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Cluster Effects of the Manufacturing Industry in Sichuan Province: Insights from County-Level Economic Development

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Abstract: Manufacturing industry clusters contribute to the optimization of regional industrial structures and the improvement of economic growth efficiency. The role of inter-county carriers can further enhance the cluster effects of the manufacturing industry in Sichuan Province, promoting coordinated development across industries and accelerating the transformation of new productive forces. This study evaluates the degree of industrial agglomeration of the manufacturing industry in 183 counties in Sichuan Province. The results indicate that Sichuan's manufacturing industry exhibits a clear clustering effect, with a particularly pronounced structural agglomeration centered around Chengdu. However, economic development across counties in the province remains unbalanced. The Generalized Method of Moments (GMM) regression analysis confirms that total factor productivity (TFP) and industrial interlinkages exert a significant positive influence on the agglomeration of the manufacturing industry.

Keywords: Sichuan Province; County-level economy; Manufacturing industry; Total factor productivity

1. Introduction

The interaction between county-level economies and industrial clusters is a common economic phenomenon in the process of regional economic development. County-level groups in China play an important role in linking the urban-rural dual structure in the course of economic development. Currently, the total economic output of county-level economies in the country has surpassed 10 trillion yuan, accounting for 41% of the national economy. The economic development of county-level regions is a crucial component of socialist modernization and constitutes a comprehensive economic system composed of various economic agents. To promote the better development of county-level economies in China, the government has introduced relevant policies at different times. One such policy is the *Several Opinions on Innovation-Driven Development of County-Level Economies*, issued in 2017, which proposes various encouragement measures targeting key factors affecting the development of county-level economies. However, a key issue that remains unresolved is how to further enhance the carrier role of counties, effectively promote the agglomeration effect of industrial clusters, and facilitate the optimization and upgrading of industrial structures. Industrial clusters refer to the phenomenon where enterprises producing similar products or operating within the same industrial chain gather in specific spaces or regions to seek an external economy. Studies have shown that the development of manufacturing industry clusters significantly promotes enterprise production efficiency, optimizes industrial structures, and fosters regional economic growth. Since the reform and opening up, while China's manufacturing exports have grown rapidly, structural defects still exist. The manufacturing industry faces challenges in its transformation and upgrading, particularly in promoting resource integration across the eastern, central, and western regions, as well as achieving the scale effects of county-level groups, which remains a topic for further discussion. Research on the interaction between county-level economies and industrial clusters has generally reached a consensus among scholars: fostering local industrial clusters is an effective way to accelerate the development of county-level economies and enhance their competitiveness.

Sichuan Province is located in the upstream ecological protection zone of the Yangtze River, with Chongqing to the east, Yunnan to the south, Tibet to the west, and Gansu and Shaanxi to the north, giving it significant geographical and strategic importance. The province comprises 14 county-level cities, 130 counties, and 4 autonomous counties. According to the deployment of the provincial Communist Party of China (CPC) committee and government, Sichuan's county-level regions are currently divided into 809 town-level areas, with 700 central towns. Nearly 70% of the total economic output of the county-level economies in Sichuan has already surpassed 10 billion yuan. In 2022, General Secretary Xi Jinping proposed the requirement to "break the urban-rural dual structure within counties as a priority" at the Central Conference on Rural Work. In response, the General Office of the CPC Central Committee and the State Council issued the *Opinions on Promoting Urbanization Construction with Counties as an Important Carrier*, emphasizing the role of county-level economies surrounding major cities as economic support, strengthening the extended chain of characteristic economies, expanding industrial clusters, and enhancing the scale effects of dominant industries. From the perspective of the proportion of industrial output value, the industrial manufacturing value added is relatively high in the regions of Panzhihua, Luzhou, Deyang, and Yibin. Panzhihua benefits from its rich mineral resources, while Luzhou and Yibin are mainly characterized by the liquor industry, with Deyang focusing on the development of equipment manufacturing and materials processing. In contrast, the industrial output value in the regions of Bazhong, Ziyang, Aba Prefecture, and Ganzi Prefecture accounts for less than 30%, far below the national average.

