Regular Paper

Chen, S., Su, W., Chen, J., Li, K.W. (2021), "The Effects Of COVID-19 On Manufacturer Operations: Evidence from China", *Transformations in Business & Economics*, Vol. 20, No 2 (53), pp.41-61.

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BUSINESS & ECONOMICS

THE EFFECTS OF COVID-19 ON MANUFACTURER OPERATIONS: EVIDENCE FROM CHINA[1]

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Received: June, 2020
1st Revision: March, 2021
2nd Revision: April, 2021
Accepted: May, 2021

ABSTRACT. The COVID-19 outbreak has spread globally at an extremely fast pace and has seriously affected the economic development and stability of the social order in various countries, impacting the normal business operations of manufacturers. In this

[1] **Acknowledgements**. This work is supported by the project of the National Social Science Fund of China (No. 16ZDA053, No.16BTJ026, and No.19ZDA122). **Disclosure statement**. No potential conflict of interest was reported by the authors.

study, a sample comprising 1329 manufacturers in Hangzhou, China is analysed using logistic regression and path analysis methods to identify the main factors related to COVID-19 that affect manufacturers' operations, as well as the possible causal relationships between them. The empirical results of the logistic regression reveal that COVID-19 primarily affects the operating performance of manufacturers in five regards: business continuity, capital chain gap, supply chain integration, laborforce availability, and stimulating policies. The conclusions derived from the path analysis indicate that the degree of traffic and logistics congestion is a key factor, as it hinders manufacturers' business continuity, which ultimately causes a gap in the capital chain and determines manufacturers' demand for stimulating policies. Based on the research results, we propose recommendations to support manufacturers in their efforts to resume operations and realise economic recovery.

KEYWORDS: COVID-19, manufacturer, business operations, logistic regression, path analysis.

JEL classification: M21, C53,L89.

Introduction

Since the initial emergence of COVID-19 in Wuhan, China, the outbreak has spread rapidly around the world. At present, the United States and South America have become the new COVID-19 outbreak epicentres. At the time of writing, nearly 87,698,196 cases of infection have been recorded in the world, and approximately 1,888,074 infected individuals have died of pneumonia. The global economic order and social stability are confronting severe challenges. Ataguba (2020) believes that the major macroeconomic indicators of every country will be severely impacted by COVID-19. Martin McKee (2020) and Acikgozan and Gunay (2020) both find that in the face of COVID-19's impact, a global economic recession is inevitable. The International Monetary Fund (IMF) predicts that the GDP of developed countries will drop by 6.1% in 2020 (IMF, 2020). To strengthen efforts targeting the prevention and control of COVID-19, governments have implemented many control measures, such as prohibiting public gatherings and cutting off the traffic links in the outbreak areas. While these measures have obviously achieved positive effects in terms of the prevention and control of infectious diseases, they have also had a significantly negative impact on the operations of various industries, such as tourism and manufacturing (Piotr, 2020).

The importance of the manufacturing industry plays an indisputable role as a cornerstone of a country's economic development and is the lifeblood of its competitiveness. During the COVID-19 outbreak, manufacturing industry operations were restricted in almost all countries, the supply chain faced severe challenges, and global trade was almost completely interrupted (Ayittey, 2020). Due to the severe restrictions that were imposed on transportation and logistics and the shutdown of both up and downstream enterprises in the supply chain, the continuous operations of manufacturing enterprises have been affected and the risk of a rupture in the capital chain continues to increase.

According to a survey conducted by the USA's National Association of Manufacturers (NAM), nearly 80% of manufacturers expect COVID-19 to have an impact on their capital turnover, and over 50% of manufacturers will face difficulties in their production and operations for a long duration (NAM, 2020). In the context of public health events, such as COVID-19, it is meaningful to identify the micro-factors that disrupt the normal operations of the manufacturing industry, to discuss how to effectively alleviate manufacturer operating pressure, and formulate policies to promote the normalisation of manufacturers' production and operations.

The Chinese government's active policy response to COVID-19 has achieved remarkable results. In the second quarter of 2020, China's GDP increased by over 20% compared to that of the first quarter, and the national economy has achieved a V-shaped reversal. The purchasing manager index of China's manufacturing industry rose to 50.9 in June 2020, indicating that manufacturing operations are gradually recovering. Given China's success in promoting its own economic recovery following the impact of COVID-19, this study attempts to explain the factors affecting manufacturing operations during the COVID-19 outbreak, summarise China's experience in promoting continuous business operations, and provide references for relevant countries or regions in the formulation of policies.

To achieve the research purposes aforementioned, we propose the hypothesis that COVID-19 affects manufacturer operations and constructs a relationship network connecting the factors under examination by conducting empirical analysis to calculate the relative importance of each factor. The path analysis method is then used to explain the possible paths of influence among the factors.

The remainder of this article is organised as follows. In Section 1, the factors related to public emergencies that affect business operations are organised and summarised. The theoretical hypothesis of this article is proposed on this basis. Section 2 describes the research design and encapsulates the selection of variables, data sources, and related empirical methods. Section 3 presents the empirical analysis where the results of logistic regression, dominance analysis, and path analysis will be shown, and the realistic implications will be further interpreted. Result analysis and recommendations should be strengthened in Section 4.

1. Hypothesis Development

The continuity and repetition of the impact are the primary difference between public health events and natural disasters, accidents, disasters, social security, and other events.

Considering the COVID-19 has been spreading worldwide since February 2020, and it will last for nearly 12-18 months without an effective vaccine implemented. In a recent opening report, the Director-General of the World Health Organisation (WHO) pointed out that COVID-19 will be with humankind for a long time (WHO, 2020). Based on the current situation, areas in which the epidemic was well controlled in the early stage, such as Europe and East Asia, may also confront the second wave of COVID-19. Drawing on the analysis framework of public emergencies, it is believed that COVID-19's impact on all types of enterprises, including manufacturers, is primarily observed in the aspects of business continuity, pressure on the capital chain, and difficulties in supply chain integration, labour force availability, and stimulating plans.

1.1 Business Continuity

Whether in the short or long term, COVID-19 has caused a significantly negative effect on the normal production operations of enterprises. During the initial COVID-19 outbreak, strong government control may have directly interrupted enterprise production and operations. For example, in February 2020, the Chinese government implemented a mandatory quarantine policy for the purpose of epidemic prevention and control, thus resulting in the closure of thousands of enterprises for over a month. In April, under a government-led policy through which enterprises were encouraged to gradually resume production, some were still unable to carry out operations in a timely manner (Lu *et al*., 2020). In the long run, with the normal implementation of COVID-19 prevention and control measures, corporate business activities have slackened, and business continuity has been significantly affected (Hailu, 2020). Koonin (2020) holds that it is extremely important to devise COVID-19 prevention and control plans to ensure the business continuity of enterprises. Hence, Hypothesis 1 is proposed: the business continuity of enterprises will be affected by COVID-19.

