Evaluation and Analysis of Indirect Industrial Economic Losses Caused by the Wenchuan Earthquake

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Abstract. The rapid development of socio-economics has increased the complexity of factors influencing indirect earthquake losses and prolonged the impact duration, presenting significant challenges for assessing these losses. This study focuses on the 8.0 magnitude Wenchuan Earthquake that occurred on May 12, 2008, to investigate industrial indirect economic losses, comprehensively analyzing the effect of the earthquake on the gross production value (GPV) of various industrial sectors in Sichuan Province, and estimating sector-specific indirect losses based on the GDP approach. It was found that the industry-specific indirect economic loss for Sichuan's total industrial output to recover to pre-earthquake levels amounted to RMB 1223.734 billion, approximately 13 times the direct economic losses. This figure is also higher than the estimates obtained from other methods cited in the literature. Five years after the earthquake, the indirect economic loss reached RMB 2772.229 billion, more than double the aforementioned figure, reflecting the characteristics of sector-specific indirect losses and their sustained impacts, while discussing the relationship between recovery time and industrial resilience. The analysis lays the groundwork for developing predictive evaluation methods for indirect economic losses in industrial sectors, contributing to sustainable development planning for industries and regions before an earthquake, and providing technical support for post-earthquake reconstruction and disaster prevention and mitigation strategies.

Keywords: Disaster prevention and mitigation; Resilience; Indirect economic losses; Recovery time

1 Introduction

In the contemporary era of rapid economic development, the impact of earthquake disasters is far from limited to the visible physical damage and direct economic losses. Its indirect impact on the social and economic system is often more far-reaching and complex, often exceeding the scale of direct economic losses. For example, the direct economic loss of Sichuan Province caused by the 2008 Wenchuan earthquake reached 828.69 billion yuan. Dujikui[1] and others used the GDP data of the disaster area to

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assess the indirect economic loss of Wenchuan M8 earthquake reached 1030billion yuan. Sunhuina [2] calculated the indirect economic losses of Sichuan Province as 737.177 billion yuan, 625.313 billion yuan, 648.089 billion yuan and 1259.813 billion yuan respectively according to the empirical coefficient method, distribution coefficient method, consumption coefficient method and Harold Domar model. It can be seen that the indirect economic loss caused by the Wenchuan earthquake has exceeded the direct loss, and the related impact outside the disaster area and the sustained impact on various industries in the later stage have not been considered. The total indirect impact on enterprise production (the total production loss of enterprises that were not directly damaged by the earthquake for one year) of the magnitude 9.0 Earthquake in eastern Japan in 2011 was 11.4 trillion yen, while the total direct loss of enterprise production was estimated to be 0.1 trillion yen, and the total indirect loss was more than 100 times of the total direct loss [3]. This is only the estimated result of one year, and the continuous impact of Fukushima nuclear power in the earthquake area is still today. It can be seen that with the development of urban agglomerations and intensive industries, once a major earthquake occurs, the indirect economic loss and subsequent sustained impact will far exceed the direct economic loss, which seriously restricts the sustainable development of the region.

For the indirect loss assessment of earthquake, the contents mainly include: the loss of production suspension and reduction of enterprises, land price loss, regional indirect economic loss and industry related loss [4-8]. At present, there are three commonly used evaluation methods [9]: empirical coefficient method, which assumes that there is a positive correlation between indirect economic loss and direct economic loss, and uses the coefficient to adjust on the basis of direct economic loss evaluation. But it is subjective and ignores other influencing factors and regional differences; The GDP comparison method refers to an evaluation method for analyzing the indirect economic losses in the disaster area by analyzing the regional GDP changes before and after the earthquake. Because the change of GDP after the earthquake is unknown, it is only suitable for the indirect loss estimation research for many years after the earthquake; The input-output method, based on the input-output table and the direct economic loss of each department, evaluates the indirect economic loss of each department, but it belongs to the static model, and the measurement time is limited to the year of earthquake disaster.