2. Theoretical Foundation

An industrial cluster refers to the geographic concentration of interconnected companies, specialized suppliers, service providers, firms from related industries, and government and other relevant institutions within a specific sector, which is characterized by both competition and cooperation (Ottaviano, 2011). Industrial clusters exhibit features of both competition and collaboration, complexity, and growth. At firstly, many scholars used the spatial Gini coefficient to measure agglomeration and confirmed the significant phenomenon of manufacturing industry clusters. Reischauer (2018) measured the degree of manufacturing agglomeration in the industrial sectors of European Union (EU) countries from 1968 to 1995, finding that the degree of specialization was steadily increasing. Timmer & Szirmai (2000) measured the agglomeration levels of various types of manufacturing industries, confirming that resource-dependent industries exhibited higher levels of agglomeration, and manufacturing industries with clear locational advantages also tended to cluster. Actually, the agglomeration level of technology-intensive industries had decreased over time. Li et al. (2019) argued that factors such as average firm size, labor intensity, resource input rate, and human capital scale all have a positive effect on the spatial agglomeration of media manufacturing industries. Jorgenson (2011) used the EG indicator to measure the agglomeration trend of the manufacturing sector in the United States.

Although scholars have employed various methods to evaluate the phenomenon of manufacturing industry agglomeration, the conclusions are consistent: industrial agglomeration optimizes the quality of factors and promotes the high-quality development of regional economies. Zeng et al. (2023) studied the level of marine industry agglomeration in coastal provinces of China, finding a high degree of similarity in the industrial chain layout between provinces. Huang & Liu (2023) suggested that labor quality, infrastructure construction, and the proportion of high-quality capital all positively affect manufacturing agglomeration. Because of the COVID-19, the digital transformation of whole industries speeds up (Cheng et al., 2023). With the upgrading of information and the emergence of building cities, the innovation has become the key point of the manufactured industry cluster (Jovicic, 2019). The regional differences and high-quality development cause there are differing results in terms of industrial agglomeration and technological innovation between the eastern and western regions (Jin & Ying, 2023; Li et al., 2020). The positive tax system would be sensitive to macroeconomic performance of nation measured in terms of inflation and the growth of real income (Dholakia, 2000). Some researcher conducted a CPVL model analysis on 69 counties and cities in Zhejiang Province, confirming the existence of regional collaborative agglomeration and no differentiated impact from city size (Yang, 2023). Under the influence of national policies, industries in the eastern region have gradually shifted toward the central and western regions, simultaneously accelerating the cultivation of advanced manufacturing in the central and western regions (Ma & Huang, 2023). Also, there are some studies about the current development of the manufacturing sector in Chongqing, suggesting that agglomeration can improve industrial production efficiency. Besides Chongqing, in the north of Sichuan Province, the development trend of advanced manufacturing industry clusters in Deyang City and developed an indicator system for factors influencing the development of manufacturing industry clusters (Jin & Ying, 2023).

There are various methods for measuring industrial clusters, including industry concentration, spatial Gini coefficient, and location entropy. The GEM model was selected as the basis for measurement in this study. In this model, "G" represents basic variables, "E" represents the number of manufacturing enterprises, and "M" represents market demand. Additionally, innovation-driven factors were incorporated as source indicators for the competitiveness scores of each industrial cluster. The specific indicator system is shown in Table 1.

Table 1. GEM-IN model evaluation indicator system

Primary Indicators	Secondary Indicators	Symbol	Indicator Nature
Basic factors	Total labor force	G1	+
	Regional GDP	G2	+
	Investment for infrastructure construction	G3	+
	Proportion of manufacturing output value	G4	+
Enterprise factors	Number of manufacturing enterprises	E1	+
	Presence of industry associations	E2	+
	Number of production service enterprises	E3	+
Market factors	Per capita income level	M1	+
	Per capita retail sales of consumer goods	M2	+
	Export trade scale	M3	+
	Total output value of the service industry	M4	+
Innovation-driven factors	Number of patent applications	IN1	+
	Number of high-tech enterprises	IN2	+

