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Abstract: Based on the connotation and process of innovation-driven development, we have developed a comprehensive evaluation system containing 20 indicators in five aspects, including innovation factors, innovation subjects, innovation environments, innovation outputs, and development performance, to measure the levels of innovation-driven development in Sichuan province. Selecting 21 cities and prefectures in Sichuan province as research objects, we evaluated and measured the innovation-driven development levels of each city and prefecture using the entropy weight method (EWM). According to the evaluation results, the 21 cities and prefectures were divided into four categories depending on their levels of innovation-driven development: advanced-level, high-level, medium-level, and low-level. The results show that there are obvious spatial differences in terms of innovation-driven development levels among cities and prefectures in Sichuan province. Specifically, Chengdu, Mianyang, Panzhihua, and Deyang cities rank among the top four cities because of their advanced and high levels of innovation-driven development, while other cities and prefectures are at the medium and low levels. We also analyzed the innovation-driven development policies and practices of cities and prefectures in Sichuan province, to provide guidance for implementing innovation-driven development strategies in the cities and prefectures in the future.

Keywords: innovation-driven development, entropy weight method, comprehensive evaluation, spatial differences

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Introduction

Michael E. Porter, an American academic known as the father of competitive strategy, divides economic development into factor-driven, investment-driven, innovation-driven, and wealth-driven stages (Porter, 1990). In the innovation-driven stage, innovation is the driving force for economic development. Since the reform and opening-up, China has made fruitful achievements in economic development. China's economy has shifted from a high-speed growth stage to a high-quality development stage (Hou, 2019). Regional and urban developments are transforming from factor-driven and investment-driven development to innovation-driven development, making innovation an important driver in improving the competitiveness of regional and urban industries (Liu, Zhou & Jiang, et al., 2019). As early as 2012, China put forward the innovation-driven development strategy and stressed the critical position of scientific and technological innovation in its economic and social development. In 2016, the State Council officially issued the *Outline of the National Strategy of Innovation-Driven Development*, making overall plans for the implementation of China's innovation-driven development strategy. Sichuan province, located in southwest China, is a big province with a large population, vigorous economic development, and rich scientific and educational resources. It plays a crucial role in China's overall development. With the comprehensive implementation of the innovation-driven development strategy, Sichuan province has seen continuous improvements in independent innovation capability, optimization and upgrading in industrial development, and high-quality advancement in economic development. Therefore, innovation as the driving force of the province's endogenous growth is playing an increasingly important role. At the new stage of historical development, China proposed to "uphold the central role of innovation in its modernization drive and made self-reliance in science and technology the strategic pillar for the country's development" at the fifth plenary session of the 19th Central Committee of the Communist Party of China (CPC). Sichuan province actively implemented the plans of the CPC Central Committee. In the first year of the 14th Five-Year Plan, Sichuan province issued the *Decision of the CPC Sichuan Provincial Committee on Furthering Innovation-Driven High-Quality Development*, taking innovation as the driving force for its high-quality development. Against this backdrop, it is of great significance to measure and horizontally compare the innovation-driven development of all cities and prefectures in Sichuan province, to clarify the priorities for implementing innovation-driven development strategies in different areas. Moreover, it is also important to effectively enhance innovation-driven development levels of various regions and build Sichuan into a model province of innovation-driven development, thus providing references for the high-quality development of the whole country.