1.2 Pressure on the Capital Chain

Because business continuity is hindered, under the premise of a sharp drop in operating income, enterprise personnel salaries and operating expenses must still be paid as usual; thus, the pressure on a given enterprise's operating capital suddenly increases, and cash flow shortages have become a common phenomenon (Lee *et al*., 2015; Psillaki, Eleftheriou, 2015). Khan (2013) believes that the lower an enterprise's cash reserves, the weaker its ability to survive when unexpected events strike, which means that enterprise demand for financing will be stronger. In a study of the impact of natural disasters (e.g. Hurricane Katrina) on business performance, Marshall (2015) also found that companies that have successfully dealt with cash flow difficulties are significantly less impacted than those without similar experience. This indicates that if no advance preparations are made, the pressure on an enterprise's capital chain will prevail during emergencies. Liu *et al*. (2020) points out that Chinese small-medium enterprises (SMEs) have experienced greater pressure in terms of cash flow in their endeavours to maintain and resume operations during COVID-19. Therefore, Hypothesis 2 is proposed: pressure on the capital chain will affect enterprise operations duringCOVID-19.

1.3 Difficulties in Supply Chain Integration

Dahlhameran and Tierney (1998) believe that the shortage of supplies and materials is the primary problem faced by enterprises during post-disaster business recovery, and the supply chain's capacity for integration will directly determine the degree to which enterprise operations can recover. In a study on the impact of the Great East Japan Earthquake (the 2011 earthquake off the Pacific coast ofTōhoku) on business operations, Tokui *et al*. (2017) found that enterprises suffered huge losses due to supply chain disruption, and post-disaster business recovery was also delayed. Under the impact of COVID-19, Gray (2020) and Hobbs (2020) examined agricultural enterprises and food processing enterprises to identify the impact of transportation interruptions on the enterprise's supply chain. It is noteworthy that the number of orders placed with enterprises also decreased significantly with the continuous negative influence of disaster events, and the weakened market demand, downstream of the supply chain (Cooling, 2015; Lee, Warner, 2006). Thus, the spread of COVID-19 will affect the integration of the enterprise supply chain and will further affect the business performance of enterprises. Therefore, Hypothesis 3 is proposed: difficulties related to supply chain integration will affect enterprise operations during COVID-19.

1.4 Labour Force Availability

Much like natural disasters, public health events impact the personal safety of individuals, however, in the case of the latter, fear of such events gets infused among people (Becker, 2004), especially those working under uncertain circumstances. At the beginning of the COVID-19 outbreak, employees were concerned about getting infected during operations and had doubts regarding the completion and thoroughness of a given enterprise's protective measures; thus, reducing their willingness to return to work. Sawano (2020) holds that employees' return to work and the recruitment of new employees can only be achieved when a reliable working environment is guaranteed and responsibility for employee safety is guaranteed. Khan's (2013) research shows that enterprises with a significant labour loss during public emergency events may have greater difficulty in post-disaster recovery. Hence, Hypothesis 4 is put forth: Workforce availability will affect enterprise operations during COVID-19.

1.5 Stimulating Policies

Pathak *et al*. (2018) considered that the government can have a positive impact on enterprise operations by adjusting industrial policies and implementing public policies when emergencies occur. For example, in addition to providing interest-free loans, the government can also implement tax reduction and exemption policies to promote enterprise operations after disasters, as well as encourage investment in the financial market, thereby alleviating the pressure on enterprise capital and ensuring business continuity (Gotham, 2013; Nakatani, 2016). Biggs *et al*. (2012) point out that stimulating plans that benefit enterprises and are formulated by the government are vital to the survival and business recovery of enterprises that have been affected by natural disasters. Zhu (2020) indicates that the Chinese government rapidly responded to the demands of enterprises during COVID-19, and formulated and implemented policies as quickly as possible, thus achieving differentiated stimulating policies for different industries, which supported enterprises in overcoming difficulties in their respective operations. Therefore, Hypothesis 5 is proposed: stimulating policies will affect enterprise operations during COVID-19.

2. Research Design

2.1 Variable Selection

Based on Hypotheses 1 to 5, variables relevant to the empirical analysis are selected to verify the statistical significance of these hypotheses. The corresponding relationship between each hypothesis, as well as the variables and the corresponding symbol, can be seen in *Table 1*.

Due to the government's control measures in the early stage of the COVID-19 outbreak and the subsequent guidance policies, normal enterprise production and operations are blocked, and production capacity is affected, which may prevent contracts from being fulfilled in a timely manner. Therefore, for Hypothesis 1, the degree of production recovery(x_1), the degree of delay in resuming work (x_2), the time required to restore normal operations(x_3), and the difficulty in implementing contracts (x_4) were selected as the primary factors affecting enterprise business continuity. The more time that is required to restore normal operations and the longer the delay in resuming work, the more sub-optimal the business continuity of a given enterprise will be. The lower the degree of production recovery, the more seriously the business continuity of enterprises will be affected, and the more difficult it will be for enterprises to produce products and implement the contracts on time.

Table 1. Hypotheses and variable selection

Hypothesis	Variable names	Symbols	Meaning of variable value
Hypothesis 1	Degree of production recovery	x_1	0 = 'more than 90%', 1 = '70%~90%', 2 = '50%~70%',3 = '30%~50%', 4 = '10%~30%',5 = 'less than 10%'
	Degree of delay in resuming work	x_2	0 = '1 week',1 = '2 weeks', 2 = '3 weeks',3 = '4 weeks', 4 = 'more than 4 weeks'
	Time required to restore normal operations	x_3	0 = 'already return to normal level', 1 = '1-2 weeks',2 = '2weeks-1month', 3 = '1-3 months',4 = '3-6 months', 5 = '6-12 months'
	Difficulties in contract implementation	x_4	0 = 'no',1 = 'yes'
Hypothesis 2	Pressure from operations costs	x_5	0 = 'no',1 = 'yes'
	Cash flow gap	x_6	0 = 'no demand',1 = 'less than 10%', 2 = '10%~30%',3 = 'more than 30%'
Hypothesis 3	Passive reduction in orders	x_7	0 = 'no reduction',1 = 'less than 5%', 2 = '5%~10%',3 = '10%~30%', 4 = 'more than 30%'
	Degree of traffic and logistics congestion	x_8	0 = 'less than 10%',1 = '10%~30%' 2 = '30%~50%',3 = '50%~70%' 4 = 'more than 70%'
Hypothesis 4	Proportion of non-local employees in enterprises	x_9	0= 'less than50%',1= '50%~70%' 2= 'more than 70%'
Hypothesis 5	Bonds issuance	x_{10}	0 = 'no',1 = 'yes'
	Subsidized loan interest	x_{11}	0 = 'no',1 = 'yes'

Source: a specialized investigation about the impact of COVID-19 on business operations organized by the authors in Hangzhou, China.