In order to analyze the sustained impact of indirect losses after the Wenchuan earthquake, based on the GDP changes of various industries in Sichuan after the earthquake, this paper uses the GDP method to estimate the indirect losses of various industries, compares the industry characteristics and sustained impact of indirect losses, and analyzes the relationship between recovery time and Industry resilience, so as to lay the foundation for the construction of subsequent evaluation methods.

2 Economic Growth Model

At present, the domestic research on indirect economic loss assessment mainly focuses on the calculation using economic models, such as input-output model and its extended model, computable general equilibrium model and its extended model, etc. Wujingyuan et al. (1998)[10] based on the input-output model, gave the measurement methods of indirect production suspension loss, product backlog loss and investment premium loss. Linjunqi, Zhong Jiangrong, et al. (2007)[11] presented an evaluation method of industrial related losses of earthquake disasters based on the input-output table. Dujikui et al. (2008)[1] used the GDP data of the disaster area, the earthquake damage coefficient of each evaluation sub area, the recovery time of the production and operation of the enterprise service industry, and the impact time of the earthquake on the production and operation of the enterprise service industry to evaluate the indirect economic loss of the earthquake disaster. Lijianglin et al. (2011)[12] constructed the evaluation index system of regional earthquake disaster economic loss, and analyzed its indexes using PCA method to obtain the weight value of each index, and then constructed the evaluation model of regional earthquake disaster economic loss under the influence of multiple indexes.

For the same earthquake, the indirect economic losses obtained by different evaluation methods are also different. At present, the empirical coefficient method and input-output model [13] are used to reflect the changes of the economic system at a certain point in time, which can not meet the dynamic needs of indirect economic loss assessment. Although the GDP method considers the change of the development trend after the earthquake, it is only suitable for the indirect loss estimation research for many years after the earthquake because the change of GDP after the earthquake is unknown. In order to analyze the sustained impact of indirect losses after the earthquake, it is also necessary to understand the growth mode of regional economy after coping with the impact of recession.

At the beginning of the 21st century, Reggiani and other scholars firstly introduced the study of resilience to the field of economics when studying the ability of regional economy to cope with the impact of recession. Among them, Simmie J and others have studied four growth modes after the impact on the regional economy [14]. On this basis, combined with the growth mode of the total industrial production (IPV) of various industries after the Wenchuan earthquake, this paper gives the corresponding four categories, as shown in Figure 1. From the perspective of industry resilience, class A industry is a weak resilience industry, that is, after the impact of the earthquake, the economic growth will be permanently and negatively affected; Class B industries are industries with strong resilience, that is, after the impact of the earthquake, economic growth "rebounded" rapidly. In the figure, A (1) is a negative lagging industry. After the earthquake, the economy rapidly showed negative growth. After a period of time, it developed at a rate lower than that before the earthquake, and the economic level was lower than that before the earthquake; A (2) is also a negative lagging industry. After a period of time, the economic growth rate is higher than that before the earthquake, but the economic level is still lower than that before the earthquake. B (1) and B (2) are both positive and lagging industries. After the earthquake, the economy showed negative growth, but after a period of time, it grew faster than before the earthquake, and the economic level will exceed the original level in the same period; B (1) after the economic level exceeds the original level in the same period, the economic growth slows down and the economic level will fall below the original level in the same period;

B (2) will also slowdown, but the economic level has been higher than the original level in the same period.