Literature Review

In terms of the measurement of innovation-driven development levels, the international focus is on the evaluation of innovation capability. F. M. Scherer (1982) and Luis Suarez-Villa (1990) measured innovation capability via patent statistics. Jeffrey L. Furman, Michael E. Porter, and Scott Stern, et al. (1990) established an index system based on the infrastructure and environmental conditions of innovation to evaluate innovation capability. The Global Innovation Index (GII), jointly released by the World Intellectual Property Organization (WIPO), Cornell SC Johnson College of Business, and the Institut Européen d'Administration des Affaires (INSEAD) has made continuous measurements of the innovation capacity of many global economies from the perspectives of innovation input and output since 2007 (Cornell SC Johnson College of Business, INSEDA & WIPO, 2020). The European Innovation Scoreboard (EIS), released by the European Commission, measures innovation performance through comprehensive innovation indicators (World Economic Forum, 2019). The evaluation system includes four first-level indicators (framework conditions, investments, innovation activities, and impacts), 10 second-level indicators, and 27 third-level indicators, and mainly carries out the dynamic evaluation of the innovation capacity of EU member states. In addition, the Global Competitiveness Index (GCI) (World Economic Forum, 2019) released by the World Economic Forum and the Global Knowledge Economy Index (KEI) released by the World Bank have formed internationally influential evaluation systems for innovation capability in foreign countries (World Bank, 2007).

With the comprehensive implementation of the innovation-driven development strategy in China, the measurement of innovation-driven development levels has attracted extensive attention from the academic circles, and a series of research results have been achieved at national, regional, provincial and municipal levels. Zhou Ke, Tang Juanli, and Gu Zhouyang (2018) constructed an evaluation system consisting of four first-level indicators (innovation foundation/conditions, innovation input, innovation output, and innovation contribution/impacts), 14 second-level indicators, and 39 third-level indicators, and conducted a comprehensive evaluation of China's innovation-driven development capability using the entropy weight method. Shao Hanhua and Qi Rong (2019) constructed an innovation-driven development index system applicable to cities and evaluated and analyzed regional differences and dynamic evolution of innovation-driven development levels in the Yangtze River Economic Belt from three perspectives: innovation input and output, regional innovation environments, and innovation-driven effects. Li Xuhui, Chen Ying, and Cheng Gang (2020) constructed an evaluation index system for innovation-driven development of the Yangtze River Economic Belt under the "Driver-Pressure-State-Impact-Response" (DPSIR) framework. This system contains 31 specific indicators in five criteria layers, including innovation drivers, innovation pressures, innovation states, innovation impacts, and innovation responses. Yin Mengji (2015) believes that the output of scientific and technological innovation in a region is mainly reflected in the production and sales of new products, the number of new patents, and the transaction amounts in the technology market. He measured the economic development using GDP and the technological innovation levels using the sales revenue of new products, the number of patents approved, and the transaction amounts in the technology market, and made an empirical study of the innovation development levels of provincial administrative regions in China. Liu Zuojing, Yan Xiaoxu, and Chen Jianxin (2018) constructed an evaluation model integrating regional innovation and economic development based on the coupling theory. The regional innovation system consists of three indicators, including innovation input, innovation output, and innovation environments, as does the economic system, including the economic aggregate, economic structure, and economic benefits. Their paper measured and evaluated the coupling coordination degree of the innovation and economic systems of Guangdong province from spatial and temporal perspectives. Yuan Yong and Hu Haipeng (2020), based on the connotation of innovation-driven development, established a comprehensive evaluation system for measuring innovation-driven development at the municipal level from five aspects, including the provisions of an innovation environment, gathering of innovation resources, allocations of innovation resources, innovation outputs, and innovation's effects on economic and social development. In general, Chinese academics tend to construct the system for evaluation of innovation-driven development from three perspectives: by selecting several representative indexes based on the "input-output" model; by considering such factors as innovation environments, innovation resources, and innovation subjects based on the "input-output" model by applying the DPSIR model. At present, most academics construct the evaluation systems based on the "input-output" model, and they tend to consider more factors such as innovation factors, innovation environments, and environmental subjects in their research instead of merely considering innovation input and output. In addition, although the evaluation systems built based on the DPSIR model consider the interactions between different factors, simple linear causality has excessively simplified the actual process of index selection (Cao, 2005). Therefore, less representative and low-causality factors may be selected, leading to inaccurate results. To this end, we developed an evaluation system that can reflect the process and results of innovation-driven development by fully considering factors such as innovation factors, innovation subjects, and achievement transformations based on the "input-output" model. In terms of research methods, domestic research results are mainly achieved through the entropy weight method. Supported by ample data, this method can eliminate overlapped information among various index variables and effectively avoid the errors caused by human (subjective) factors, acquiring highly objective results. Moreover, it has been verified by various empirical studies. Therefore, drawing on the existing results, we adopted the entropy weight method to measure the innovation-driven development of Sichuan province, to ensure the objectivity of the evaluation results.