The pressure experienced by enterprises in the capital chain mainly stems from operating costs and cash flow conditions. Therefore, this study selects the pressure stemming from operations costs (x_5) and the gap in the cash flow (x_6) as the prime factors by which Hypothesis 2 is evaluated. The operating costs of an enterprise include personnel wages and welfare expenditures, as well as costs associated with materials, manufacturing, management, capital, etc. The higher the operating cost, the greater the challenge for enterprises to resume production and operations; meanwhile, the more limited the cash flow, the greater the pressure on the company's capital turnover.

In Hypothesis 3, the main variables that reflect enterprise capacity for integration in the supply chain are the passive reduction of orders (x_7) and the degree of traffic and logistics congestion (x_8). Under the conditions created by the epidemic, the degree of traffic and logistics congestion reflects whether an enterprise's current supply chain is unblocked and whether raw materials can be guaranteed, while the strength of its capacity for integration in the supply chain is concentrated in the passive reduction of orders. Given certain realities, such as the regulation of public transportation and the suspension of the recruitment market during the COVID-19 outbreak, we adopted a proportion of non-local employees in an enterprise (x_9) as an explicit variable to measure the rate of sufficient workforce evaluated by Hypothesis 4. This approach was adopted because the difficulties confronting local employees in returning to work are fewer than those faced by non-local employees.

The risk of business operations during the epidemic is mainly manifested in the collapse of the capital chain. To prevent such risks, the government has formulated stimulating business-benefit policies. As many types of policies exist, to evaluate Hypothesis 5, we selected two variables to reflect the effect of policies on business operations, namely, supporting enterprises in the issuance of bonds (x_{10}) and subsidised loan interest (x_{11}).

2.2 Sample and Variable Value

To carry out the empirical analysis, we collaborated with Hangzhou Municipal Commission of Development and Reform, China and selected 1,329 manufacturers located in Hangzhou as our sample, designed a questionnaire, and then oversaw its implementation in June 2020. The questionnaire comprises five aspects: production and operations, employment, capital, logistics, and government policies. Due to the mandatory nature of government departments, a total of 1327 valid questionnaires were collected, of which 852 (64.2%) were valid responses from Small and medium enterprises (SMEs), and the remaining are Non-SMEs(35.8%).

The manufacturers in the sample comprise those involved in the production of textiles, metal products, special equipment, general machinery, electronic and communication equipment, and chemical raw materials and products; they comprise 8.29%,7.84%,6.41%,5.58%,5.28% and 4.90% of the sample, respectively.

As this questionnaire involves sensitive issues, to facilitate the cooperation of enterprises in the survey, all questions are quantified in the form of categorical variables. The value of each variable can be seen in *Table 1*.

2.3 Methods

2.3.1 Logistic Regression

According to Table 1, it can be seen that all variables are discrete, and the dependent variable y is dichotomous. When the dependent variable is discrete, methods such as probit regression and logistic regression are generally applied (Agresti, 2007). Because the logistic regression model has strong explanatory power and the output result is a probability prediction value, this approach is widely used to model dichotomous variables. Therefore, this study uses logistic regression to analyse how the aforementioned factors affect manufacturing operations. The mathematical form of the logistic regression model can be presented as follows.

$$\ln\left(\frac{p}{1-p}\right)=\beta_0+\sum_{i=1}^{n}\beta_i x_i \quad (1)$$

In Eq.(1), $p=\mathrm{P}(y=1|x;\beta)$ represents the probability that COVID-19 has a serious impact on manufacturer operations, that is, the probability when the value of the variable y is equal to 1. β_0 denotes the intercept in the logistic model, and β_i represents the coefficient of explanatory x_i; further, both β_0 and β_i are the parameters which remain to be estimated by using either gradient descent method or Newton's method.

3.3.2 Dominance Analysis

According to the estimation results of the logistic regression model, the factors with a statistically significant impact on manufacturing operations can be evaluated. To distinguish the relative importance of these factors, the dominance analysis (DA) method can be used for further analysis (Azen, 2009).

DA is an intuitive and appealing procedure that is used to determine predictor importance, which solely requires a measure of model fit (e.g. R^2) to determine the additional dominance of any given predictor for any specific subset model. Given n explanatory variables, DA considers all possible combinations of the explanatory variables and conducts 2^{n-1} sub-models; the average additional dominance of the R^2 that is attributable to an explanatory variable within each sub-model is then recorded. For example, let $C_{x_i}^{(k)}$ be the average additional dominance of x_i across all $\binom{n-1}{k}$ models comprising $k+1$ variables (x_j and k additional variables):

$$C_{x_i}^{(k)} = \sum_{j=1}^{\binom{n-1}{k}} (R^2_{y,x_i,s_j} - R^2_{y,s_j}) / \binom{n-1}{k} \qquad (2)$$

Where s_j denotes a distinct subset of the k explanatory variables, on top of x_i, and $\binom{n-1}{k}$ represents the number of distinct combinations of k out of all explanatory variables, other than x_i. R^2_{y,x_i,s_j} is the R^2 for the distinct subset of variables s_j, plus x_i. R^2_{y,s_j} is the R^2 for the distinct subset of variables s_j excluding x_i.

Finally, by averaging these values across k orders, the total dominance C_{x_i} for the variable x_i is obtained as Eq.(3). For two variables x_i and x_j, if $C_{x_i} > C_{x_j}$, then predictor x_i dominates x_j.

$$C_{x_i} = \sum_{k=0}^{n-1} C_{x_i}^{(k)} / n \qquad (3)$$

3.3.3 Heterogeneity Analysis: Baseline Model, SME Model and Non-SME Model

To further analyse the heterogeneity between manufacturers of different sizes when they are impacted by these factors, three models are constructed, including baseline model, SME model, and Non-SME model, respectively. The observations in the first model comprise all the enterprises in the sample, the second model only includes SMEs in the sample, while the last model only contains Non-SMEs in the sample, which is opposite to the second model. Under the framework of these three models, comparing the parameter estimation results of the logistic regression and the relative importance of the factors can more effectively highlight the heterogeneity of enterprises. All calculation processes are conducted using R software.

3. Empirical Results

3.1 Descriptive Statistics

Based on the questionnaires completed by the manufacturers in June 2020, the data was summarised and descriptive statistics for each variable were obtained, to highlight the unique characteristics of the SMEs and compare them with Non-SMEs, their variable statistics are displayed separately in *Table 2*.