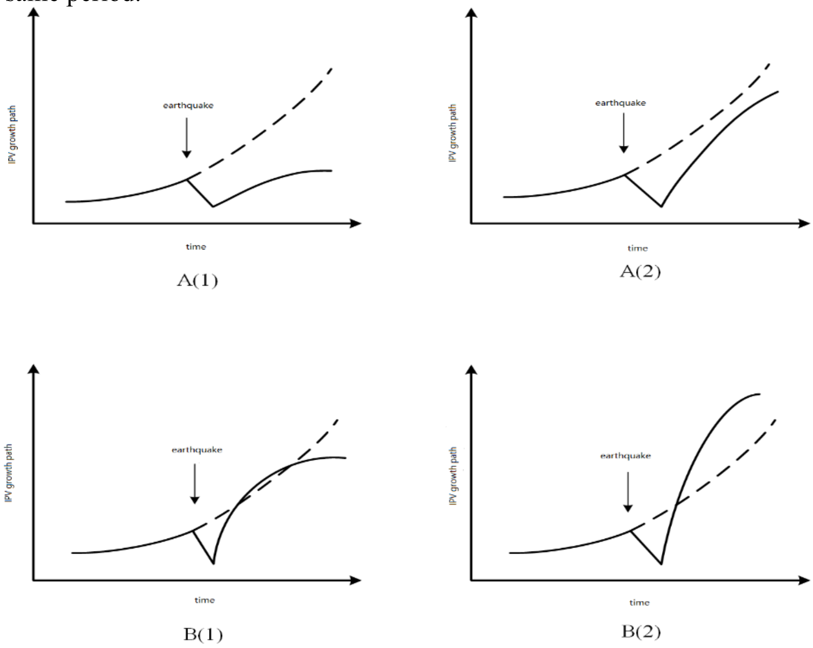


Fig. 1. Industry growth patterns post-earthquake.

3 Indirect Economic Loss Assessment Based on GDP Method

The industrial sectors in the disaster area will be affected to varying degrees after the earthquake, which will generally lead to the decline of the total industrial production of various industrial sectors in the region. Comparing the actual change trend with the extension of the change trend of the total output value before the earthquake, it is considered that the area enclosed when the total industrial output value recovers to the level before the earthquake is the indirect economic loss l of the industry, as shown in Figure 2. The calculation formula is as follows:

$$S_1 = \frac{1}{2} \times (m_1 - m_2) \times (t_1 - t_0) \tag{1}$$

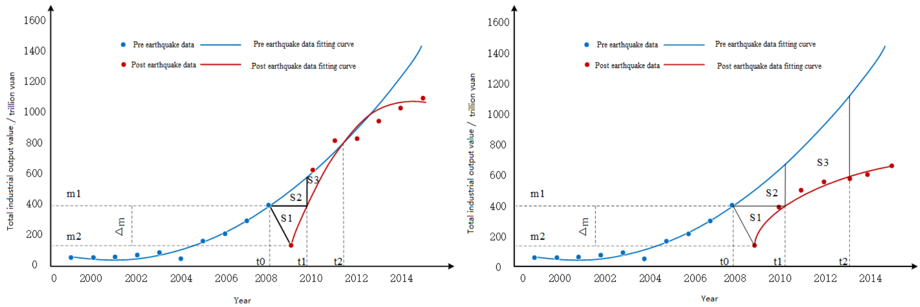
$$S_2 = \int_{t_0}^{t_1} [f_1(t) - m] dt \tag{2}$$

$$S_3 = \int_{t_1}^{t_2} [f_1(t) - f_2(t)] dt \tag{3}$$

$$L = S_1 + S_2 \tag{4}$$

$$L' = S_1 + S_2 + S_3 \tag{5}$$

Where t_0 is the occurrence time of earthquake disaster; t_1 is the time when the total industrial output value returns to the level before the earthquake; t_2 is the time when the actual gross industrial output value first reached the original level in the same period after the earthquake or 5 years after the earthquake; m_1 is the total industrial output value at the time of earthquake disaster; m_2 is the lowest value of total industrial output value after the earthquake disaster; $f_1(t)$ refers to the extension of the change law curve of the total industrial output value of the industry before the earthquake; $f_2(t)$ refers to the actual change law curve of the total industrial output value of the industry after the earthquake disaster; Δt is the time after the earthquake when the total industrial output value returned to the level before the earthquake; L is the indirect economic loss of the industry; $L'$is the indirect economic loss of the industry five years after the earthquake or when the total industrial output value after the earthquake reaches the original level for the first time in the same period. In order to simplify the calculation, S_1 approximation is regarded as a triangle. In addition, since the method is based on annual data, the monthly data changes before and after the earthquake are ignored. For example, the Wenchuan earthquake occurred on May 12. In this paper, the area enclosed by the declining trend of annual data from 2008 to 2009 and the extension of the change trend of gross output value before 2008 is approximately regarded as the indirect economic loss in 2008.



(a) Strong resilience (b) Weak resilience

Fig. 2. Definition of indirect economic losses post-earthquake.

