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Spatial distribution Pattern and Influencing Factors of Fujian Manufacturing Industry in Southeastern China: An Empirical Study Based on the Negative Binomial Regression Model

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Abstract:
Introduction: The manufacturing industry is an important component of urban economy, and its spatial configuration profoundly influences its urban planning, infrastructure development, resource allocation, and sustainable development. A scientific industrial layout can effectively promote the growth, transformation, and upgrading of regional economies.

Objectives: Based on data for manufacturing enterprises in Fujian Province spanning 2009–2021, this study explores the spatial distribution patterns of general and innovative manufacturing enterprises at different scales and the factors affecting their spatial distribution.

Methods: we conduct spatial statistical analysis using standard deviation ellipse, spatial autocorrelation, kernel density, and negative binomial regression.

Results: 1) The spatial distribution of manufacturing enterprises is uneven, mainly distributed along coastal urban belt centered on Ningde, Fuzhou, Quanzhou, Xiamen, and Zhangzhou. General manufacturing has been centered on Quanzhou–Xiamen, while innovative manufacturing centers have shifted from Xiamen to Quanzhou. 2) There are significant spatial agglomeration characteristics, forming two core hotspot areas of Xiamen–Zhangzhou–Quanzhou and Fuzhou. However, innovative manufacturing enterprises exhibit stronger polarization and diffusion phenomena. 3) The spatial pattern evolves from a "point-axis" pattern to a "point-cluster belt" pattern, with stronger spillover effects observed for innovative manufacturing enterprises. 4) The factors affecting the spatial pattern of manufacturing enterprises in Fujian Province show significant changes. Among them, regional distance to ports, industrialization level, financial support strength, transportation accessibility, and population size have significant effects. But the coefficient of distance to ports decreases sharply, external development level changes from having a significant positive effect to not have an effect. Furthermore, patent R&D and the number of economic development zones have more significant effects on innovative manufacturing enterprises.

Conclusions: Compared to other coastal provinces in eastern China, Fujian Province's manufacturing industry is more concentrated in coastal areas, and with the industrial transformation and upgrading, the demand for high-quality workers is increasingly strong. Fujian Province should further integrate into the global industrial chain, strengthen industrial clusters, accelerate the cultivation of high-quality talents, thereby promoting high-quality development of the manufacturing industry.

Keywords: manufacturing industry; spatial pattern evolution; negative binomial regression; sustainable development

INTRODUCTION

As a major part of the real economy, manufacturing is a foundation of both national and regional development[1]. It is an important component of urban economies and a driving force in the evolution of urban spatial patterns. China is the world's largest manufacturer[2], but it lags in terms of independent innovation. In recent years, with the worldwide acceleration of technology and urbanization, the costs of land, labor, and other factors have risen rapidly. Since the outbreak of the 2008 financial crisis, a number of developed countries have proposed "industrial renaissance"[3] strategies to reorganize their manufacturing industries. This has imposed greater challenges on the development and innovation of China's manufacturing industry. Manufacturing accounts for more than one-third of the GDP of Fujian Province and about 70% of its R&D expenditure[4], making it the cornerstone of the region's economic growth and transformation. Therefore, investigating the spatial pattern evolution of manufacturing in Fujian Province holds practical significance for optimizing its industrial spatial structure and promoting its innovative transformation and sustainable development.

With increases in land and labor costs in urban areas, manufacturing has migrated to peripheral suburban areas[5]. Many studies have investigated the spatial pattern evolution of this process. Traditional industrial location theories, new economic geography, gradient transfer theory, and cluster theory provide theoretical support for selecting and optimizing manufacturing locations[1]. Early research was based on classical location theories, mainly focusing on the suburbanization of manufacturing and studying factors such as location conditions, economic costs, traffic accessibility, scale effects, and policy regulation[6–10]. In the context of globalization, studies have used approaches such as evolutionary economic geography, gradient transfer theory, and cluster theory to investigate the international migration of manufacturing industries. Such studies have found that the main factors affecting the migration of manufacturing industries from developed to developing countries include cost, market size, institutional systems, and national policies[11–13].

Regarding the spatial evolution of manufacturing in China, studies have focused on different spatial dimensions, such as the national level, city clusters, economic belts, provinces, and municipalities. At the national level, China's manufacturing industries have generally shown a pattern of moving from inland areas to coastal regions and then back again[14–15]. Regionally, manufacturing in major cities is undergoing typical suburbanization processes. Studies have investigated various factors affecting the spatial patterns of manufacturing, such as labor, land, environment, transportation, markets, technology, institutions, and path dependence. However, owing to differences in spans of time and space, industrial characteristics, and research methods, the findings of such studies are varied[1,2,5,16,17]. In terms of methods, GIS technologies and data improvements have greatly facilitated research on manufacturing industries, with multi-time series and multiscale enterprise data enabling the study of the spatial pattern evolution of manufacturing. Exploratory spatial data analysis methods have been used to study the evolution of manufacturing space morphology.

While the abovementioned research provides a reference for the present work, there are nevertheless some gaps in the literature. First, most studies focus on provincial areas, city clusters, economic belts, and large cities (e.g., Beijing, Shanghai, Guangzhou, Shenzhen) at different scales. Fewer studies have been conducted based on multiple spatial scales, such as provinces, municipalities, and counties. Second, manufacturing industries are usually divided simply based on traditional industry attributes into resource-, labor-, technology-, and capital-intensive industries[17]. This ignores the effects of technological development on industrial attributes; for example, the modern textile industry might not be a labor-intensive industry[18]. Third, fewer studies have specifically examined the spatial pattern evolution of manufacturing in Fujian Province, and there are problems such as insufficient sample sizes and short time spans[19–21].

