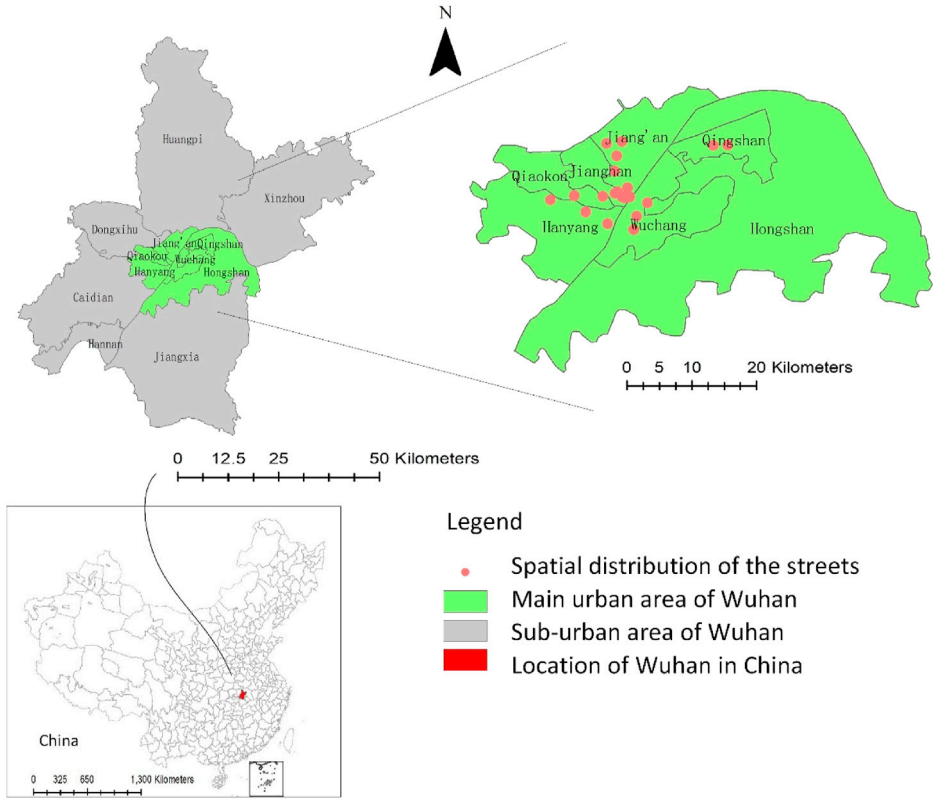


FIGURE 1
Study area and investigated streets distribution.

Wuchang District, Qingshan District, Hongshan District, Jianghan District, Qiaokou District, Jiang'an District, and Hanyang District (Figure 1). Wuhan has a vast area and it is well known for its well-developed economy and large population. Unfortunately, such megacity is more prone than others to the accumulation, breeding and wide spread of emergencies and their consequences.

Since December 2019, several cases of unexplained pneumonia had been found in several hospitals in Wuhan, Hubei Province, which lately had been confirmed as acute respiratory infectious diseases caused by the novel coronavirus infection (Dietz et al., 2020). The pandemic had developed rapidly in Wuhan, followed by associated confirmed cases in many places in China (Di Renzo and Gualtieri, 2020). Wuhan was placed on lockdown for 76 days from January 23 to 8 April 2020, in response to the outbreak of the virus (Bo, 2020). During this period, many small, medium-sized and micro enterprises suffered huge losses and experienced heavy blows such as closures and work stoppages (Li, 2022). In order to support these business, Wuhan's government had issued a series of policies to help small, medium and micro enterprises overcome difficulties, such as tax reduction, rent reduction and interest-free loans (Li, 2022).

Since the start of the pandemic, Wuhan has been reported to experience three waves by July 2022. Differently from the city-wide lockdown adopted in the first wave of the pandemic, the latter two waves have seen the application of partial lockdown measures by the government. By July 2022, businesses that survived the first wave of the pandemic have therefore experienced a total of one, two or three lockdowns. The difference in the medium and long-term performance of these businesses that have experienced different waves of lockdown is therefore worthy of concern.

3.2 Data collection and methods applied

The current study focused on the operating status of businesses that survived the first wave of the pandemic after the second and third waves of lockdowns. Furthermore, it investigated the factors linked with the sustained business operations and strategies. The data was obtained *via* conducting two field surveys and questionnaire surveys on business samples in Wuhan on 23 July 2020 (three and a half months after the first wave of lockdown was lifted) and 23 July 2022 (2 years after the first survey). The business operating status were obtained through field investigation. The data obtained from the questionnaire survey were used to identify the factors related to the sustained business operation in the context of the pandemic. Field investigation and questionnaires were commonly used to obtain data related to business operating performance after a crisis. Many studies related to business post-crisis recovery have documented business operating status through field investigation and invited owners to participate in questionnaires to obtain data (Khan and Sayem, 2013; Li and Hong, 2019; Li and Wang, 2020), which proves the usability and validity of such methods as field investigation and questionnaires.

TABLE 2 Business samples distribution.