The GDP method uses the change of the total industrial output value of each industry to assess the indirect loss, and the quoted parameter data statistics are detailed and easy to obtain. The measurement time is not only limited to the period of earthquake disaster activity, but also limited to the recovery of the total industrial output value to the level before the earthquake. It can even analyze the long-term impact of the earthquake disaster on the total industrial output value, which is conducive to the investigation of the change trend of the subsequent longer period, which is in line with the characteristics of the continuity of indirect losses, and is of great significance for the measurement and research of industrial resilience[15]. This method also has certain assumptions, such as not considering the impact of associated losses outside the disaster area, and not considering the impact of other factors on industry development after the earthquake. Due to the requirements of judging the development trend of the industry after the earthquake, it is difficult to obtain the recovery time, which is not suitable for the needs of pre earthquake prediction and earthquake emergency assessment. The indirect loss assessment, recovery time and recovery trend analysis of GDP method based on historical earthquake cases will be beneficial to the further research and improvement of this method and expand its scope of application.

4 Example Analysis

In order to analyze the sustained impact of indirect losses after the Wenchuan earthquake, this paper uses the GDP method to estimate the indirect losses of various industries based on the GDP changes of various industries in Sichuan after the Wenchuan earthquake.

4.1 Data Sources

The data in this paper are mainly from "China Statistical Yearbook", "China industrial enterprise database" and "Sichuan statistical yearbook" from 1999 to 2015. Taking 1999-2015 as the research sample interval, this paper collected the total industrial output value of Industrial Enterprises above Designated Size by industry in Sichuan Province from 1999 to 2015. The specific industry classification name was based on the current "National economic industry classification" (GB/T 4754-2002), and a total of 37 industries were counted. Since the 2011 data is based on the "National economic industry classification" (GB/T 4754-2011), some industry data have been processed in order to reach a consensus between 1999 and 2015.

4.2 Data Processing

In this study, the data of the gross industrial output value of various industries were screened according to the setting requirements of the evaluation method. For example, the change trend of the gross industrial output value of the oil and gas exploitation industry, handicrafts and other manufacturing industries was discrete after 2008, which was caused by other factors except earthquake impact. Figure 3 shows the scatter diagram of the gross industrial output value of other manufacturing industries from 1999 to 2015; After 2008, the total industrial output value of the tobacco products industry did not show a downward trend due to the impact of the earthquake, but made profits due to disasters, showing a significant upward trend, as shown in Figure 4, which is a scatter diagram of the total industrial output value of the tobacco products industry from 1999 to 2015. The specific data of unused industries are shown in Table 1.

Table 1. Industrial gross output data for selected years.

	···	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Oil and gas extraction industry	···	241.29	292.56	432.25	419.51	512.4	405.61	399.58	115.41	486.3	541.43

Handicrafts and other manufacturing	…	16.55	30.03	27.56	38.92	112.85	81.93	48.53	106.69	158.63	166.85
Tobacco industries	…	92.42	71.57	131.25	217.09	172.53	203.66	234.13	259.3	287.23	269.02

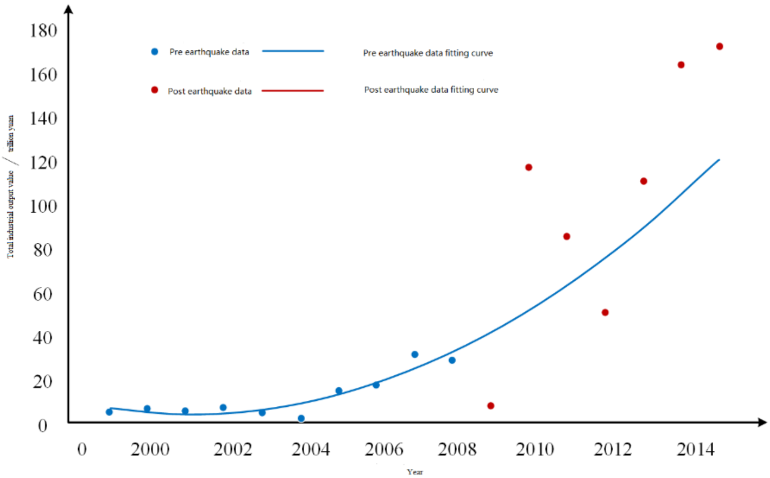


Fig. 3. Gross industrial output value of handicrafts and other manufacturing industries.