The GEM model emphasizes three fundamental components of industrial agglomeration: basic factors, enterprise factors, and market factors. The interrelations between these factors are further refined. Considering that the drivers of industrial agglomeration are directly linked to the total economic output of the region, the total labor force, regional Gross Regional Product (GDP), and investment for infrastructure construction were selected as secondary variables. The development of manufacturing industry clusters and the degree of supply chain maturity are interdependent, with the number of industry enterprises, the presence of industry associations, and the number of production service enterprises selected as secondary variables. Market factors take into account domestic and international market demand, with per capita income, per capita consumption, and export volume chosen as secondary variables. Innovation-driven factors are represented by the number of patent applications and the number of high-tech enterprises. Panel data for the years 2011-2022 were selected, with data sourced from the statistical yearbooks of various prefecture-level cities in Sichuan Province.

3. Agglomeration Degree Evaluation of the Manufacturing Industry in Sichuan Province

The concentration of economic development in the counties of Sichuan Province was assessed using industrial sectors as the primary evaluation reference. Data for the assessment was filtered based on the number of enterprises and annual output values within industrial sectors, with missing values being excluded. Industry codes were based on the *2002 National Economic Industry Classification Codes*, and the regions were divided as follows: the Chengdu central region (centred around the prefecture-level cities of Deyang, Meishan, Ziyang, Leshan, Mianyang, etc.), the southern Sichuan region (mainly consisting of cities such as Yibin, Luzhou, Neijiang, and Zigong), the northern Sichuan region (with Nanchong, Dazhou, Bazhong, and Guang'an as the core cities), the Panzhihua-Xichang region (mainly including Liangshan Prefecture and Panzhihua), and the western Sichuan region (primarily consisting of Ganzi Prefecture and Aba Prefecture). These regions were used to evaluate county-level resources.

From the manufacturing output values and enterprise numbers in Sichuan Province since 2000, it is observed that the growth rates of the 10 sectors monitored in this study have all surpassed five times the previous levels. Notably, the transportation sector, high-tech manufacturing led by electronics and information technology, non-metallic mining, and pharmaceutical manufacturing have all achieved growth rates of 20 times or more. It is worth noting that energy-related manufacturing industries reached an output value of 100 billion yuan in 1999 and grew to 1.3 trillion yuan by 2021, accounting for nearly 30% of the total industrial output value in this category. Due to the broad distribution of counties across Sichuan Province, manufacturing industry clusters still require regional integration driven by large-scale industrial enterprises. Some scholars validated the collective action theory in rural areas (Dalenogare et al., 2018), demonstrating that village size does not contribute to the improvement of industrial clusters. Most enterprises in counties are small or medium-sized. Despite an abundant labor force, there is a lack of corresponding production capital, which limits the ability to scale up production and achieve industrial transformation or upgrading (Kathuria & Natarajan, 2013; Majumder & Sawhney, 2020). Table 2 shows the agglomeration degree of the manufacturing industry in Sichuan's five major regions from 2011 to 2022.

Table 2. Agglomeration degree of the manufacturing industry in Sichuan's five major regions (2011-2022)

	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Southern Sichuan region	1.174	1.132	1.135	1.247	1.216	1.256	1.314	1.309	1.452	1.472	1.478	1.511
Panzhihua-Xichang region	1.01	1.04	1.18	1.25	1.295	1.325	1.251	1.301	1.271	1.285	1.311	1.285
Western Sichuan region	1.005	1.054	1.008	1.176	1.243	1.289	1.318	1.451	1.243	1.293	1.262	1.278
North Sichuan region	1.117	1.191	1.207	1.211	1.217	1.303	1.323	1.312	1.376	1.416	1.515	1.591
Central region	1.361	1.291	1.276	1.364	1.378	1.412	1.532	1.623	1.683	1.703	1.716	1.736
Mean	1.013	1.028	1.070	1.115	1.126	1.183	1.235	1.263	1.273	1.258	1.237	1.268
Standard deviation	0.121	0.113	0.141	0.101	0.114	0.1355	0.151	0.145	0.189	0.214	0.217	0.286

Data source: Calculated using Stata 18.0.