Table 2. Descriptive statistics

Variable	Explanation	Proportion			Variable	Explanation	Proportion		
		Full sample	SME sample	Non-SME sample			Full sample	SME sample	Non-SME sample
y	0 = less or no impact	24.64%	25.47%	23.16%	x_6	0 = no demand	23.74%	19.37%	31.58%
	1 = great impact	75.36%	74.53%	76.84%		1 = less than 10%	30.60%	32.98%	26.32%
x_1	0 = more than 90%	1.96%	1.88%	2.11%		2 = 10%~30%	30.90%	35.21%	23.16%
	1 = 70%~90%	7.91%	5.16%	12.84%		3 = more than 30%	14.77%	12.44%	18.95%
	2 = 50%~70%	16.58%	14.79%	19.79%	x_7	0 = no reduction	36.62%	38.97%	32.42%
	3 = 30%~50%	16.73%	13.73%	22.11%		1 = less than 5%	19.82%	18.90%	21.47%
	4 =10%~30%	17.31%	16.43%	18.95%		2 = 5%~10%	18.16%	16.78%	20.63%
	5= less than 10%	39.49%	48.00%	24.21%		3 = 10%~30%	15.75%	16.43%	14.53%
x_2	0 = 1 week	20.50%	14.44%	31.37%		4 = more than 30%	9.65%	8.92%	10.95%
	1 = 2 week	37.83%	45.19%	24.63%	x_8	0 = less than 10%	4.37%	4.11%	4.84%
	2 = 3 week	20.95%	22.65%	17.89%		1 = 10%~30%	5.12%	5.28%	4.84%
	3 = 4 week	9.87%	7.51%	14.11%		2 = 30%~50%	22.76%	22.18%	23.79%
	4 = more than 4 weeks	10.85%	10.21%	12.00%		3 = 50%~70%	51.09%	50.59%	52.00%
x_3	0 = already return to normal level	2.49%	2.46%	2.53%		4 = more than 70%	16.65%	17.84%	14.53%
	1 = 1- 2 weeks	25.55%	29.23%	18.95%	x_9	0= less than 50%	4.22%	4.93%	2.95%
	2 = 2 weeks-1 month	38.81%	35.80%	44.21%		1= 50%~70%	76.04%	74.77%	78.32%
	3 = 1-3 month	27.58%	26.76%	29.05%		2= more than 70%	19.74%	20.31%	18.74%
	4 = 3-6 month	4.30%	4.34%	4.21%	x_{10}	0 = no	59.76%	62.79%	54.32%
	5 = 6-12 month	1.28%	1.41%	1.05%		1 = yes	40.24%	37.21%	45.68%
x_4	0 = no	75.43%	75.82%	74.74%	x_{11}	0 = no	52.83%	40.85%	74.32%
	1 = yes	24.57%	24.18%	25.26%					
x_5	0 = no	61.42%	63.38%	57.89%		1 = yes	47.17%	59.15%	25.68%
	1 = yes	38.58%	36.62%	42.11%					

Source: summarized based on the specialized investigation about the impact of COVID-19 on business operations.

Based on the frequency distribution of a variable x_1, the production capacity of 78.16% of SMEs has not yet reached 50% of its normal level, while this proportion is 65.27% for the Non-SMEs sample. This finding indicates that SMEs face a greater struggle in recovering their production capacity.

Based on a given company's judgment regarding the necessary duration of a delay in resuming work (x_2), 45.19% of SMEs are expected to take two weeks, while 31.37% of Non-SMEs are expected to take only one week. This shows that SMEs require relatively more time to prepare to resume work.

Regarding the time required to restore normal operations (x_3), the difference between the SMEs and Non-SMEs is negligible; 67.49% of SMEs expect a full restoration to occur in less than one month, compared to 65.33% of the manufacturers in the Non-SMEs sample.

When asked whether there are difficulties in fulfilling contracts（variable x_4), 24.18% of SMEs said that they have difficulties, while the proportion of this item in the Non-SMEs sample of manufacturers is slightly higher (25.26%). Regarding the question of pressure from operations costs (x_5), 36.62% of SMEs answered "yes", while 42.11% answered this question in the affirmative in the Non-SMEs sample. From the perspective of a gap in cash flow (x_6), the proportion of manufacturers with a gap of over 10% is 42.11% in the Non-SMEs sample and 47.65% in the SME sample. This shows that SMEs are experiencing more operational difficulties during the COVID-19 outbreak.

From the perspective of the passive reduction of orders (x_7), the situation experienced by the SMEs is slightly better than the average of the Non-SMEs sample. In the Non-SMEs sample, 67.58% of manufacturers were forced to reduce orders, while the proportion is only 61.03% in that of the SME. In terms of the magnitude of a reduction in orders, 25.35% of SMEs indicated that their orders were reduced by over 10%, while 25.48% in the Non-SMEs sample experienced the reduction in orders, which is slightly higher than SMEs.

In terms of the degree of traffic and logistics congestion (x_8), from both the SME and Non-SMEs samples, it was revealed that about 50% of manufacturers (50.59% VS 52.00%) believe that the degree of traffic and logistics congestion has reached 50%-70% of the normal level. From the frequency distribution of the variable x_9, the situation of the Non-SMEs sample is similar to that of the SME but has a higher proportion of non-local employees.

From the perspective of stimulating policies, 45.68% and 25.68% of-SMEs samples hope to obtain policy support for bond issuance and subsidised loan interest, respectively. In the same situation, the two ratios in the SME sample are 37.21% and 59.15%, respectively. This indicates that SMEs are more inclined to seek loan interest subsidies.

3.2 Results of Logistic Regression

Table 3 shows the estimation results of the regression coefficients of the baseline model, SME model, and Non-SME model, respectively. In the baseline model, the pseudo R^2 is 0.365, the Akaike information criterion (AIC) statistic is 935.412, and the Log-likelihood statistic is -455.71. In the SME model, the pseudo R^2 , the AIC statistic, and the Log-likelihood statistic are 0.402, 580.3and-278.149, while these statistics in the Non-SME model are 0.322, 367.982, and -171.99, respectively. This indicates that the three models' goodness of fit meets the requirements. The areas under the ROC Curve(AUC) in the baseline model, SME model and Non-SME model reached 0.896, 0.913, and 0.864, respectively, which indicates that the logistic classifier has a good classification performance. The explanatory variables in the model are all statistically significant, and Hypotheses 1 through 5 have been verified.

Table 3. Parameter estimation results of logistic regression

variables	Baseline model			SME model			Non-SME model		
	Estimate	Std. Error	Pr(>|z|)	Estimate	Std. Error	Pr(>|z|)	Estimate	Std. Error	Pr(>|z|)
Intercept	-6.263	0.464	0.000***	-6.973	0.611	0.000***	-5.212	0.370	0.000***
Degree of production recovery (x_1)	0.114	0.058	0.051*	0.146	0.079	0.063*	0.161	0.734	0.109
Degree of delay in resuming work (x_2)	0.258	0.079	0.001***	0.356	0.119	0.003***	0.149	0.100	0.170
Time required to restore normal operation (x_3)	0.440	0.098	0.000***	0.445	0.123	0.000***	0.351	0.109	0.035**
Difficulties in contract implementation (x_4)	0.715	0.225	0.001***	0.796	0.292	0.006**	0.619	0.166	0.088*
Pressure of operations costs (x_5)	0.552	0.184	0.003***	0.546	0.238	0.022**	0.420	0.363	0.160
Cash flow gap (x_6)	0.213	0.088	0.015**	0.218	0.122	0.074*	0.216	0.299	0.106
Passive reduction of orders (x_7)	0.255	0.067	0.000***	0.278	0.089	0.002***	0.227	0.134	0.034**
Degree of traffic and logistics congestion (x_8)	1.268	0.102	0.000***	1.304	0.129	0.000***	1.205	0.107	0.000***
Proportion of non-local Employees in enterprises (x_9)	0.881	0.219	0.000***	0.930	0.281	0.001***	0.647	0.166	0.071*
Bonds issuance (x_{10})	0.921	0.183	0.000***	1.023	0.247	0.000***	0.649	0.358	0.024**
Subsidized loan interest (x_{11})	1.125	0.180	0.000***	1.310	0.223	0.000***	1.160	0.287	0.002***
AIC	935.412			580.300			367.982		
AUC	0.896			0.913			0.864		
Pseudo R-square	0.365			0.402			0.322		
Log-Likelihood	-455.710			-278.149			-171.990		

Notes: *, **, and *** are significant at the 10%, 5%, and 1%levels, respectively.