Street name	Total sample	Valid sample
Minzu Road	27	25
Minquan Road	23	22
Minyisi Road	31	29
Beihu Road	13	13
Houhu Avenue	21	20
Jiefang Avenue	11	11
Chongren Road	23	19
Youyi Road	17	17
Jianghaner Road	18	17
Wufu Road	17	15
Sanyanqiao Road	23	19
Zhongyi Road	12	8
Youyinan Road	16	13
Yingwu Avenue	25	19
Hanyang Avenue	21	17
Yulong Road	18	18
Heping Avenue	15	13
Zhonghua Road	33	27
Zhangzhidong Road	26	23
Gongyesan Road	27	26
Jianshesi Road	13	11
Total	430	382

3.2.1 Sampling procedure

To ensure the representativeness and unbiased sample selection, the probabilistic proportional sampling (PPS) method was used for the initial sample selection. According to the probability sampling proportional to the size of permanent resident population in the research area at the end of 2019, 21 blocks were randomly selected from the main city of Wuhan, China. Thereafter, a street in each block was randomly selected and a questionnaire survey was conducted on all businesses along the street identified. The twenty-one streets selected in the current study are all located in areas with high population density to weaken the influence of different human flow caused by distinct locations on business performance. The sample distribution is shown in Table 2. A total of 430 owners of businesses along the 21 selected streets participated in the survey. Excluding the business samples that did not experience the first wave of pandemic lockdown and the samples with incomplete questionnaire data, a total of three hundred and 82 valid business samples were obtained. The first survey was conducted on 23 July 2020, with three hundred and 82 valid samples from businesses that had survived the first round of lockdown. Two years later, an additional round of field investigation was carried out to observe the medium and long-term operating status of these three hundred and 82 business samples.

3.2.2 Node variables

One of the aims of the current study was to identify the key variables influencing the operation of small businesses experiencing lockdowns induced by multiple pandemic waves. The business operating status referred to the medium - and long-term operating status of the businesses that survive in the short term under the impact of the pandemic. This can be classified into two categories: 1) Continued operation of initially surviving businesses; or 2) initially surviving businesses closed by July 2022. The names, locations, and operating status of three hundred and eighty-two businesses were recorded in both field surveys. If the same business in the same location was open for both survey periods, it was marked as one; otherwise, it was marked as two. According to the indicators summarized in the literature review presented in Section 2.6, the variables involved in the field investigation and their measurements are shown in Table 3.

The first component, owner characteristics, was measured by selecting five variables. Gender was measured dichotomously. Education, age, industry experience and owners' expectations of business climate were measured on ordinal scales. Combining the abovementioned five indicators, the comprehensive evaluation of the owners to their business operation ability was divided into three levels: Good, general, and poor.

The second component, business characteristics, was measured by choosing five variables. Most of the small businesses along the street in China's urban built-up areas are engaged in retail, service or production (Liu and Li, 2022; Liu and Tong, 2022). Therefore, Business types are divided into three categories: Manufacturing, retail, service. Business size and pre-pandemic financial condition were measured on ordinal scales. Other variables were measured dichotomously: Whether the business facility was owned or leased, whether the business provided local or regional service. Combining the abovementioned five indicators, the owners' comprehensive evaluation to their businesses running status was divided into three levels: Well, general and poor.

The third component, COVID-19 induced business operational problems, was measured by picking five variables. Closure durations were measured on an ordinal scale. The remaining four variables was measured using dichotomous variables: Whether the business suffered from raw material supply problems; whether the business suffered customer losses; whether the business suffered employee losses, whether the business experienced an increase in pandemic prevention costs. Combining the abovementioned five indicators it was possible to determine whether each business had experienced any COVID-19 induced operational problems.

The fourth component, COVID-19 response measures, was measured using five dichotomous variables: Whether the business has taken measures of reducing the number of employees; whether the business has taken measures of technological innovation; whether the business has adopted measures to transform the approach into an online platform; whether the business has taken measures to reserve pandemic prevention resource; whether the

TABLE 3 Variables and their coding scheme.

Variables	Coding scheme
Business operating status	The operating states of initial surviving business in the subsequent pandemic. 1 = continued to be open, 2 = closed
Owner characteristics	Self-evaluation of owner's operating ability. 1 = Good, 2 = General, 3 = Poor
Gender	1 = Male, 2 = Female
Education	1 = primary school or below, 2 = junior middle school, 3 = high school/junior college, 4 = university degree or above
Age	1 = 20 or below, 2 = 21–35, 3 = 36–50, 4 = 51 and above
Industry experience	1 = less than 2 years' experience, 2 = 2–5 years' experience, 3 = more than 5 years' experience
Owners' expectations of business climate	1 = gotten worse, 2 = remained about the same, 3 = improved
Business characteristics	Owners' self-evaluation of their business. 1 = Well, 2 = General, 3 = Poor
Business types	1 = manufacturing, 2 = wholesale/retail, 3 = service
Business size	1 = 1 full-time employees, 2 = 2–4 full-time employees, 3 = 4 or more full-time employees
Primary market	1 = regional/national, 2 = local
Owned or leased facility	1 = owned facility, 2 = leased facility
Pre-pandemic financial condition	1 = not doing well, 2 = general, 3 = good
COVID-19 induced business operation problems	Whether the business has experienced COVID-19 induced operational problems. 1 = yes, 2 = no
Closure duration	1 = less than 3 months, 2 = 3–6 months, 3 = more than 6 months
Raw material supply	1 = yes, 2 = no
Customer loss	1 = yes, 2 = no
Employee loss	1 = yes, 2 = no
Pandemic prevention costs increased	1 = yes, 2 = no
COVID-19 response measures	Whether the business has taken COVID-19 response measures. 1 = yes, 2 = no
Employee reduction	1 = yes, 2 = no
Technological innovation	1 = yes, 2 = no
Online transformation	1 = yes, 2 = no
Pandemic prevention resource reserve	1 = yes, 2 = no
Multi-point location	1 = yes, 2 = no
Supports from government and NGOs	Whether the business has received supports from government or NGOs. 1 = yes, 2 = no
Loans	1 = yes, 2 = no
Rent subsidies or tax reduction	1 = yes, 2 = no
NGO assistances	1 = yes, 2 = no

business has taken measures to locate benefits across multiple sites. Combining the abovementioned five indicators it was possible to determine whether the business has taken COVID-19 response measures.