Evaluation System, Research Methodology, and Data Sources

Evaluation System

Innovation-driven development involves not only the gathering of innovation factors, the allocation of innovation resources, and the output of innovation results but also the application and diffusion of innovation results and innovation-driven economic and social development. Therefore, the evaluation of the innovation-driven development levels focuses on both the driving role of innovation in economic and social development and the link between the front end and the back end of innovation-driven development (Yuan & Hu 2020). Based on the connotations and various links of innovation-driven development and the principles of scientificalness, systematicness, representativeness, and accessibility, we developed an evaluation index system by reviewing relevant literature and considering the regional development characteristics of Sichuan province through repeated screenings, adjustments, and optimizations. The evaluation index system, taking the comprehensive index of innovation-driven urban development as the target layer, consists of 20 indexes with five categories each, including innovation factors, innovation subjects, innovation environments, innovation outputs, and development performances.

(a) Innovation factors: This index mainly reflects the allocation of innovation factors such as human, capital, and material resources. Innovation factors are at the front-end of innovation-driven development and the basis for innovation subjects to conduct innovation activities. They are mainly reflected in fund investments, talent support, and platform construction.

(b) Innovation subjects: Innovation subjects are the main force in conducting scientific and technological innovation, mainly including enterprises, colleges and universities, scientific research institutes, industrial technology institutes, and other new R&D institutions.

(c) Innovation environments: This mainly refers to the external environments of innovation-driven development. A good innovation environment can provide conditions and support for the implementation of innovation activities and can guide and promote scientific and technological innovation by the innovation subjects. It is mainly reflected by relevant indicators such as policy environments, market-oriented levels, and construction of public facilities.

(d) Innovation output: It mainly refers to the achievements attained in the innovation process. Knowledge is the source of innovation and is created by recombining and reallocating innovation resources to promote the development of high-tech industries through the transformation of scientific and technological achievements, thus forming new markets and economic growth points. Innovation output is mainly reflected through relevant indicators such as knowledge creation, achievement transformation, and industrial development.

(e) Development performance: This mainly refers to the level of innovation-driven economic and social development, i.e., to what extent are economic development and social progress promoted through the application of innovation output in economic and social activities. It is mainly reflected by economic efficiency, production efficiency, people's livelihoods, environments, and other related indexes.

Table 1 *Index System for Evaluation of Innovation-Driven Urban Development Capability in Sichuan Province*

Target layer	Criteria layer	Index layer
Innovation-driven urban development level (A_1)	Innovation factors (B_1)	Proportion of R&D expenditures in GDP (X_1)
		Proportion of local scientific and technological expenditures in public finance expenditures (X_2)
		Proportion of R&D employees per 10,000 persons (X_3)
		Number of sci-tech innovation platforms (X_4)
	Innovative subjects (B_2)	Number of colleges and universities (X_5)
		Number of scientific research institutions (X_6)
		Number of high-tech enterprises (X_7)
		Number of new R&D institutions (X_8)
	Innovation environments (B_3)	Additional tax deductions for expenditures on R&D (X_9)
		Number of high-tech business incubators (X_{10})
		Market-oriented levels (X_{11})
		Collections in public libraries per 10,000 persons (X_{12})
	Innovation output (B_4)	Number of patents applied for per 10,000 persons (X_{13})
		Number of invention patents held per 10,000 persons (X_{14})
		Contract amounts of the technology markets (X_{15})
		Proportion of the output values of high-tech industries in operating income of industrial enterprises (X_{16})
	Development performance (B_5)	Per capita GDP (X_{17})
		Overall labor productivity (X_{18})
		Per capita disposable income of urban residents (X_{19})
		Reduction rate of overall energy consumption per 10,000 yuan of GDP (X_{20})