Source: summarized by the authors based on the calculation results of Python software.

(1) Regression coefficients of factors on business continuity

In the SME model, the variables corresponding to hypothesis 1 are significant, meanwhile x_4 and x_3 have the highest estimated coefficients of 0.531 and 0.469, respectively. While, the Non-SME model shows that the effects of x_4 and x_3 are significant with the estimated coefficients of 0.619 and 0.351, respectively.

In a comparison of the SME model and the Non-SME model, it can be inferred that the impact of other explanatory variables on business continuity is more significant in the SME model than in the Non-SME model. This may be because when suffering from the impact of the epidemic, SMEs with weak capacity for supply chain integration have poor operational recovery capabilities. Therefore, compared to large manufacturers, they struggle to complete contracts and require more time to resume normal operations.

(2) Regression coefficients of factors on capital chain pressure

In the SME model, the estimated coefficients of x_5 and x_6 are 0.546 and 0.218, respectively, and the corresponding odds ratios are 1.726 and 1.244. In the Non-SME model, the estimated coefficients of x_5 and x_6 are 0.42 and 0.216, respectively, and the odds ratios are 1.522 and 1.241, respectively.

This means that in the SME model, the impact of pressure on the capital chain is more significant than that revealed in the Non-SME model, which may be because SMEs are facing more severe cost pressures, and the gap in the cash flow prevents most SMEs from survival.

(3) Regression coefficients of factors on supply chain integration

The estimated coefficients of x_7 and x_8 in the SEM model are 0.278 and 1.304, respectively, and the corresponding odds ratios are 1.320 and 3.684. Meanwhile, in the Non-SME model, these two estimated coefficients are 0.227 and 1.205, and their odds ratios are 1.255 and 3.337, respectively. According to the regression results, traffic and logistics congestion has a strong influence impact on the models, especially on of SMEs. When the degree of traffic and logistics congestion increases by one unit, the impact of COVID-19 on Non-SMEs and SMEs increases by 3.337and 3.684 times, respectively.

(4) Regression coefficients of factors on labour force availability

In the Non-SME model, the estimated coefficient x_9 is 0.647 and the odds ratio is 1.91. The estimated coefficient x_9 is 0.93 and the corresponding odds ratio is 2.535 in the SME model. By combining the descriptive statistics in Section 4.1, it can be found that the proportion of non-local employees in the SMEs is slightly lower than that of the Non-SME sample, but the coefficient estimates are slightly higher than those of the Non-SME model. This may be due to financial and resource constraints, as SMEs cannot adopt a centralised and organised approach through which they may encourage some non-local employees to return to work like large enterprises.

(5) Regression coefficients of factors on stimulating policies

For the Non-SME model, the estimated coefficients of x_{10} and x_{11} are 0.649 and 1.16, respectively, and the odds ratios are 1.914 and 3.19. In the SME model, the estimated values of these two variables are 1.023 and 1.31, and the corresponding odds ratios are 2.782 and 3.706. The regression results show that all enterprises have a strong demand for stimulating policies that benefit enterprises, especially SMEs.

3.3 Dominance Analysis of Factors

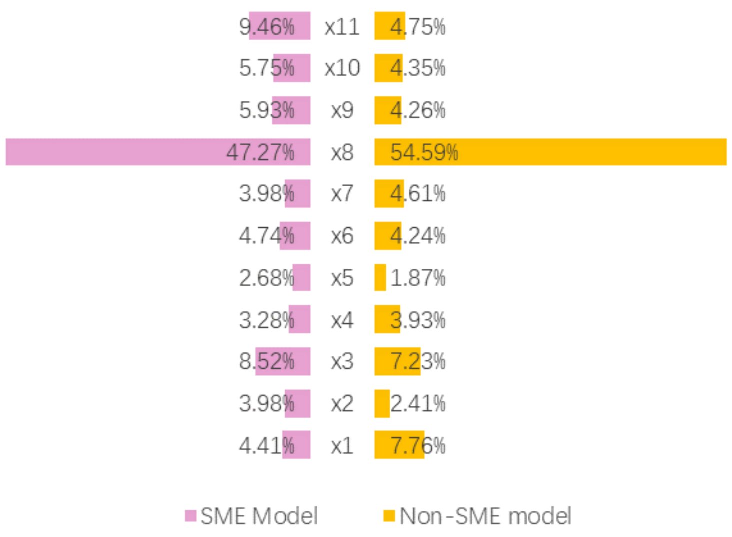
In accordance with *Table 3*, the relative importance of the corresponding factors for the baseline model, SME model and Non-SME model is calculated, and the results are presented in *Table 4*.

From *Table 4* and *Figure 1*, the following conclusions can be drawn when comparing with SME model and Non-SME model. First, factors related to the supply chain are the most important for both models. The total dominance of x_8 in the SME model (0.190) is slightly higher than that of the Non-SME model (0.175), while the relative importance (47.27%) is lower in the former than in the latter (54.59%). Second, the top three factors of relative importance are discrepant in the SME model (x_8, x_{11} and x_3) and Non-SME model (x_8, x_3 and x_1), which means different factors have a different impact on the two models. Third, based on the variation in the relative importance of all factors, the SME model is smaller than the Non-SME model. This means that shortcomings in SME operating capabilities are present in all factors (rather than manifesting in only one or a few). When confronted with the impact of the epidemic, SMEs are more seriously impacted and are therefore more vulnerable (Runyan, 2006).