The fifth component, which regards all the types of supports released by both government and NGO, was measured using three dichotomous variables: Whether the businesses applied for loans to support their operations; whether the businesses received rent subsidies or tax reduction, whether the business received help from NGOs. Combining the abovementioned three indicators it was possible to determine whether the business has received supports from government or NGOs.

3.2.3 Statistical method

3.2.3.1 Bayesian Network

The Bayesian Network, first proposed by Pearl in 1988, is a model of uncertain knowledge representation and inference based on probability theory and graph theory (Pearl, 1988). Bayesian networks usually consist of a Directed Acyclic Graph (DAG) and Conditional Probability Table (CPT). The former is used to describe the interdependence between variables, and the latter is used to reflect the strength of the causal relationship between nodes (Song and Kou, 2021). Although regression methods, such as Logistic regression and Probit regression, can also quantitatively identify the factors affecting business sustained operation after the pandemic, it

is difficult to reflect the complex structural relationships among each variable. Comparatively, the Bayesian Network has more advantages in the visualization of multivariate knowledge diagram (Wang and Amriljaharadak, 2020).

The Bayesian network structure is used to describe the interaction between variable nodes. A and B are linked by directed arcs if there is a relevance between node A and node B. The directed arc points from A to B represents that A is the parent of B and B is the child of A. If a variable has no parent node, the conditional probability of this variable is the prior probability. The conditional probability table is the parameters of the Bayesian network, which reflects the strength of the causal relationship between nodes (Zheng and Chen, 2020). Bayesian networks rely on the Bayes rule formula (Eq. 1) to infer the influence of explanatory variables on relevant results.

$$P(\mathrm{A}|\mathrm{B}) = \mathrm{P}(\mathrm{BA})/\mathrm{P}(\mathrm{B}) \tag{1}$$

Where, P (A |B) is the probability of event A under the condition of event B has occurred; P(BA) is the probability that event A and event B occur together; P(B) is the prior probability of event B. The structure of the Bayesian network can be expressed by using Eq. 2.

$$S = (\mathrm{V}, \mathrm{L}) \tag{2}$$

Where, S represents the structure of Bayesian network; V is the nodal variable set, V = {V1, V2, V3,...,Vn}; L is a directed edge and $\mathrm{L} = \mathrm{V_i V_j}$ (Vi, Vj∈V).

3.2.3.2 Network structure construction and parameter learning

The construction of the Bayesian network includes model structure construction and node parameter learning. Although the traditional three-stage analysis, SGS and other machine learning algorithms can obtain the statistical relationship between the variables, they cannot reflect the real causal relationship between them. To date there are many relevant existing previous studies which used the Bayesian network to discuss the influencing factors of dependent variables or the causal relationship between variables (Chen and Lv, 2022; Johnson and Lulla, 2022; Xie and Xie, 2022), demonstrating the usability and validity of using this model to explore the factors influencing sustained business operations. Accordingly, the current study referred to the existing studies on post-pandemic business recovery or sustained operation (Xiao and Su, 2020; Katare and Marshall, 2021; Raghavan and Demircioglu, 2021; Taneo and Noya, 2021) and constructed a Bayesian network structure model based on the causal relationship between variables discussed in the previous studies, as shown in Figure 2.

Node parameter learning refers to finding the conditional probability distribution among node parameters based on sample data after the determination of the network structure model. This study used the maximum likelihood method for the parameter learning, which was obtained by MATLAB BNT toolbox programming.

3.2.3.3 Sensitivity analysis and diagnostic analysis

The sensitivity analysis and the diagnostic analysis were used to measure the relationship between node variables in the Bayesian network model developed. The sensitivity analysis adopts the forward reasoning ability of the Bayesian network to evaluate the influence of input variables on target variables by changing input variables and observing the change amplitude of variable response probability, which can be expressed by the percentage of the variance reduction (VR). The larger the VR value is, the greater is the influence of input variables on target variables. The diagnostic analysis was implemented to set a specific state on the target variable, and then observe the probability change amplitude of the influence factor to evaluate its impact. The greater is the change of the probability value, the greater is the effect of the influence factor on the target variable. The calculation formula of the variance reduction (VR) is shown in Eq. 3.

$$\begin{aligned} V_{VR} &= V(\mathrm{Q}) - \mathrm{V}(\mathrm{Q}|\mathrm{F}) \\ &= \sum_q P(\mathrm{q})\left[\mathrm{X}_q - \sum_q P(\mathrm{q})\mathrm{X}_q\right]^2 - \sum_q P(\mathrm{q}|\mathrm{f})\left[\mathrm{X}_q - \sum_q P(\mathrm{q}|\mathrm{f})\mathrm{X}_q\right]^2 \end{aligned} \tag{3}$$

Where, $\mathrm{V_{VR}}$ is variance reduction percentage; V is the variance; Q represents the target node; F indicates other nodes; Symbols q and f represent the state of Q and F, respectively; $\mathrm{X_q}$ is the true value corresponding to state Q.