Research Methodology

We determined the weight of each index in the index system for evaluation of innovation-driven development capability using the entropy weight method and then measured and horizontally compared the comprehensive indexes of urban innovation-driven development based on the weighted sum model. In information theory, entropy is defined as a measure of the disorder of the system. It has been widely used in many fields, such as the evaluation of innovation-driven development levels and sustainable development capacities. Based on the values of each index, the weight of indexes was determined using the entropy weight method according to their dispersion degrees. The higher the dispersion degree of an index, the lower the entropy. This means this index has a greater degree of differentiation and carries more information, thus having a greater influence on the comprehensive evaluation of each factor in the system. The entropy weight method is an objective weighting method that can effectively measure the importance of indexes in the evaluation system based merely on the differentiation between the values (He, Xie & Wang, 2020). The specific steps are as follows (Zhou, Tang & Gu, 2018; Zhu & Wei, 2015):

(a) Nondimensionalize the data. Since the evaluation system has many indexes that are measured in different units, it is impossible to proceed with the calculations directly. Therefore, the basic data needs to be nondimensionalized to eliminate the impacts caused by the different dimensions of the various indexes.

$$X'_{ij} = \frac{X_{ij}-\bar{X}_j}{S_j} \quad (1)$$

where, X'_{ij} refers to the nondimensionalized value of index j of City i; X_{ij} refers to the original value of index j of City i; $\bar{X}_j$ is the average value of index j; and S_j is the sample standard deviation of index j.

Calculations using Formula (1) may generate some negative dimensionless data. However, since the data used in the entropy weight method must be positive, such negative data needs to be processed through translation to obtain new data.

$$A_{ij}=X'_{ij}+a \quad (2)$$

where, A_{ij} is the value after translation of X'_{ij} and a is the translation amplitude. To minimize the error factor in the basic data, caused by translation, and ensure more obvious evaluation results, the value of a should be as close to $|\min(X'_{ij})|$ as possible.

(b) Calculate the proportion P_{ij} of the value A_{ij} after translation in the index j of the n cities.

$$P_{ij}=\frac{Aij}{\sum_{i=1}^{m} Aij}\ (i=1,2,n;j=1,2,...m) \quad (3)$$

where, n is the number of samples (cities and prefectures) and m is the number of evaluation indexes.

(c) Calculate the information entropy E_j of index j.

$$E_j=-K\sum_{i=1}^{n} P_{ij} \ln P_{ij} \quad (4)$$

where, K is a constant, $K=\frac{1}{\ln n}$

(d) Calculate the value of information utility G_i of index j. The value of information utility indicates the effects of the index on the research object. The greater the value of information utility, the greater the weight of the index.

$$G_i=1- E_j \quad (5)$$

(e) Calculate the weight W_i of the index j.

$$W_i=\frac{G_j}{\sum_{j=1}^{m} G_j} \quad (6)$$

(f) Calculate the comprehensive index C_{ij} of innovation-driven urban development.

$$C_{ij}=\sum_{j=1}^{m} W_j P_{ij} \qquad (7)$$

Data Sources

The data in the evaluation index system selected for this study came from the Sichuan Statistical Yearbooks and the statistical yearbooks of the various cities and prefectures for the relevant years. Therefore, all the data sources cited in this paper are authentic and dependable. To ensure the availability and comparability of the data, the "science and technology innovation platforms" mentioned in this paper mainly include engineering research centers, key laboratories, and enterprise technology centers at the provincial level and above, and the "number of high-tech business incubators" mainly refers to the high-tech business incubators registered at the national and provincial levels. The "proportion of output value of the high-tech industry in operating income of industrial enterprises" is derived from the data of industrial enterprises with a scale above the designated one, and the "market-oriented level" is reflected by the "proportion of the added value of the private economy in regional GDP."