Table 4. The relative importance of factors in three models

Variables	Baseline model			SME model			Non-SME model		
	Total dominance	Relative importance	Rank	Total dominance	Relative importance	Rank	Total dominance	Relative importance	Rank
x_1	0.017	4.56%	6	0.018	4.41%	7	0.025	7.76%	2
x_2	0.012	3.39%	10	0.016	3.98%	9	0.008	2.41%	10
x_3	0.031	8.61%	2	0.034	8.52%	3	0.023	7.23%	3
x_4	0.013	3.60%	9	0.013	3.28%	10	0.013	3.93%	9
x_5	0.010	2.64%	11	0.011	2.68%	11	0.006	1.87%	11
x_6	0.016	4.47%	7	0.019	4.74%	6	0.014	4.24%	8
x_7	0.016	4.38%	8	0.016	3.98%	8	0.015	4.61%	5
x_8	0.185	50.49%	1	0.190	47.27%	1	0.175	54.59%	1
x_9	0.021	5.67%	5	0.024	5.93%	4	0.014	4.26%	7
x_{10}	0.021	5.80%	4	0.023	5.75%	5	0.014	4.35%	6
x_{11}	0.023	6.38%	3	0.038	9.46%	2	0.015	4.75%	4

Source: summarized by the authors based on the calculation results of Python software.



Source: summarized based on the *Table 4.*

Figure 1. **Relative Importance of factors between Non-SME and SME Models**

In addition, the sum of the total dominance of the variables is equal to the pseudo R-square of that model, regardless of the model. For example, the sum of total dominance in the

SME model is 0.402, which is equal to the pseudo R-square of the SME model listed in *Table 3*. This further demonstrates the advantage of the dominance analysis: the relative importance of each factor can be represented more accurately and visually.

4. Further Analysis: The Path of Influence between Factors

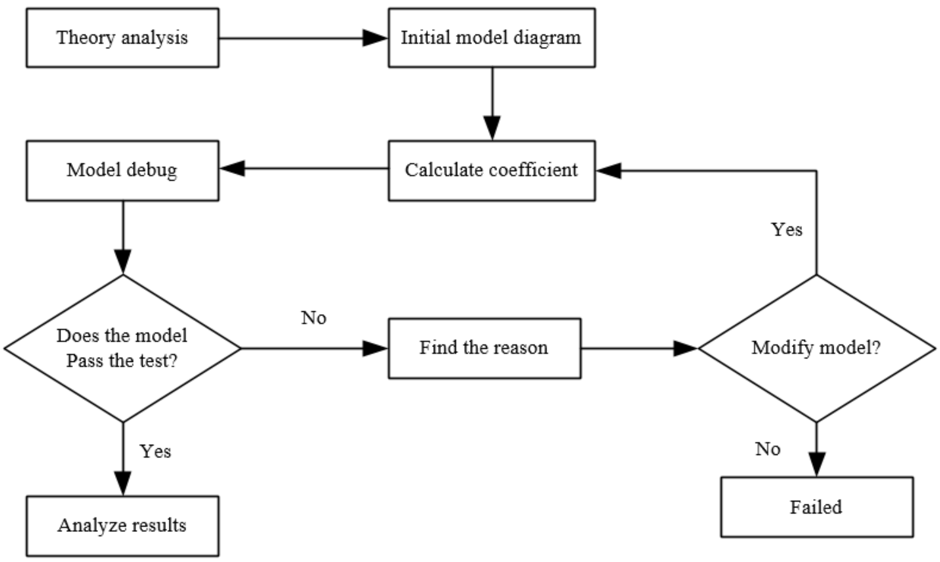
4.1 Path Analysis

The logistics regression analysis in Section 4 can clarify the factors that affect manufacturer operations. However, it is noteworthy that a causal relationship may exist between them. For example, the cash flow gap (x_6) may affect the passive reduction of orders (x_7), while the latter may also be the reason for the former. To further explain the possible causal relationship between the factors and their influence mechanism, the path analysis method is applied.

Path analysis is a multivariate analysis method that explains the causal relationship between variables (Wright, 1918). The model used herein can be expressed as follows.

$$\boldsymbol{\eta} = \mathbf{B}\boldsymbol{\eta} + \boldsymbol{\Gamma}\boldsymbol{\varepsilon} + \mathbf{e} \qquad (4)$$

In Eq.(4), $\boldsymbol{\eta} = (\eta_1, \eta_2, \ldots, \eta_n)'$ and $\boldsymbol{\varepsilon} = (\varepsilon_1, \varepsilon_2, \ldots, \varepsilon_m)'$ represent the vectors of the endogenous and exogenous variables, respectively. $\mathbf{B}_{n\times n}$ and $\boldsymbol{\Gamma}_{m\times m}$ represent the matrix of the path coefficients to be estimated, which corresponds to $\boldsymbol{\eta}$ and $\boldsymbol{\varepsilon}$. These are generally estimated via the least square method; $\mathbf{e}$ is the error term vector that corresponds to the endogenous variable, which satisfies the conditions as follows: $E(e_i) = 0$ and $Cov(e_i, e_j) = 0$.



Source: created by the authors.

Figure 2. **Steps in the Path Analysis**

The causal relationship between the variables, the path of influence (indicated by the direction of the arrow), and the direction of influence (positive or negative) in the path analysis are shown in a path diagram. *Figure 2* shows the steps in the path analysis.

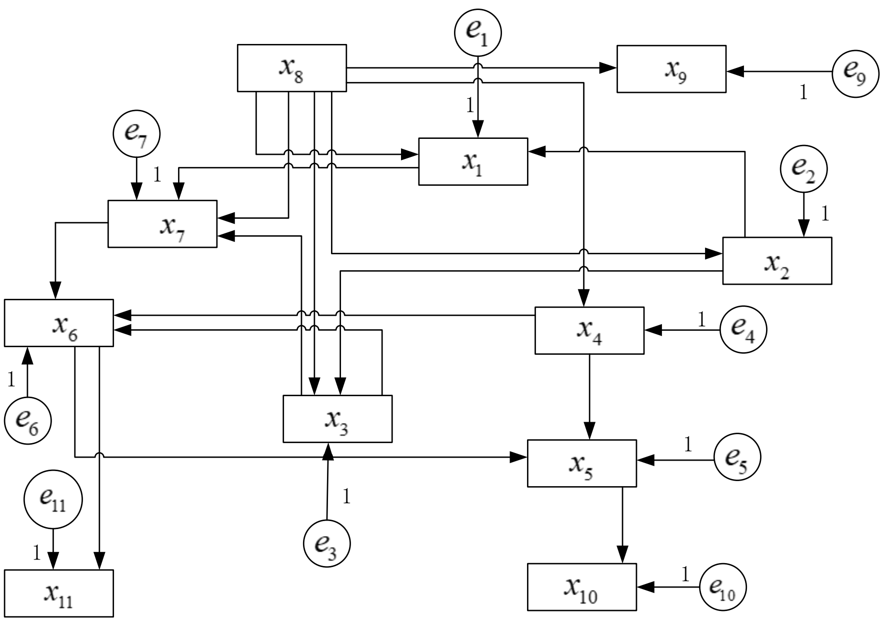
4.2 Model Representation

According to the conclusion in Section 4.3, the relative importance of the variable x_8 is the highest among the 11 variables. During the COVID-19 outbreak, the strict lockdown and travel control policies implemented by the government caused interruptions in traffic and logistics. Thus, the variable x_8 is primarily affected by the lockdown and is an exogenous variable in the model.