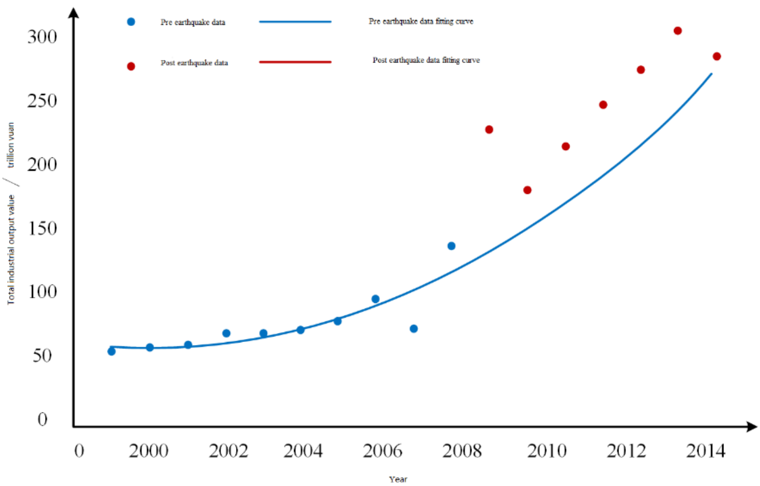


Fig. 4. Gross industrial output value of tobacco industry.

4.3 Results Analysis

4.3.1 Overall Trends of Change

After statistical analysis, a scatter plot with connecting lines of the total output value of various industrial sectors in Sichuan Province from 1999 to 2015 was obtained, as shown in Figure 5. In terms of trend changes, the total output value of all industrial sectors showed a steady upward trend from 1999 to 2015, with an overall scale that continuously expanded. However, most of the 34 industries analyzed in this study experienced varying degrees of decline in 2003 and 2008, clearly reflecting the impact of the 2003 SARS outbreak and the 2008 Wenchuan Earthquake on the total output value of various industrial sectors in Sichuan Province. Since the impact of the 2003 SARS outbreak on the industrial sectors was relatively minor compared to that of the Wenchuan Earthquake, subsequent data analysis disregarded the effects during this period. Following the Wenchuan Earthquake, the total output value of all industrial sectors in Sichuan Province reached its lowest point in 2009, and subsequently continued to show an upward trend without any sector experiencing a decline, although the growth rate slowed down in some sectors, such as the production and supply of electricity, steam, and hot water. This indicates that the various industrial sectors in Sichuan Province suffered an extremely severe external shock in 2008, which seriously affected their sustained development thereafter.

The post-earthquake change trends of each industry are categorized into four types of industrial total output growth patterns as shown in Figure 1. Three industries fall into the A (1) growth pattern, eleven industries into the A (2) growth pattern, eleven industries into the B (1) growth pattern, and nine industries into the B (2) growth pattern. Approximately 60% of the industries were able to recover to their original economic levels for the corresponding period after being impacted by the earthquake, about 30% exceeded their original economic levels, while only about 10% experienced a "permanent downturn" in economic growth, with economic levels significantly lagging behind the original levels for the corresponding period. This indicates that most industrial sectors in Sichuan Province have demonstrated commendable recovery capabilities following an earthquake, showing a high level of economic resilience [16].