4 Results

4.1 Statistical analysis of target node variables

The target node variable of the current study is the business operating status. Figure 3 shows the operating status of businesses experiencing different waves of lockdown when the two surveys were conducted. Among the businesses that survived in the first wave of the pandemic, zero experienced two additional rounds of lockdown, ninety experienced one additional round of lockdown, and two hundred ninety did not experience additional lockdown in the following 2 years. Focusing on the rate of businesses that did not close, there was slight difference between small business experiencing one round of lockdowns and those experiencing two rounds of lockdowns, 66.9 percent for those that experienced one lockdown and 64.1 percent for those that experienced two lockdowns, respectively.

4.2 Model construction results

The sample data were divided into two groups (those that experienced one wave and those that experienced two waves of the pandemic) to show the Bayesian network after implementing the parameter learning within Netica software, as shown in Figures 4, 5, respectively. About 57.5 percent of the small businesses that survived the first wave of the pandemic achieved sustained operation after 2 years later. In terms of the owner characteristics, 41.1 percent of owners rated their ability to run small businesses as good, while only 21.6 percent of owners considered their ability to run small businesses as poor. 36.9 percent of the owners rated their businesses as operating well. 82.8 percent of small businesses experienced COVID-19 induced operation problems after the first wave of pandemic. About two-thirds of the small businesses have taken certain COVID-19 response measures, and about a third

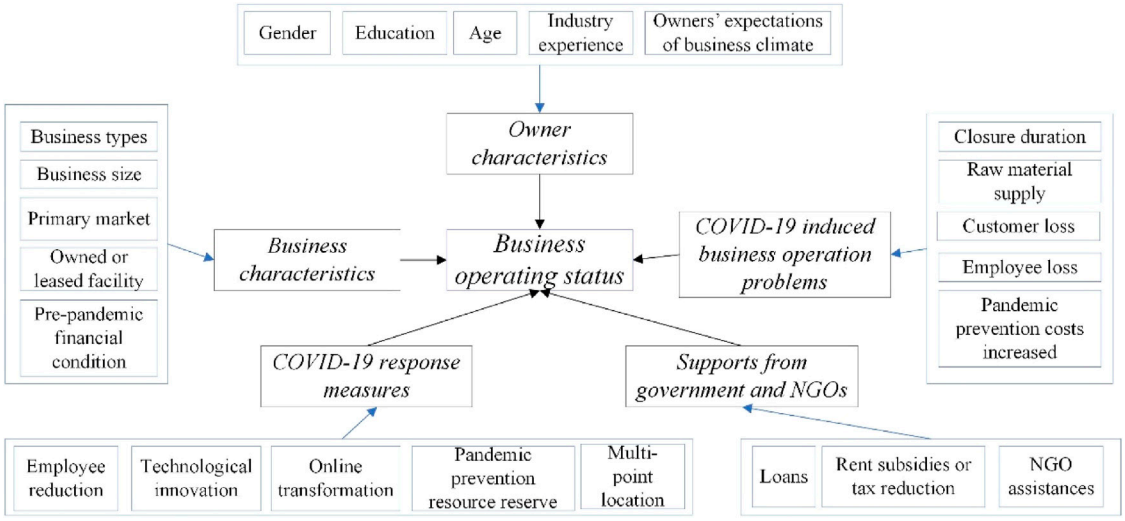
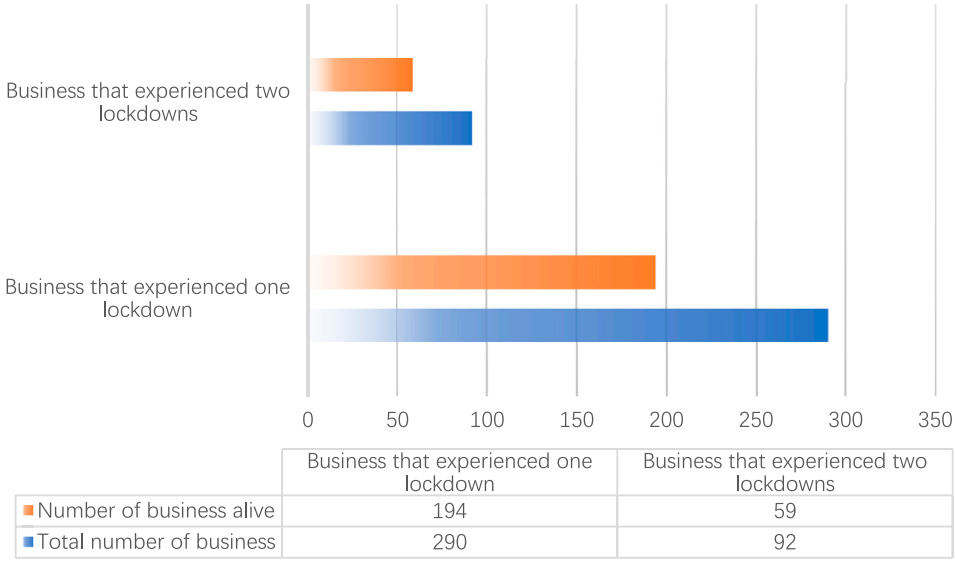


FIGURE 2
The structure diagram of the Bayesian network implemented.