Overall, between 2011 and 2022, the agglomeration degree of the manufacturing industry in Sichuan Province has shown a steady upward trend, with industrial output values continuing to play a relatively important role in the province's overall economy. The southern Sichuan region exhibited a general increase in agglomeration degree, with slight fluctuations observed between 2011 and 2012, followed by consistent growth. The agglomeration degree in the western Sichuan region reached a relative peak in 2018, before experiencing a subsequent decline. The Panzhihua-Xichang region's agglomeration degree generally lagged behind, with significant fluctuations observed, particularly a decline in 2017, followed by a slow recovery. From the mean change in the GEM index, it can be observed that Sichuan's overall standard deviation has consistently fluctuated and increased year on year, indicating that industrial development in the province has remained relatively steady. However, a slight decline in 2020 was observed, which is likely attributable to the impact of the COVID-19 pandemic, as well as the new requirements placed on industrial systems and mechanisms by the national macroeconomic environment. However, the proportion of emerging industries in Sichuan remains low, and the pace of industrial development has slowed, leading to a less pronounced overall economic impact.

4. Industrial Agglomeration Effect Analysis

4.1 Basic Model

Based on the previous analysis, the manufacturing industry in Sichuan Province exhibits significant regional agglomeration effects. Core cities also generate a siphon effect on surrounding counties, attracting homogenous enterprises. Under such agglomeration effects, both upstream and downstream enterprises in the manufacturing chain can reduce costs and rapidly form a comparative advantage within the industrial cluster. To further analyze the specific influencing factors of industrial clusters, a basic regression equation was constructed as follows:

$$Y_{ij} = \alpha_{it} + \sum X_{it}\,\beta_{it} + \varepsilon_{it} + \mu_{it} + \gamma_{it} \tag{1}$$

A non-parametric regression method was employed, which is a regression technique known for its low model bias and good stability. In Eq. (1), Y_{ij} represents the explained variable, X_{it} is the explanatory variable, μ_{it} denotes the time-fixed effects, γ_{it} indicates the fixed effects of the manufacturing industry, and ε_{it} is the error term.

4.2 Variable Description

Drawing on the model of industrial agglomeration and regional development differences (Sveikauskas et al., 2016). In order to better understand the relationship and internal mechanisms of manufacturing industry agglomeration and county-level economic growth, the following three influencing variables were selected: TFP, enterprise quantity, and policy development level. Additionally, control variables were selected, including regional GDP, total workforce, and the proportion of people with high education. Table 3 shows the descriptions of the variables.

Table 3. Variable description

Independent Variables	Definitions
TFP	Total factor productivity of the region
SC	Enterprise scale (number of enterprises)
OP	Policy openness (incentive effects)
CON	Control variables
i represents the county code, and *t* represents the year.	

The calculation method for TFP and the data were obtained by Solow residual method to calculate the TFP for Sichuan Province. This variable was treated as a moderating variable, and an interaction term with policy openness was included to examine the moderating effect. The model can be expressed as follows:

$$S_{ij} = \alpha_{it} + \beta_1 TEP_{it} + \beta_2 CON_{it} + \beta_3 SC_{it} + \beta_4 OP_{it} + \mu(TEP_{it} \cdot OP_{it}) + \varepsilon_{it} \quad (2)$$

In the selection and analysis of control variables, 2008 was used as a reference year for the control analysis of county-level economic development. The development situation of counties in Sichuan Province prior to 2008 and the economic growth following this period were analyzed. The data was sourced from the national economic and social development statistical bulletins for 2011-2020, as well as the *Sichuan Statistical Yearbook* and the statistical yearbooks of individual cities and prefectures.

4.3 Results Analysis

Based on the model setup described above, an initial basic regression analysis was conducted. Given that the variables are not independent of each other, and thus not exogenous, the potential impact of endogeneity was considered. To address this, a two-step system GMM estimation method was applied to estimate the model. The results are presented in Table 4.