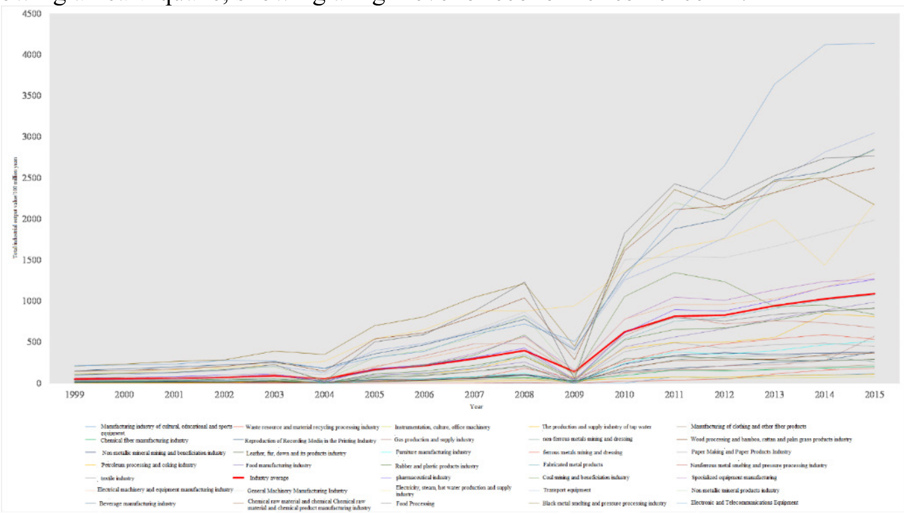


Fig. 5. Changes in the Total Output Value of Industrial Enterprises across Various Sectors in Sichuan Province from 1999 to 2015.

4.3.2 Recovery Time

By analyzing post-earthquake development trends, the time required for each industry to recover to pre-earthquake levels can be determined, as indicated in the Δt column of Table 2. The vast majority of industries were able to restore their total industrial output value to pre-earthquake levels within two years. Only the electricity, steam, and hot water production and supply industry had a recovery time of less than one year (0.96 years); a total of 30 industries had recovery times between one and two years; only four industries had recovery times of two years or more: the instrument manufacturing and office machinery industry (3.65 years), gas production and supply industry (2.04 years), leather, fur, down, and their products industry (2.19 years), and petroleum processing and coking industry (2.13 years), with the instrument manufacturing and office machinery industry taking over three years (3.65 years) to recover. This indicates that the speed of economic activity recovery in Sichuan Province was relatively fast, and most industries demonstrated strong resilience. However, evaluating indirect losses caused by the earthquake in industrial sectors based solely on one year of data yields relatively conservative results, which may not even meet the requirements for recovery to pre-earthquake levels.

Thirteen industries had output values exceeding the average, nine of which belong to the top ten strategic emerging industries [18], specifically: chemical raw materials and chemical products manufacturing, pharmaceutical manufacturing, non-metallic mineral products manufacturing, general machinery manufacturing, specialized equipment manufacturing, transportation equipment manufacturing, electrical machinery and equipment manufacturing, and electronic and communication equipment manufacturing. Based on existing research findings on industry resilience indicators [17], it is possible to further develop an evaluation method for predicting recovery time, expanding the applicability of the GDP approach, for use in pre-earthquake predictions and post-earthquake emergency assessments.

Table 2. Indirect economic losses by industry

Number	Industry name	Average (Billion Yuan)	Δt/year	L	L'	α_1
1	Manufacturing of cultural, educational, and sporting goods	2.718	1.25	2.56	2.62	0.99
2	Recycling and processing of waste resources and scrap materials	3.468	1.56	8.39	8.64	0.90
3	Manufacturing of instruments, meters, and cultural office machinery	3.800	3.65	188.99	425.11	2.82
4	Production and supply of tap water	4.236	1.00	9.40	15.34	0.27
5	Manufacturing of clothing and other textile products	7.386	1.52	59.99	67.96	0.96
6	Manufacturing of chemical fibers	7.927	1.50	52.90	72.31	0.74
7	Replication of recorded media in the printing industry	11.234	1.92	118.77	198.51	1.10
8	Production and supply of town gas	11.567	2.04	90.99	199.7	0.84
9	Non-ferrous metal mining and dressing	11.904	1.46	83.18	93.4	0.83