	Business that experienced one lockdown	Business that experienced two lockdowns
Number of business alive	194	59
Total number of business	290	92

FIGURE 3
Survival rate of business experiencing one and two rounds of lockdowns since the first wave of the global COVID-19 pandemic, respectively.

have received help from government or NGOs after the first wave of the pandemic.

As shown in Figure 5, about 52.4 percent of the small businesses that survived the first wave of the pandemic achieved sustained operation after one additional wave of the pandemic. 33.4 percent of owners rated their ability to run small businesses as good, while only 29.5 percent of the owners rated their businesses as operating well. Compared with small businesses that experienced only one wave of COVID-19, small businesses that experienced two waves of COVID-19 had a smaller proportion (69.9 percent) of operation problems caused by the pandemic, and a smaller proportion of small businesses took COVID-19 response measures (63 percent), while a larger proportion of small businesses received help from government or NGOs (52.1 percent).

4.3 Sensitivity analysis results

With the target variable "business operating state" as the analysis variable, Netica software was used to conduct the sensitivity analysis on other variables to explore the influence of each variable on the target variable. The effects that 27 driving factors had on the target

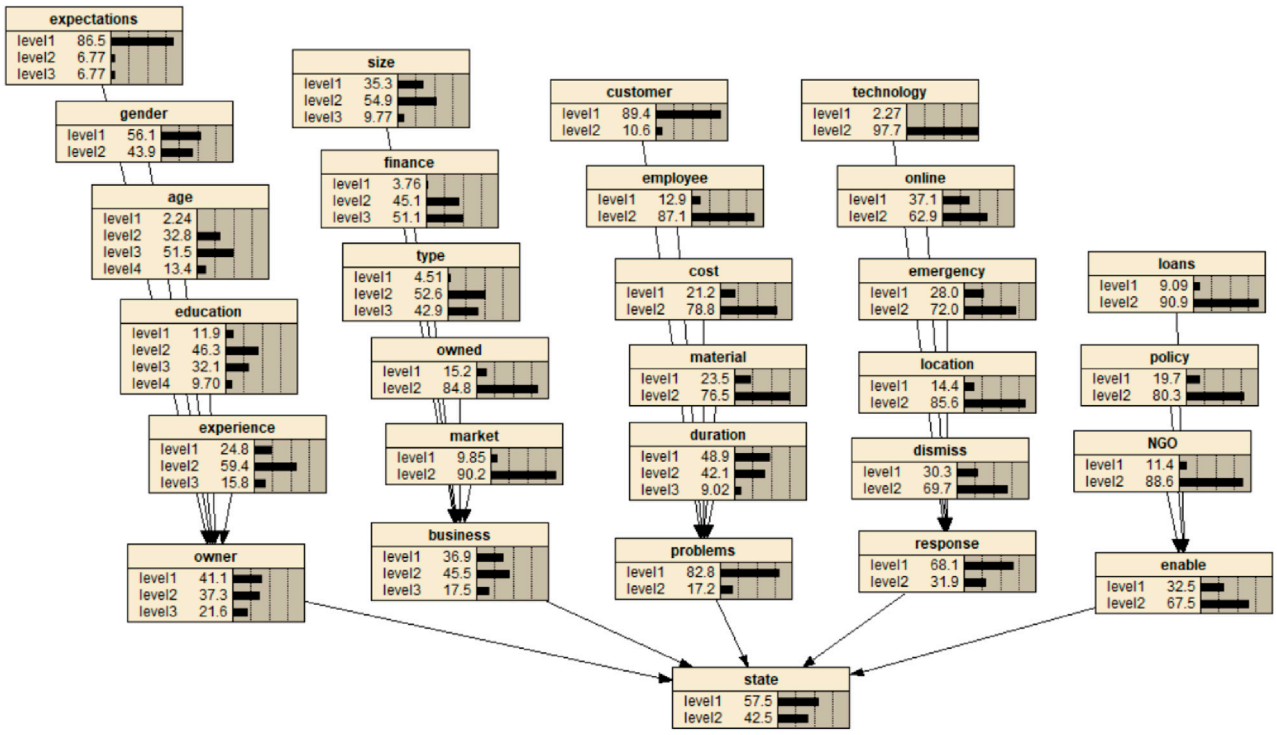


FIGURE 4
Bayesian network results for businesses that experienced one wave of pandemic.