Table 4. GMM regression analysis results

	Model 1	Model 2	Model 3	Model 4	Model 5
TEP	0.6961***	0.06817***	0.0122***	0.0747***	0.0606***
	(0.119)	(0.233)	(0.001)	(0.005)	(0.005)
CON	0.2682***	02669*	0.2550**	0.0046*	0.0089*
	(0.0006)	(0.0017)	(0.014)	(0.035)	(0.115)
SC		0.172			0.0773
		(0.007)			(0.114)
OP			0.022***		0.0968*
			(0.015)		(0.0394)
Time fixed effect	Y	Y	Y	Y	Y
Sector fixed effect	Y	Y	Y	Y	Y
Constant	5.336	6.234	6.483	5.123	0.358
	(0.291)	(0.279)	(0.293)	(0.198)	(1.062)
Observations	462	462	462	462	462
R-squared	0.5621	0.6832	0.6858	0.415	0.7328

Note: ***, **, and * indicate significance at the 1%, 5%, and 10% levels, respectively.

From the results of Models 1 to 5 presented in the table, it can be observed that TFP has a positive and effective impact on the manufacturing industry agglomeration in Sichuan Province. The coefficients of TFP are all positive and have passed the significance tests. The improvement of TFP is crucial for enhancing the competitiveness of the manufacturing industry and for driving economic growth. It facilitates the diffusion and dissemination of technology across the industrial chain, while also attracting more specialized talent and suppliers, which in turn supports industrial upgrading. The enterprise scale variable, however, does not show significant results in Models 2 and 5, although a positive influence is still indicated. This outcome suggests that the number of enterprises within Sichuan Province does not have a decisive impact on manufacturing industry agglomeration. This is likely due to the fact that the manufacturing enterprises in Sichuan are relatively large in size, primarily state-owned, with fewer private and small- to medium-sized enterprises participating in the manufacturing process. Moreover, these smaller enterprises contribute less to total output value. The policy openness variable exhibits a significant positive effect in Models 3 and 5, confirming that policy support has a lasting impact on the development of the manufacturing industry.

Considering the potential bias effect of TFP on manufacturing industry agglomeration, it is also recognized that agglomeration may influence TFP through various mechanisms, such as accelerating resource flows between industries and improving technical efficiency. Therefore, an interaction term (TFP * policy openness) was added in this study to conduct a robustness check. The results of this check are shown in Table 5.

After introducing the interaction term, a comparison of the coefficients of the original variables is necessary. It can be observed that the effect of TFP on industrial agglomeration in Sichuan Province remains significant, with the advantages of manufacturing clusters still largely dependent on the region's overall resource level. Although the influence of policy openness and the number of manufacturing enterprises on industrial agglomeration is positive, their significance and the strength of their effects require further investigation. The analysis focuses primarily on the basic manufacturing industries, including transportation, electronics, and energy manufacturing.

The results obtained using the GMM estimation method confirm that the model specification and selection of instrumental variables are appropriate, and that these factors do have a significant impact on manufacturing industry agglomeration within the province. This conclusion is logically sound. During the phase of infrastructure construction, any expansion in the manufacturing industry inevitably leads to the flow and concentration of resources. Whether in terms of capital, human resources, or policy guidance, these factors tend to shift from low-return sectors to high-return sectors, creating new sources of economic growth. However, as the industrial structure of manufacturing optimizes and adjusts, the demand for factors changes, particularly the proportion of input factors. High-tech manufacturing industries will require more capital, and the agglomeration effect will shift with the distribution of human capital (Choi, 2019).