10	Wood processing and manufacturing of bamboo, rattan, palm, and straw products	12.143	1.58	108.20	122.24	1.01
11	Non-metallic mineral mining and quarrying	13.939	1.43	62.65	65.46	0.62
12	Manufacturing of leather, fur, down, and their products	13.970	2.19	372.17	1233.47	1.73
13	Manufacturing of furniture	15.697	1.46	122.83	138.47	1.01
14	Iron and steel ore mining and quarrying	19.068	1.57	96.42	1394.14	0.53
15	Manufacturing of paper and paper products	20.641	1.53	189.78	210.77	0.96
16	Petroleum processing and coking	26.285	2.13	427.89	1221.28	1.32
17	Food manufacturing	30.480	1.70	303.19	352.72	1.17
18	Manufacturing of rubber and plastic products	32.019	1.74	370.51	678.47	1.13
19	Manufacturing of metal products	35.712	1.70	340.61	406.58	0.97
20	Smelting and pressing of non-ferrous metals	37.008	1.96	740.50	2685.81	1.53
21	Textile industry	37.305	1.78	504.79	1123.15	1.27
22	**Industry average**	**40.841**	**1.57**	**316.58**	**421.22**	**0.79**
23	Pharmaceutical manufacturing	43.961	1.80	502.55	638.96	1.17
24	Coal mining and washing	47.136	1.51	133.49	243.59	0.23
25	Manufacturing of specialized equipment	48.995	1.80	548.92	1615.67	0.96
26	Manufacturing of electrical machinery and equipment	49.028	1.88	678.71	2118.96	1.21
27	Manufacturing of general-purpose machinery	78.092	1.49	649.03	2653.77	0.75
28	Production and supply of electricity, steam, and hot water	90.551	0.96	160.43	290.04	0.18
29	Manufacturing of transportation equipment	96.648	1.57	546.53	740.19	0.66
30	Manufacturing of non-metallic mineral products	98.142	1.29	663.44	736.08	0.81
31	Beverage manufacturing	99.765	1.36	399.39	460.06	0.51
32	Manufacturing of chemical raw materials and chemical products	104.202	1.63	956.28	1240.47	0.92
33	Food processing industry	109.230	1.85	1622.76	3817.97	1.32
34	Smelting and rolling of ferrous metals	113.154	1.43	867.05	2168.93	0.71
35	Manufacturing of electronic and communication equipment	128.316	1.32	254.05	281.45	0.35

4.3.3 Indirect Economic Losses

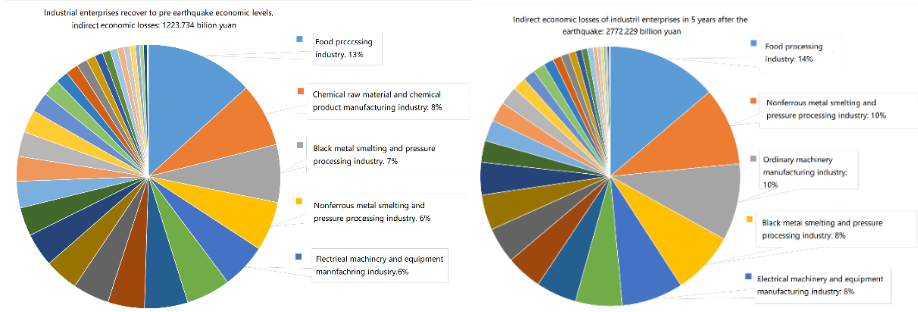
The indirect economic losses incurred by each industry upon recovery to pre-earthquake levels can be derived from Equation (4), as shown in item L of Table 2. According to item L in Table 2, the industry with the highest indirect economic loss is the food processing industry (162.276 billion yuan), which ranks 33rd out of 35 in terms of output value; the smallest indirect economic loss is observed in the manufacturing of cultural, educational, and sporting goods (0.256 billion yuan), which also has the lowest rank in output value. This indicates that indirect economic losses are not only related to recovery time but also depend on the size of the industry's output value. Sixteen industries have indirect economic losses exceeding the industry average, while eighteen industries do not. Summing up the indirect economic losses across all industries yields a total indirect loss for Sichuan Province's industrial sector of 1223.734 billion yuan, which is 13 times the direct economic loss of 93.5 billion yuan, as shown in Figure 6. Among these, the top five industries ranked by indirect economic losses are the food processing industry (13%), chemical raw materials and chemical products manufacturing (8%), smelting and rolling of ferrous metals (7%), smelting and rolling of non-ferrous metals (6%), and manufacturing of electrical machinery and equipment (6%).