Meanwhile, traffic and logistics congestion may cause interruptions in the company's supply chain, hinder business continuity, and increase the difficulties encountered by employees endeavoring to return to work. Further, this increases the pressure on the company's capital chain and eventually causes manufacturers to seek policy support. Therefore, the remaining 10 variables are set as endogenous variables. Based on the above analysis, this article adopts the recursive path analysis model as follows.

$$\mathbf{X}_i = \mathbf{B}\mathbf{X}_i + \gamma x_8 + \mathbf{e}_i \quad \{1 \le i \le 11 \mid i \ne 8\} \tag{5}$$

In Eq.(5), $\mathbf{X}_i = (x_1, x_2, \ldots, x_7, x_9, x_{10}, x_{11})'$ is the vector of the endogenous variables, $\mathbf{B}$ represents the matrix of the path coefficients to be estimated, γ is the coefficient of exogenous variables x_8 to be estimated, and $\mathbf{e_i} = (e_1, e_2, \ldots, e_7, e_9, e_{10}, e_{11})'$ is the error term vector corresponding to the endogenous variables.



Source: created by the authors.

Figure 3. **Path of Influence of Explanatory Variables**

The path analysis model is adjusted and iterated through exploratory analysis until the goodness-of-fit index of the model satisfies the test statistically. Finally, the influence relationship between the variables that is obtained by the path model is displayed as a path diagram. Based on the previous analysis, the possible path of influence between the variables is illustrated in *Figure 3* and empirical analysis is carried out.

In *Figure 3*, the direction indicated by the arrow illustrates the direction of the path of influence. For example, the arrow from x_2 pointing to x_1 indicates that x_2 has an impact on x_1, while its influence coefficient remains a question for resolution by the model. The arrow from e_9 to x_9 represents the path of influence of the residual term e_9 on the endogenous variable x_9. Generally, the influence coefficient of the residual term on the endogenous variable is set to 1. In the model, the path coefficient and related statistics are calculated using SPSS17.0 and AMOS17.0 software.

4.3 Results of Path Analysis

4.3.1 Fitting Effect of the Models

Table 5 shows the fitting effect of the path model between the explanatory variables in the SME model and the Non-SME model. From *Table 5*, it can be seen that for both the Non-SME and that of the SME, the goodness-of-fit index (GFI) and the root mean square of the approximate error (RMSEA), the root mean square residual (RMR), as well as the AIC and other statistics, can meet the corresponding requirements, thus indicating that the fitting effect of the path analysis is very good.

Table 5. The fitting effect of path analysis

Index		Criteria	SME model	Non-SMEmodel
Absolute fit index	GFI	Greater than 0.9	0.973	0.978
	RMR	Less than 0.05，the smaller the better	0.045	0.031
	RMSEA	Less than 0.05，the smaller the better	0.046	0.046
Information index	AIC	The smaller the better	132.364	162.327

Source: Breckler, 1990; Steiger, 1990.

4.3.2 Factors' Path of Influence

The influence of paths and coefficients among the explanatory variables in the SME and Non-SME models are listed in *Table 6*. The paths of influence are explained for each of the factors individually in the following section.

(1) The path of influence on business continuity

From *Table 6*, it can be observed that x_1, x_2, x_3 and x_4 are all affected by x_8, and x_2 has positive effects on x_1 and x_3, respectively, in terms of internal business continuity factors. These paths of influence are all statistically significant both in the SME model and the Non-SME model.

In the Non-SME model, the path coefficients of $x_1 \leftarrow x_8$ and $x_2 \leftarrow x_8$ are 0.355 and 0.182, respectively, which is higher than the corresponding path coefficients in the SME model (0.192 and 0.146).

While in the SME model, the path coefficients of $x_1 \leftarrow x_2$ and $x_3 \leftarrow x_2$ are 0.410 and 0.191, respectively, which are higher than the corresponding coefficients in the SME model, the latter of which are 0.242 and 0.077.

To sum up, in the SME model, the impact of the degree of delay in resuming work (x_2) on SMEs is more serious, this may because the higher the degree of delay in resuming work (x_2), the more time the SMEs need to restore normal operation and production. While the impact of the degree of traffic and logistics congestion on Non-SMEs is more serious, the potential reasons may be that the Non-SMEs have a relatively large scale of business, once traffic and logistics are interrupted, the supply chain system will be greatly affected, so the recovery process of production and operation of Non-SMEs become more severe.

Table 6. The parameter estimates of path analysis

Path	SEM model			Non-SME model		
	Estimate	S.E.	P	Estimate	S.E.	P
$x_1 \leftarrow x_2$	**0.410**	0.039	<0.001***	0.242	0.045	<0.001***
$x_1 \leftarrow x_8$	0.192	0.047	<0.001***	**0.355**	0.065	<0.001***
$x_2 \leftarrow x_8$	0.146	0.041	<0.001***	**0.182**	0.066	0.006***
$x_3 \leftarrow x_2$	0.191	0.027	<0.001***	0.077	0.029	0.008***
$x_3 \leftarrow x_8$	**0.264**	0.033	<0.001***	0.230	0.042	<0.001***
$x_4 \leftarrow x_8$	0.091	0.015	<0.001***	0.078	0.021	<0.001***
$x_5 \leftarrow x_4$	0.118	0.038	0.002**	0.081	0.052	0.123
$x_5 \leftarrow x_6$	0.070	0.017	<0.001***	0.037	0.021	0.074*
$x_6 \leftarrow x_3$	0.123	0.032	<0.001***	0.060	0.055	0.278
$x_6 \leftarrow x_4$	0.174	0.073	0.017**	**0.349**	0.114	0.002***
$x_6 \leftarrow x_7$	0.112	0.023	<0.001***	0.099	0.037	0.007***
$x_7 \leftarrow x_1$	0.064	0.034	0.056*	0.089	0.045	0.048**
$x_7 \leftarrow x_3$	0.119	0.049	0.016**	0.030	0.070	0.661
$x_7 \leftarrow x_8$	0.188	0.051	<0.001***	0.129	0.071	0.068*
$x_9 \leftarrow x_8$	0.099	0.017	<0.001***	0.084	0.021	<0.001***
$x_{10} \leftarrow x_5$	0.080	0.034	0.019**	0.014	0.046	0.761
$x_{11} \leftarrow x_6$	0.087	0.018	0.006**	0.049	0.040	0.03**

Notes: 1) *, **, and *** are significant at the 10%, 5%, and 1%levels, respectively. 2) The arrow direction indicates the path effect from variable A to variable B. For example, $x_1 \leftarrow x_2$represents $x_2$affectx_1.

Source: summarized by the authors based on the calculation results of Amos software.

(2) The path of influence on the capital chain

In the SME model, both x_4 and x_6 have positive effects on x_5, and x_6 is affected by x_3, x_4, and x_7, and all these effects are statistically significant. The path coefficients of $x_5 \leftarrow x_4$ (0.118), $x_6 \leftarrow x_4$ (0.174), and $x_6 \leftarrow x_3$ (0.123) are relatively large.