Evaluation Process, Results, and Analysis

Determination of Index Weights

The data in the 20 indexes of the 21 cities and prefectures of Sichuan province in 2019 were processed using formulas (1) – (6) to reflect the weight of each evaluation index. Based on the results, the weights of the indexes in the criteria layer are calculated. As noted in Table 2, the innovation environment has the greatest weight in the criteria layer, accounting for 23.42%, followed by development performance with a weight of 22.02%, and innovation output with a weight of 19.16%. This indicates that a good innovation environment is a key factor in improving the innovation-driven development level of the cities and prefectures in Sichuan province. Development performance is the ultimate goal of innovation-driven development, which has a significant impact on the innovation-driven development levels of the 21 cities and prefectures. It is also an effective way to improve the innovation-driven development levels by applying innovation output such as created knowledge and achieved results to industrial development and social life to drive economic and social development. In terms of specific indexes, the market-oriented level accounts for the highest proportion, reaching 8.74%, indicating that an improvement in the market-oriented level has a very positive impact on the technological innovation of enterprises.

Table 2 *Weights of Evaluation Indexes*

Criteria layer	Weight	Index layer	Entropy	Utility value	Weight
Innovation factors (B_1)	0.1873	Proportion of R&D expenditure in GDP (X_1)	0.9784	0.0216	0.0466
		Proportion of expenditures on science and technology in public finance expenditures (X_2)	0.9770	0.0230	0.0497
		Proportion of R&D employees per 10,000 persons (X_3)	0.9772	0.0228	0.0493
		Number of sci-tech innovation platforms (X_4)	0.9807	0.0193	0.0417
Innovative subjects (B_2)	0.1668	Number of colleges and universities (X_5)	0.9807	0.0193	0.0417
		Number of scientific research institutions (X_6)	0.9808	0.0192	0.0414
		Number of high-tech enterprises (X_7)	0.9810	0.0190	0.0411
		Number of new R&D institutions (X_8)	0.9803	0.0197	0.0426
Innovation environment (B_3)	0.2342	Added tax deductions for expenditures on R&D (X_9)	0.9806	0.0194	0.0420
		Number of high-tech business incubators (X_{10})	0.9780	0.0220	0.0475
		Market-oriented level (X_{11})	0.9596	0.0404	0.0874
		Collections in public libraries per 10,000 persons (X_{12})	0.9735	0.0265	0.0573
Innovation output (B_4)	0.1916	Number of patents applied for per 10,000 persons (X_{13})	0.9786	0.0214	0.0463
		Number of invention patents held per 10,000 persons (X_{14})	0.9776	0.0224	0.0483
		Contract amounts of the technology markets (X_{15})	0.9810	0.0190	0.0410
		Proportion of the output values of high-tech industries in operating income of industrial enterprises (X_{16})	0.9741	0.0259	0.0559
Development performance (B_5)	0.2202	Per capita GDP (X_{17})	0.9753	0.0247	0.0533
		Overall labor productivity (X_{18})	0.9760	0.0240	0.0518
		Per capita disposable income of urban residents (X_{19})	0.9761	0.0239	0.0516
		Reduction rate of overall energy consumption per 10,000 yuan of GDP (X_{20})	0.9706	0.0294	0.0635

Calculation of Combined Scores

Calculations using Formula (7) reveals the combined scores and sub-scores for innovation-driven development levels for the 21 cities and prefectures of Sichuan province in 2019. These scores are presented in Table 3, and there are obvious spatial differences in innovation-driven development levels of the 21 cities and prefectures in Sichuan province. Chengdu gets the highest combined score, which is 1.5 times that of Mianyang, ranking second, and nearly 3 times that of Ganzi Tibetan Autonomous Prefecture, ranking last.