The indirect economic losses incurred by each industry over five years post-earthquake can be derived from Equation (5), as shown in item L' of Table 2. According to item L' in Table 2, the industries with the highest and lowest indirect economic losses after five years remain the same as those for immediate indirect losses: the food processing industry (381.797 billion yuan) and the manufacturing of cultural, educational, and sporting goods (0.262 billion yuan). Among these, seventeen industries have indirect economic losses exceeding the industry average after five years, while another seventeen do not. Compared to item L, all industries show a significant increase, with twelve industries exceedingly twice their original losses; notably, the mining and selection of ferrous metals reached an increase of 14.46 times. Summing up the indirect economic losses across all industries after five years yields a total of 2772.229 billion yuan, as shown in Figure 6. Among these, the top five industries ranked by indirect economic losses are the food processing industry (14%), smelting and pressing of non-ferrous metals (10%), general-purpose machinery manufacturing (10%), smelting and pressing of ferrous metals (8%), and manufacturing of electrical machinery and equipment (6%).This indicates that indirect losses have a lasting impact, continuing to expand significantly even years after the earthquake, with both magnitude and growth rate being substantial and noteworthy. Compared to the top five industries at the time of recovery to pre-earthquake levels, the ranking changes after five years, which also demonstrates that different industries exhibit varying degrees of vulnerability and recovery capability when subjected to external shocks, reflecting differences in industrial resilience [18-19].

To reflect the extent of indirect economic losses relative to each industry's own development, a ratio α_1 is introduced, as shown in the following equation.

$$\alpha_1 = \frac{(S1+S2)}{m_1} \tag{6}$$

Thirteen industries have a ratio α_1 greater than or equal to 1. Among these, the industry with the highest α_1 is the manufacturing of instruments, meters, and cultural office machinery (2.82), indicating that its indirect economic loss is 2.82 times the pre-earthquake total output value of the industry, suggesting that this industry was severely impacted by the earthquake. The industry with the lowest α_1 is the production and supply of electricity, steam, and hot water (0.18), meaning that its indirect economic loss is 0.18 times the pre-earthquake total output value of the industry, although the loss only amounts to 20% of the pre-earthquake industrial output value, it still represents a significant scale that cannot be overlooked.



(a) Recover to pre-earthquake levels (b) Five years post-earthquake

Fig. 6. Proportion of indirect economic losses by industrial enterprises in Sichuan Province

5 Conclusions and Outlook

The industry development data following the Wenchuan earthquake provide a solid data foundation for assessing indirect economic losses across various industries. This study is based on the changes in GDP of various industrial sectors in Sichuan after the Wenchuan earthquake, analyzing their growth patterns and estimating indirect losses using the GDP method, and comparing the characteristics and sustained impacts of indirect losses to analyze the relationship between recovery time and industry resilience[20-21]. The estimated indirect economic loss for the recovery of Sichuan Province's total industrial output value to pre-earthquake levels is 1223.734 billion yuan, approximately 13 times the direct economic loss, which is also higher than the evaluation results obtained by other methods cited in the literature[22]; The indirect economic loss over five years post-earthquake amounts to 2772.229 billion yuan, more than twice the former figure, reflecting the characteristics and sustained impact of indirect losses across different industries. The results indicate that the magnitude of indirect economic losses in industrial sectors due to earthquakes is substantial and can far exceed direct economic losses; Compared to other existing assessment methods, evaluations based solely on data from the year of the disaster tend to be relatively conservative; The continuous increase in indirect losses cannot be ignored and exhibits strong industry-specific characteristics; Most industries demonstrate high levels of economic resilience and can recover quickly after an earthquake, while only a few industries have insufficient economic resilience and need to enhance their adaptability and renewal capabilities to cope with external shocks.

The findings and conclusions of this study provide both data and a theoretical foundation for further research on the economic resilience of regional industries. It is proposed to integrate economic resilience indicators of regional industries with recovery time to develop a predictive method for post-earthquake recovery times. Additionally, by analyzing inter-industry linkages outside the disaster area based on supply chain analysis, this study aims to extend the applicability of GDP-based methods in assessing associated losses across different sectors.

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