Table 5. Regression results for the interaction term of TFP and policy openness

	Model 1	**Model 2**	**Model 3**	**Model 4**	**Model 5**
$TEP_{it} \cdot OP$	0.3055	0.117**	0.423***	0.002*	0.123*
	(1.33)	(0.174)	(0.124)	(0.098)	(0.745)
TEP	0.2712***	0.1733***	0.365***		0.002***
	(0.056)	(0.119)	(0.116)		(0.112)
CON	0.001***	0.015***	0.215***	0.115***	0.311***
	(0.0008)	(0.0511)	(0.001)	(0.005)	(0.003)
SC		0.4189			0.0001
		(0.215)			(0.201)
OP			1.039***		0.0087*
			(0.006)		(0.121)
Constant	1.382	2.212	2.389	2.654	2.124
	(0.339)	(0.008)	(0.006)	(0.003)	(0.002)
Observations	462	462	462	462	462
R-squared	0.4711	0.4801	0.727	0.692	0.7011

A comparison of the results in Table 4 and Table 5 reveals that the inclusion of the interaction term makes the impact of the explanatory variables on manufacturing industry agglomeration more pronounced. Notably, the significance of the control variables is consistently at the 5% level, indicating that regional economic output, population size, and the proportion of highly educated individuals continue to play a positive role in promoting the development of the manufacturing industry. For Sichuan Province, Chengdu still exhibits strong population siphon and agglomeration effects, accelerating the development of the manufacturing cluster in the central region, with Chengdu as the core. Regarding the influence of policy openness and enterprise numbers, it can be observed that Sichuan Province still relies heavily on policy guidance. The role of enterprises in promoting industrial agglomeration remains limited and requires further strengthening.

5. Conclusion and Recommendations

The phenomenon of manufacturing industry agglomeration at the county level in Sichuan Province is closely related to the resource structure it possesses. In terms of the direction of manufacturing industry agglomeration, the western Sichuan region follows a typical resource-dependent county-level development model, primarily relying on local abundant tourism, mineral, and land resources to develop traditional basic industries. The southern and northern counties mainly rely on industrial chain clusters extended from core cities, gradually forming an agglomeration model focused on processing, leveraging stages such as assembly and component manufacturing within the industrial value chain (Cho, 2000). At the spatial level, Sichuan's overall structural layout continues to be centred around the Chengdu metropolitan area, with surrounding counties lacking sufficient coordination. This is particularly evident in the area of economic productivity improvement, where greater emphasis should be placed on the role of TFP. The primary factors influencing the improvement of TFP are derived from technological innovation and progress (Samaniego & Sun, 2016). In the absence of technological innovation levels and a conducive external environment, enterprises tend to opt for introducing new technologies, which are then absorbed and innovated upon. Conversely, in a more favourable external environment, enterprises prefer to conduct independent research to elevate technological capabilities. Sichuan Province's overall TFP remains relatively low, but it holds considerable development potential.

From the perspective of county-level spatial distribution, Sichuan Province is well-positioned to establish a model for the integrated development of emerging industries based on its existing manufacturing industry. For example, the northern region, with Mianyang as its centre, could focus on building a technology industry cluster. A substantial investment in human and material resources would be required to enhance the technological content of manufacturing, utilizing technological innovation to increase the added value of production. In the south, with Yibin as the core, a transportation hub city could be developed, leveraging the convenience of a logistics hub to foster a high- and mid-end manufacturing cluster. This would optimize distribution processes, enhance the efficiency of comprehensive logistics transport, and attract more manufacturing industries from the Sichuan-Chongqing region, thereby generating scale effects in the regional manufacturing industry. The western region could, with Panzhihua as the core, create a new industrial cluster, accelerating the transformation of traditional manufacturing industry into new types of manufacturing industry, with a focus on green and smart manufacturing to enhance the level and sophistication of manufacturing processing.

Furthermore, the goal of enhancing TFP should be prioritized, with stronger incentives introduced to stimulate innovation within industries. Active participation in the construction of the western section of the "Belt and Road" initiative should be pursued, increasing the export volume of international trade to the west. This would promote the advancement of industrial clusters towards the stages with higher added value and productivity, enabling deeper integration into the global value chain and facilitating the rapid formation of innovative, strategic industrial clusters.

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Data Availability

The data used to support the research findings are available from the corresponding author upon request.

Conflicts of Interest

The authors declare no conflict of interest.

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