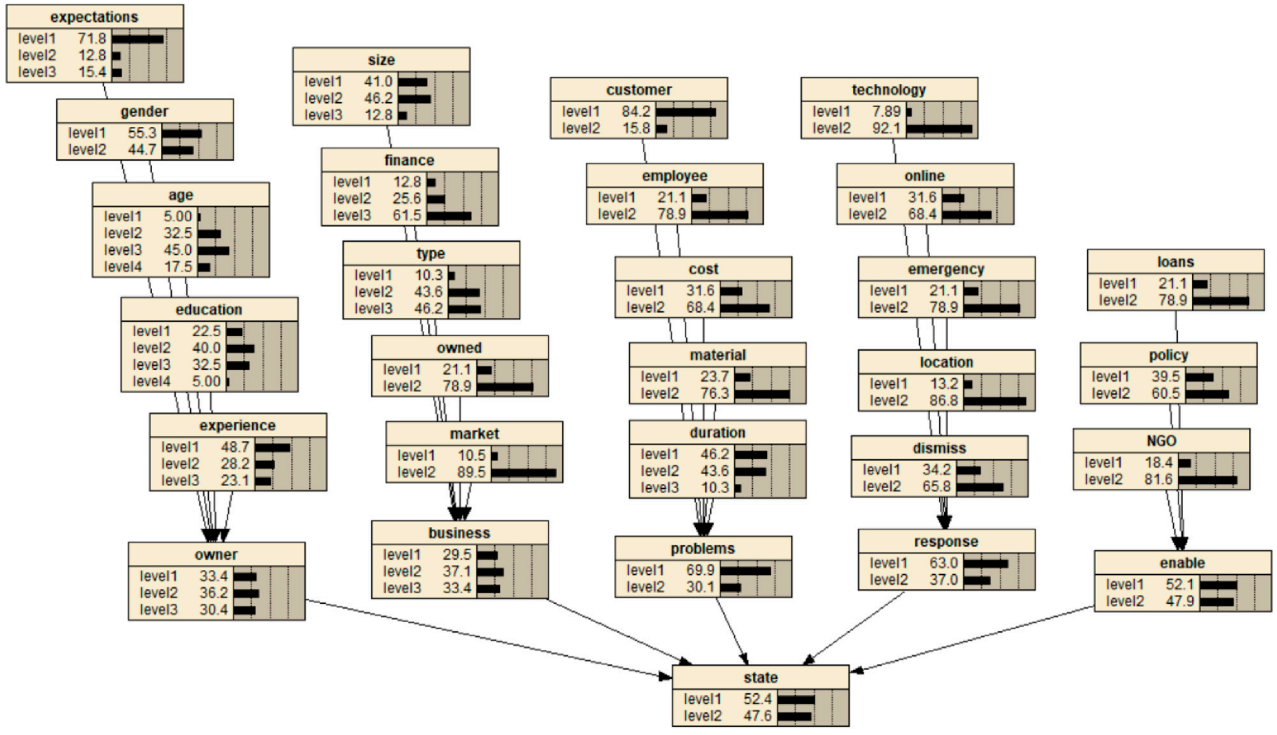


FIGURE 5
Bayesian network results for businesses that experienced two waves of pandemics.

TABLE 4 Sensitivity analysis results of the target variables (%).

Node variables	Business operating states	
	Experienced one wave of pandemic	Experienced two waves of pandemic
Owner characteristics	1.46	0.45
Gender	0.06	0.00
Education	0.14	0.00
Age	0.20	0.01
Industry experience	0.12	0.16
Owners' expectations of business climate	0.03	0.00
Business characteristics	2.47	0.45
Business types	0.14	0.01
Business size	0.35	0.00
Primary market	0.06	0.02
Owned or leased facility	0.07	0.01
Pre-pandemic financial condition	0.18	0.00
COVID-19 induced business operation problems	0.13	0.02
Closure duration	0.01	0.00
Raw material supply	0.04	0.01
Customer loss	0.03	0.00
Employee loss	0.13	0.01
Pandemic prevention costs increased	0.05	0.00
COVID-19 response measures	1.71	0.02
Employee reduction	0.83	0.01
Technological innovation	0.46	0.00
Online transformation	0.86	0.01
Pandemic prevention resource reserve	0.76	0.00
Multi-point location	0.06	0.01
Supports from government and NGOs	1.01	0.54
Loans	0.71	0.17
Rent subsidies or tax reduction	0.85	0.20
NGO assistances	0.75	0.01

variables are shown in Table 4. For small businesses that experienced one wave of the pandemic, in the middle layer node variables, business characteristics have a significant impact on business sustained operation after the pandemic, with the percentage of variance reduction as high as 2.47 percent. COVID-19 respond measures, owner characteristics and supports from government and NGOs also had an important impact on sustained business operation, and the variance reduction ratios were 1.71, 1.46 and 1.01, respectively. The impact of COVID-19 induced by business operation problems on the target variable is small, and the variance reduction ratio is only 0.13. In the input layer node variables, online transformation, rent equipment or tax reduction and employee reduction had a significant impact on sustained business operations, with variance reduction ratios of 0.86, 0.85, and 0.83, respectively.

For small businesses that have experienced two waves of the pandemic, in the middle layer node variables, owner characteristics, business characteristics, supports from government and NGOs have a strong influence on sustained business operation, with variance reduction ratios of 0.45, 0.45, and 0.54, respectively. COVID-19 induced business operation problems and COVID-19 response measures had minor impact on sustained business operations. In the input layer node variables, rent subsidies or tax reduction, loans, and industry experience had a significant impact on sustained

TABLE 5 Diagnostic analysis results (%).