Table 3 *Combined Scores for Innovation-Driven Development Levels of Sichuan Province in 2019*

	Innovation factors		Innovative subjects		Innovation environments		Innovation outputs		Development performances		Innovation-driven development levels	
	Score	Ranking	Score	Rankings	Score	Ranking	Score	Ranking	Score	Rankings	Score	Ranking
Chengdu	0.0196	1	0.0224	1	0.0176	1	0.0218	1	0.0186	1	0.1000	1
Mianyang	0.0171	2	0.0082	2	0.0151	2	0.0143	2	0.0107	9	0.0654	2
Panzhihua	0.0092	5	0.0076	3	0.0113	12	0.0106	3	0.0179	2	0.0567	3
Deyang	0.0113	3	0.0074	7	0.0117	7	0.0099	4	0.0125	3	0.0527	4
Zigong	0.0095	4	0.0074	7	0.0091	17	0.0094	5	0.0122	4	0.0477	5
Yibin	0.0088	7	0.0075	5	0.0114	10	0.0080	11	0.0116	5	0.0473	6
Luzhou	0.0083	8	0.0074	7	0.0122	4	0.0077	14	0.0113	6	0.0469	7
Ya'an	0.0092	5	0.0073	10	0.0128	3	0.0078	13	0.0084	16	0.0455	8
Leshan	0.0078	10	0.0070	13	0.0105	15	0.0089	6	0.0113	6	0.0454	9
Neijiang	0.0078	10	0.0070	13	0.0114	10	0.0076	16	0.0112	8	0.0449	10
Suining	0.0080	9	0.0075	5	0.0120	6	0.0087	7	0.0079	17	0.0442	11
Nanchong	0.0074	13	0.0076	3	0.0115	8	0.0074	18	0.0100	12	0.0439	12
Dazhou	0.0072	14	0.0070	13	0.0115	8	0.0083	10	0.0092	14	0.0432	13
Guangyuan	0.0072	14	0.0070	13	0.0109	14	0.0074	18	0.0101	10	0.0426	14
Meishan	0.0071	16	0.0070	13	0.0098	16	0.0086	9	0.0101	10	0.0426	14
Guang'an	0.0068	19	0.0068	19	0.0121	5	0.0080	11	0.0078	18	0.0415	16
Ziyang	0.0076	12	0.0068	19	0.0090	18	0.0076	16	0.0098	13	0.0407	17
Bazhong	0.0067	20	0.0068	19	0.0111	13	0.0071	20	0.0077	19	0.0394	18
Aba	0.0070	18	0.0071	12	0.0085	19	0.0077	14	0.0091	15	0.0394	18
Liangshan	0.0071	16	0.0073	10	0.0071	21	0.0087	7	0.0058	21	0.0361	20
Ganzi	0.0066	21	0.0069	18	0.0076	20	0.0057	21	0.0070	20	0.0338	21

Analysis of Evaluation Results

According to the combined scores of the innovation-driven development levels, the 21 cities and prefectures of Sichuan province were classified into four categories: advanced-level area (with a combined score higher than or equal to 0.1000), high-level area (with a combined score higher than or equal to 0.0500 but lower than 0.1000), medium-level area (with a combined score higher than or equal to 0.0400 but lower than 0.0500), and low-level area (with a combined score lower than 0.0400).

The advanced-level area includes only Chengdu, the capital of Sichuan province, with a combined score of 0.1000, far exceeding the other cities in Sichuan province. Chengdu is the economic, political, and cultural center of Sichuan province and the comprehensive national science center approved by the state. Chengdu boasts a booming high-tech industry, gathering a variety of innovation factors and subjects such as scientific and technological talents, colleges and universities, scientific research institutions, and high-tech enterprises. With a strong scientific and technological foundation and innovation strength, Chengdu shows absolute advantages in terms of innovation-driven development levels and classification indexes such as innovation factors, innovation subjects, innovation environments, innovation outputs, and development performances. As a city that comes first in terms of the innovation-driven development levels of Sichuan province, Chengdu has played a certain demonstration role in the innovation-driven development of all areas of the province, but its role as a driving force is far from sufficient.