While in the Non-SME model, the path coefficients $x_6 \leftarrow x_4$ is 0.349, which means the capital factors are mainly affected by the existence of contractual performance difficulties.

According to the analysis aforementioned, the conclusion can be drawn that all the manufacturers were affected by contractual performance difficulties, which leads to capital chain pressure, especially for SMEs. The reason may be that due to the large scale of Non-SMEs, the situation of contractual performance difficulties is more critical, thus the effect for Non-SMEs is more serious than SMEs.

(3) The path of influence on supply chain

In the SME model, the path coefficients of $x_7 \leftarrow x_1$ and $x_7 \leftarrow x_3$ are 0.064 and 0.119, respectively, both of them are significant. Besides, these two coefficients are higher than those in the Non-SME model (0.089 and 0.03), which means that degree of production recovery and time required to restore normal operation are the main factors that affect the passive reduction of orders in SMEs.

The reason may be that due to the disruption of production and operation of manufacturers, the production capacity of enterprises has been declined, which leads to the passive reduction of orders, and this situation is more obvious for SMEs.

(4) Path of influence on other factors

Based on the results in Table 6, the effect of $x_9 \leftarrow x_8$ (0.099) in the SME model is greater than that in the Non-SME model (0.084) is negligible, which indicates that traffic control significantly affects the rate at which non-local employees are returning to work. Further, the effect of $x_{10} \leftarrow x_5$ (0.08) and $x_{11} \leftarrow x_6$ (0.087) in the SMEs are more serious than the Non-SMEs (0.014 and 0.049).

According to the previous analysis, it can be inferred that the difference of the impact of the degree of traffic and logistics congestion (x_8) on the labour force is negligible between SMEs and Non-SMEs, and it is no doubt that the lack of labour force under the impact of the epidemic is a common dilemma for both SMEs and Non-SMEs based on the actual situation. And this indicates that manufacturers are prompted to seek corresponding policy support (e.g. issue bonds and subsidized loan interest, etc.) when confronting pressure on the capital chain and operations costs, especially in SMEs. The reason may be that due to the properties of capital scarcity, small business scale and weak ability to resist the risk of SMEs, which leads to the higher demand for stimulating policies.

Conclusions and Implications

Conclusions

Based on the logistic regression and path analyses conducted on the sample of 1329 manufacturers in Hangzhou, China, the following conclusions are drawn.

First, the logistic regression model shows that 11 factors from 5 aspects have significantly affected manufacturer performance during COVID-19, which mainly including business continuity, pressure on the capital chain, difficulties in supply chain integration, labour force availability, and stimulating plans.

Second, according to the results of Dominance Analysis, it can be further concluded that the factors of the supply chain have the greatest influence on manufacturing enterprises both in the SME and Non-SME models, especially the degree of traffic and logistics congestion (x_8), whose relative importance is the highest in both models (47.27% and 54.59%).

Further, in terms of the path of influence connecting the explanatory variables, it can be inferred that for the Non-SMEs, the impact of traffic and logistics congestion (x_8) on business continuity and the impact of contractual performance difficulties (x_4) on the capital chain are more serious than that of SMEs. The reason is that due to the large scale of business of Non-SMEs, once the traffic and logistics are interrupted, the supply chain system will be greatly affected immediately, so the challenges faced by enterprises to resume normal production and operation are more severe. In addition, due to the contractual performance difficulties confronted by Non-SMEs, thousands of products cannot be sold and gain profits instead, which leads to a cash flow crisis.

For SMEs, the degree of delay in resuming work has a higher impact on business continuity than for Non-SMEs, this may be that due to the impact on production operations, the product capacity decreased severely, so the situation of passive reduction of orders is more severe for SMEs. Besides, the demand for stimulating policies is stronger for SMEs than for Non-SMEs due to the properties of capital scarcity, small business scale, and weak ability to resist the risk of SMEs.

Implications

According to the empirical analysis conducted herein, as well as the Chinese government's experience in combating COVID-19, it is believed that countries should strengthen the following aspects to promote the resumption of manufacturer operations.

First, the construction of an information platform should be promoted to facilitate the sharing of resources among enterprises. Through this platform, manufacturers can utilise private and official resources to improve their capacity for supply chain integration during the COVID-19 outbreak, provide various anti-epidemic materials (e.g. masks, gloves, and disinfectant) to enable employees to return to work more safely and conveniently and promote the normalisation of operations.

Second, the efficient operation of the transportation logistics system must be ensured, such as reducing transportation and logistics fees, minimising their operating costs. Besides, a special subsidy policy for transportation and logistics companies should be implemented to accelerate the recovery of manufacturers' production efficiency, especially for Non-SMEs, promote the smooth operation of their industrial chain and supply chain, and provide a basis for manufacturer business continuity.

Third, the government should promptly formulate various stimulating policies that help enterprises operate from a position of stability, especially for SMEs. For example, commercial banks should be organised to open channels for rapid loan processing, provide low-interest rates on loans, and allow manufacturers to defer or reduce loan interest payments. The securities market's support for SMEs should also be increased to issue bonds and provide financial subsidies that can ease the pressure on the capital chain and reduce manufacturer operating costs.

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COVID-19 POVEIKIS GAMINTOJŲ VEIKLAI: KINIJOS PAVYZDŽIAI

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SANTRAUKA

COVID-19 visame pasaulyje išplito itin sparčiai ir stipriai paveikė ekonomikos plėtrą bei socialinės tvarkos stabilumą daugelyje šalių, o tai turėjo įtakos įprastai gamintojų veiklai. Šiame tyrime, taikant logistinės regresijos ir kelių analizės metodus, buvo išnagrinėti 1329 gamintojų Hangdžou mieste (Kinija) pavyzdžiai, kurie padėjo nustatyti pagrindinius, su COVID-19 susijusius veiksnius, darančius įtaką gamintojų veiklai, taip pat jų galimus priežastinius ryšius. Empiriniai logistinės regresijos rezultatai atskleidžia, kad COVID-19 gamintojų darbo našumas yra veikiamas penkiais aspektais: verslo tęstinumas, kapitalo grandinės atotrūkis, tiekimo grandinės integracija, darbo jėgos prieinamumas ir skatinimo politika. Kelių analizės metodo išvados rodo, kad eismo ir logistikos perpildymo lygis tampa pagrindiniu veiksniu, trikdančiu gamintojų verslo tęstinumą, o tai galiausiai nulemia kapitalo grandinės atotrūkį ir skatinimo politikos poreikį gamintojams. Remiantis tyrimų rezultatais, siūlomos rekomendacijos dėl paramos gamintojams atnaujinti veiklą ir atgaivinti ekonomiką.

REIKŠMINIAI ŽODŽIAI: COVID-19, gamintojas, verslo operacijos, logistinė regresija, kelių analizė.