Node variables	Levels of variables	Change of the probability	
		Experienced one wave of lockdown	Experienced two waves of lockdowns
Owner characteristics	Good	+6.50	+3.30
	General	−2.10	+0.30
	Poor	−4.40	−1.00
Industry experience	Less than 2 years' experience	—	−1.00
	2–5 years' experience	—	−0.10
	More than 5 years' experience	—	+1.10
Business characteristics	Well	+8.60	+2.90
	General	−6.30	+0.20
	Poor	−2.40	−3.10
COVID-19 response measures	Yes	+12.10	—
	No	−12.10	—
Employee reduction	Yes	+3.00	—
	No	−3.00	—
Online transformation	Yes	+3.80	—
	No	−3.80	—
Supports from government and NGOs	Yes	+3.90	+3.10
	No	−3.90	−3.10
Loans	Yes	—	+1.10
	No	—	−1.10
Rent subsidies or tax reduction	Yes	+2.00	+1.90
	No	−2.00	−1.90

business operations, with variance reduction ratios of 0.2, 0.17, and 0.16, respectively.

4.4 Diagnostic analysis results

The owner characteristics, business characteristics and other influential factors were selected for the diagnostic analysis. The quantitative causal relationship between the influencing factors and the target variables was obtained by backward inference using the Bayesian network model. The value of the business operation status was set to level1, which assumed that all small businesses that survived the first wave of the pandemic at the end of 2019 were going to still be alive by July 2022 after an additional lockdown and observe the change in the probability of impact factors. The results are shown in Table 5.

Table 5 shows that for the case in which the probability of a business being alive after one wave of lockdown increased from 57.5 percent to 100 percent, the probability of owners' evaluation of their business operation ability as good increased by 6.5 percent, and the probability of owners' evaluation of their business running as well increased by 8.6 percent. This outcome indicates that when the owners had a higher evaluation of their own business operation ability, the business had a higher probability to stay alive after two waves of the pandemic. Pandemic response measures and access to government or NGO assistances can help improve the alive probability of businesses that have experienced two lockdowns. The probabilities of employee reduction, online transformation and rent equipment or tax reduction increased by 3 percent, 3.8 percent, and 2 percent, respectively. They are effective pandemic response and assistance measures to improve the probability of business alive.

For businesses that experienced two lockdowns, when their probability to stay alive increased from 52.4 percent to 100 percent, the probability of owners' evaluation of their business operation ability as good increased by 3.3 percent, and the probability of owners' evaluation of their business running as well increased by 2.9 percent. Moreover, the rich experience of the owners could improve the probability to keep the business alive. Receiving supports from the government or NGOs could help improve the probability to keep the business alive. Rent equipment or tax reductions and loans rose 1.9 percent and 1.1 percent, respectively, indicating that they are the most effective equipment to boost business alive.

5 Discussion

Many previous studies have demonstrated that the pandemic has had an obvious repercussion on businesses survival (Xiao and Su, 2020; Carracedo and Puertas, 2021; Grondys and Lusarczyk, 2021). Thus, it was expected that the higher the number of lockdown waves, the lower would have been their survival rate. However, the current study found out only a small reduction in the survival rate for businesses that experienced two waves of lockdowns compared with those that only experienced one wave. These results may be because areas that did not experience lockdowns consequent to the third wave of the pandemic, suffered as much from reduced consumer demand as areas that did.

For the situation where the owners had a higher evaluation of their own abilities in managing their businesses, a higher probability to survive the pandemics was recorded, and this applies both for businesses that have experienced one and two waves of the pandemics. This may be induced by the fact that owners who have a high evaluation of themselves and their businesses have a more positive attitude towards business operations to be implemented after each wave, and they will spare no effort to use various resources to promote more sustainable operation of their businesses (Khan and Sayem, 2013). Therefore, their business has a higher probability to survival after multiple waves of the pandemic. In addition, the current study found that experienced owners can help improve the probability of survival after experiencing two waves of pandemic. Several studies in the context of disasters also found that valuable owners' experience helps them make correct decisions and undertake efficient response measures, and they have a higher probability to keep functioning after the crisis (Marshall and Niehm, 2015; Orhan, 2016; Li and Hong, 2019).

The COVID-19 pandemic caused problems to the normal operation procedures however it had small impact on the probability of businesses' survival, and this statement is valid for both businesses that experienced one as well as those that experienced two waves of the pandemic. Many studies have found that the damage caused by natural disasters or risk accidents will adversely affect the survival of small businesses after these external shocks (Sydnor and Niehm, 2017; Brown and Seville, 2019; Carracedo and Puertas, 2021). However, the current study found little correlation between COVID-19 induced operation problems and the survival probability of a business after the pandemic. This may be because the first wave of pandemic swept Wuhan at the end of 2019. During the lockdown, except for a few small businesses that ensured people's livelihood and normal operation during the pandemic thanks to prevention measures adopted, the rest of the businesses were required to close, and thus, most of them suffered from indirect and not planned operational problems caused by the pandemic. Furthermore, the operational problems caused by the first wave of the pandemic in late 2019 may have affected the survival of some businesses, but this study focused on the sustained operation of those that survived the first wave of the pandemic and were affected by subsequent waves of the pandemic. Therefore, business operational problems caused by the first wave of the pandemic could have affect the survival of businesses in the short term but had trivial effect on the sustained operation for those that initially survived the pandemic.