The high-level area includes Mianyang, Panzhihua, and Deyang, with combined scores of 0.0654, 0.0567, and 0.0527 respectively. Mianyang is the only science and technology city in China. Owing to policy advantages in gathering innovation resources and cultivating innovation subjects, Mianyang has effectively improved its overall innovation-driven development level. However, its efficiency in transforming scientific and technological achievements is relatively low, leading to limited effects in the actual application of innovation output and a relatively weak development performance. Based on its distinctive industry of vanadium and titanium, Panzhihua has gathered a number of innovation platforms, incubators, and scientific and technological talents in the field of vanadium and titanium. It has made remarkable achievements in innovation factors, innovation subjects, innovation outputs, and development performances, but its innovation environment needs to be further improved. Focusing on promoting the construction of the Deyang National High-Tech Industrial Development Zone, Deyang is gathering innovation factors, cultivating innovation subjects such as high-tech enterprises, and accelerating the development of high-tech industries, with certain advantages in the whole province in terms of its innovation-driven development level.

The medium-level area includes 13 cities and prefectures such as Zigong, Yibin, Luzhou, Ya'an and Leshan, accounting for more than 60% of the whole province. They are mainly distributed in the Southern Sichuan Economic Zone, Northeast Sichuan Economic Zone, and Chengdu Plain Economic Zone, with certain differences between them. Zigong has certain advantages in innovation factors, innovation outputs, and development performances, but its innovation environment needs to be further optimized. Compared with its ranking in terms of its innovation-driven development level, Yibin falls behind in terms of innovation environments and innovation outputs. The innovation output of cities such as Neijiang, Nanchong, and Guangyuan needs to be further improved. Suining and Nanchong have made remarkable achievements in cultivating innovation subjects and creating innovation environments. Ya'an performs excellently in terms of the innovation environments and innovation factors. However, due to the lack of innovation subjects, it lags behind as far as innovation outputs and development performances are concerned. In general, the innovation-driven development levels of these areas is well-matched with their overall strength. Cities in the Southern Sichuan Economic Zone such as Zigong, Yibin, and Luzhou are generally superior to those in the Northeast Sichuan Economic Zone such as Nanchong, Dazhou and Guangyuan in terms of innovation-driven development levels. Cities in the Chengdu Plain Economic Zone such as Ya'an, Leshan, and Suining vary greatly when it comes to the innovation-driven development levels. Ya'an has a combined score of 0.0455, ranking 8th, while Ziyang also in Chengdu Plain Economic Zone, ranks 17th with a combined score of 0.0407.

The low-level area includes Bazhong, the Aba Tibetan and Qiang Autonomous Prefecture, the Liangshan Yi Autonomous Prefecture, and the Ganzi Tibetan Autonomous Prefecture, each with a combined score lower than 0.0400. Bazhong hits a relatively high score in respect of the innovation environments. However, restricted by other factors like its geographical location and industrial foundations, it performs poorly in gathering innovation factors and gets a relatively low score in innovation subjects, innovation outputs, and development performances. The Liangshan Yi Autonomous Prefecture, the Aba Tibetan and Qiang Autonomous Prefecture, and the Ganzi Tibetan Autonomous Prefecture are three minority autonomous prefectures populated by ethnic minorities in Sichuan province. The Ganzi Tibetan Autonomous Prefecture and the Aba Tibetan and Qiang Autonomous Prefecture are within the Northwest Sichuan Ecological and Economic Zones, with vulnerable ecological environments and weak economic strength. These two prefectures are positioned to focus on protecting their ecological environments and developing the tourism industry by relying on rich local tourism resources. Therefore, there is a limited demand for innovation, leading to a low innovation-driven development level. The Liangshan Yi Autonomous Prefecture is partly in the Panxi Pilot Zone of Innovation and Development of Strategic Resources, where scientific and technological innovations are made centering on the innovation-driven development of vanadium and titanium resources. The Liangshan Yi Autonomous Prefecture has made certain achievements in cultivating innovation subjects and boosting innovation outputs. Although it occupies a large area, due to its location in an area of ethnic minorities with a vulnerable ecological environment, the Liangshan Yi Autonomous Prefecture has seen limited development in some areas and has obvious disadvantages in terms of the innovation environments and development performances, resulting in an overall low innovation-driven development level.