Implementing measures to reduce the impacts and receiving supports from government or NGOs could improve the probability of survival for all businesses that had experienced one wave of the pandemic: More in detail, reduction of employees, online transformation and rent subsidies or tax reduction were identified as the more beneficial support to local businesses and other studies have come to similar findings. For example, Asgary and Anjum (2012) found that rent subsidies or tax reduction could help boost business recovery in the context of disasters. Exposure on online social media could increase product sales during a pandemic and thus improve businesses' survival (Katare and Marshall, 2021). Furthermore, employees' reduction and rent subsidies could reduce the cost of running businesses and increase the probability of their survival (Xiao and Su, 2020).

For businesses that have experienced two waves of the pandemic, the respond measures had negligible impact on their probability to survive, while the support from government or NGOs had a significant effect on this probability. This may be induced by the fact that the businesses suffered from aggravated loss after experiencing multiple waves of the pandemic, and the resources available to them were limited (Grondys and Lusarczyk, 2021; Taneo and Noya, 2021; Vinberg and Danielsson, 2021). Therefore, the response measures taken by businesses could no longer effectively improve their probability to survive. In this case, government's support, such as rent subsidies or tax reduction and the interest-free loans, could have helped businesses in time and increase their chances of survival.

The findings of the current study have important significance for improving the probability of small business to avoid closure after a pandemic. However, this study has also some limitations. Firstly, the current study only focuses on the operation state of the original surviving business after 2 years and ignore the business operation process in the long term after the pandemic involving several years. This is another type of study that would require future research to explore the process of businesses' survival in crisis based on multi-time and longitudinal observations covering several years. Secondly, the current study uses dichotomous variables to measure COVID-19 induced operation problems, response measures and government's support, which lacks measures that are more detailed. Future research could therefore further focus, for example, on the impact of the degree of operational problems, the degree of pandemic response measures implemented, and the degree of access to government supports on post-pandemic business survival. Finally, although the current study has concerned the influence of many factors on the operating status of businesses, including further extensive factors in the discussion could obtain even more significant findings. For example, location was suggested to be a key factor affecting business performance, both in crisis and non-crisis contexts (Lesage and Pace, 2011; Craioveanu and Terrell, 2016; Li and Zhou, 2019). Considering location factors and using spatial regression models to do some spatial analysis of business post-epidemic performance will provide more abundant findings for related research topics.

6 Conclusion

The long-term viability of small businesses that survived in the short term after the pandemic started were ignored in the previous studies conducted to date. However, the long-term operating approach of small businesses that survived the pandemic has a critical impact on any regional economic growth, social stability, and sustainable development. Thus, the current study took Wuhan as an example, focused on the rate of businesses

that survived the first wave of COVID-19 at the end of 2019 and were also affected by subsequent pandemic waves. The Bayesian model was used to quantitatively examine the impact of different variables on the probability of businesses that survived the pandemic. The main findings of this study can be summarized as follows:

(1) There was minor difference between the initial surviving businesses that did not experience additional pandemic lockdown and those that survived and had to go through one lockdown.
(2) Businesses managed by owners who had a high evaluation of their abilities, or a good assessment of their running operations, had a high probability of achieving sustained operation after one or two lockdowns.
(3) Operational problems induced by COVID-19 had minor impact on the long-term operating status of initial survival businesses.
(4) Employee reduction and online transformation have been identified as effective respond measures to the pandemic and rent subsidies or tax reduction have been seen to be effective government supports, which helped businesses and their probability to remain alive.
(5) Government supports, especially rent subsidies or tax reduction and loans, were essential to improve the alive probability of businesses that experienced two waves of lockdowns.

The Chinese experience provided in the current study may have important significance and could be used as a reference to ensure a higher chance of achieving sustained operation after multiple waves of pandemic lockdowns for small businesses in other countries. Moreover, the abovementioned findings provide important implications. For business owners, they should actively learn and understand the knowledge related to post-crisis business operation, integrate their usual experience with the special background of the pandemic, and sum up the post-epidemic operation methods applicable to their businesses. Based on the operating experience, business owners should maintain a high confidence in their ability and the way they run their business, and they should actively continue to take measures to cope with the pandemic. For example, the adoption of advanced technology could play a critical role for business survival during the COVID-19 crises especially with small businesses. For businesses suffering from multiple waves of COVID-19 lockdown, owners should pay attention to actively seek external helps, especially support policies issued by the government, in addition to taking respond measures by themselves.

The pandemic has affected many businesses in China and across the world and it is crucial to learn the following lessons:

- monitor both future exogenous events and political changes.
- Be aware of the global economy, identifying sources that could supply similar materials with lower prices to mitigate the increase of costs from other countries.
- Join forces, because small businesses could stipulate and join associations (national and international) to gain knowledge from more expert people as well as boost the opportunities of survival during challenging times.

The government should provide timely supports to small businesses experiencing the pandemic, such as tax reduction, rent subsidies and interest-free loans. In addition, policies implemented should give priority to small businesses in regions experiencing more severe impacts of the pandemic.

Data availability statement

The authors will provide data available on request.

Author contributions

FL, MR, TZ, JL, and CC methodology; FL, MR, TZ, JL, and CC formal analysis; FL, MR, TZ, JL, and CC investigation; FL, MR, TZ, JL, and CC resources; FL, MR, TZ, JL, and CC data curation; FL, MR, TZ, JL, and CC writing—original draft preparation; FL, MR, TZ, JL, and CC writing—review and editing; FL, MR, TZ, JL, and CC visualization; FL, supervision; FL, project administration; FL, funding acquisition. All authors have read and agreed to the published version of the manuscript.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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