Conclusions and Discussions

We developed a comprehensive evaluation index system to measure the innovation-driven development levels in Sichuan province. This system contains 20 indexes with five aspects each, including innovation factors, innovation subjects, innovation environments, innovation outputs, and development performances. The entropy weight method is adopted to make a comprehensive evaluation of the innovation-driven development levels of 21 cities and prefectures of Sichuan province in 2019. According to the evaluation results, the spatial patterns of innovation-driven development in Sichuan province were analyzed and the following conclusions were drawn.

(a) Innovation-driven development runs through the whole process of innovation from carrying out innovation activities and making scientific and technological achievements, to applying achievements and driving development. The evaluation system built to measure the innovation-driven development levels in Sichuan province is composed of a variety of indexes.

We used the entropy weight method to determine the weight of each index as this method can effectively eliminate the overlapping information among indexes and more objectively reflect the importance of different indexes in the evaluation system.

(b) Innovation environments and development performances are the major indexes that affect the innovation-driven development of Sichuan province, followed by innovation outputs, innovation factors, and innovation subjects. The market-oriented level is the most important index that affects the innovation-driven development levels, which means it is crucial to promoting market-oriented reform and creating a good innovation environment under the innovation-driven development strategy. Moreover, while gathering innovation factors, cultivating innovation subjects, and increasing innovation output, attention should be paid to enhancing the ability to transform and apply innovation achievements, and to accelerating the application of scientific and technological achievements in economic and social development to make innovation the primary driving force for overall economic and social development.

(c) According to the comprehensive evaluation results, Sichuan province is divided into areas defined by the four categories of innovation-driven development levels: the advanced-level area including Chengdu only; the high-level area, including Mianyang, Panzhihua, and Deyang; the medium-level area, including 13 cities and prefectures such as Zigong, Yibin, Luzhou, Ya'an and Leshan, accounting for more than 60% of the whole province; and the low-level area including Bazhong, the Aba Tibetan and Qiang Autonomous Prefecture, the Liangshan Yi Autonomous Prefecture, and the Ganzi Tibetan Autonomous Prefecture.

(d) There are obvious spatial differences in the innovation-driven development levels in Sichuan province. In general, the Chengdu Plain Economic Zone, with Chengdu, Deyang, and Mianyang as the core, ranks first in the innovation-driven development levels. However, there are relatively large internal differences between these three cities in this aspect, i.e., Chengdu is at an advanced level, Deyang is at a high level, and Mianyang is at a medium level. This is also true in the Panxi Pilot Zone of Innovation and Development of Strategic Resources. Within the Zone, Panzhihua ranks third and the Liangshan Yi Autonomous Prefecture ranks second to last, while other cities are at the medium and low levels. The cities in the Southern Sichuan Economic Zone are generally superior to those in the Northeast Sichuan Economic Zone in terms of innovation-driven development levels. This is to be expected because some cities and prefectures are affected by natural conditions, industrial foundations, and other factors, and obvious differences are observed in their innovation environments, innovation outputs, innovation factors, and innovation subjects.

(e) Although other studies have been conducted on the evaluation of innovation-driven development levels in the academic circles, no consensus has yet been reached. The evaluation index system we constructed, and presented here, considers the availability of data and the comparability between regions, but there are still constraints in selecting indexes and collecting data. For example, the policy environment under the index of innovation environments is only reflected by the "additional tax deductions for expenditure on R&D." Indexes such as scientific and technological innovation platforms and scientific and technological enterprise incubators only apply to institutions above the provincial level; the market-oriented levels are represented by a single index of "proportion of the added value of private economy in regional GDP." Therefore, we are unable to comprehensively reflect the actual situations in terms of innovation factors and innovation environments for each city and prefecture of Sichuan province, which may have an impact on the evaluation results and thus needs to be further verified through future research.

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