The contributions of this study are as follows: First, using multiperiod, long time-series data from manufacturing enterprises at multiple scales (provincial, municipal, and county levels), we use a combined point, surface, and three-dimensional measurement approach to depict the spatiotemporal patterns and evolutionary characteristics of the spatial structure of Fujian's manufacturing industry. This helps fill the gap in research on Fujian's manufacturing sector. Second, breaking with traditional factor classification models, we categorize the manufacturing industry based on innovation capability and divide it into general and innovative types for comparative analysis. In this way, we can provide more valuable guidance for the innovative transformation and upgrading of manufacturing. Third, we use a negative binomial regression model to explore the factors affecting the spatial evolution of Fujian's manufacturing industry. This enriches research perspectives in related fields, aiming to provide a decision-making reference for the sustainable development of Fujian's manufacturing sector.

OBJECTIVES

Study Area

We select Fujian Province as the research object. Fujian is located in southeastern China, on the coast of the East China Sea. Its territory spans from 23°33′N to 28°20′N latitude and 115°50′E to 120°40′E longitude, making it a key outlet to the sea. According to the Fujian Statistical Yearbook 2022, Fujian Province currently spans an area of 124,000 square kilometers and boasts a permanent population of 41.87 million. In 2021, Fujian's gross domestic product (GDP) reached 4956.61 billion yuan, with the added value of the secondary industry amounting to 2331.98 billion yuan. Notably, the manufacturing sector contributed an added value of 1829.28 billion yuan, ranking fifth in China in terms of scale and playing a pivotal role in regional economic development. Based on China's latest (2021) administrative divisions, the basic units for research consist of 83 county-/city-/district-level administrative units, including 11 county-level cities, 31 districts under prefecture-level cities, 40 counties, and the Pingtan Comprehensive Experimental Zone, all of which belong to the nine prefecture-level cities in the province (Figure 1).

Figure 1. Geographical location of Fujian Province, China.

Data processing and classification

Data for Fujian's manufacturing enterprises. We use the data platforms Qichacha (https://www. qcc.com) and Tianyancha (https://www.tianyancha.com) to collect data on manufacturing enterprises in Fujian Province from 2009 to 2021. After crosschecking in Excel, manual removal, and filtering, we obtain the establishment time, registered address, and industry category of 24,824 manufacturing enterprises in 2009, 48,330 in 2015, and 88,390 in 2021. Then, based on the registered address, we use Python and a high-level map API interface to obtain the longitude and latitude coordinates of each enterprise. On that basis, we build a spatial database of manufacturing enterprises in Fujian Province using ArcGIS.

Innovation drives the transformation and upgrading of manufacturing[22]. Accurately depicting the spatial patterns and related factors of innovative manufacturing enterprises has been a focal point of research. However, simply categorizing manufacturing types based on factor intensity not only fails to account for the effect of technological progress on industry characteristics, but it also makes it difficult to reflect the varying levels of innovation capabilities among different types of manufacturing industries. Knowledge- and technology-intensive high-tech enterprises are typical carriers of regional innovation[23]. Because of factors such as intellectual property rights, the proportion of scientific and technical personnel, and R&D expenses, high-tech enterprises are considered to have high innovation and growth potential[24]. Therefore, to further explore the differences between manufacturing enterprises, we classify recognized high-tech enterprises as innovative manufacturing enterprises. The corresponding enterprise data are obtained from the official website of High-tech Enterprise Recognition (http://www. innocom.gov.cn). After identification and screening, we obtain 1187 high-tech enterprises for 2009, 2532 for 2015, and 12,224 for 2021. We compare these with Fujian Province's database for manufacturing enterprises and select 759 high-tech manufacturing enterprises for 2009, 1262 for 2015, and 4614 for 2021.

Socioeconomic data. These come mainly from the Fujian Statistical Yearbook, China City Statistical Yearbook, China County Statistical Yearbook, National Intellectual Property Patent Database, and related municipal statistical yearbooks and county economic and social development statistical bulletins. We calculate the distance from counties and cities to ports using R language based on latitude and longitude. Major ports are selected according to the National Coastal Port Layout Plan released by the Ministry of Transport as Fuzhou port, Quanzhou port, Xiamen port, Putian port, and Zhangzhou port.

METHODS

Standard Deviation Ellipse (SDE)

SDE is typically used to study the evolution and trends of industrial spatial patterns. The main parameters include center point, major axis, minor axis, and azimuth angle. The ellipse represents the main area where spatial geographical elements are distributed, while the major and minor axes reflect the direction and dispersion degree of geographic elements, respectively. The X/Y ratio indicates polarization in a certain direction, which can be expressed as follows:

$$SDE_x = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{X})^2}{n}} \quad (1)$$

$$SDE_x = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{X})^2}{n}} \quad (2)$$

Here, x_i and y_i are the spatial coordinates of i manufacturing enterprise in Fujian Province, $\bar{X}$ and $\bar{Y}$represent the average center of all manufacturing enterprises, and n is the number of manufacturing enterprises.

Spatial Autocorrelation Analysis

Global Moran's I is used to measure regional global clustering. The larger the value, the higher the spatial autocorrelation degree. This can be used to describe the concentration of manufacturing enterprises in provinces. The formula is as follows:

$$Moran's I = \frac{n}{S_0} \cdot \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}(x_i - \bar{x})(y_j - \bar{y})}{\sum_{i=1}^{n}(x_i - \bar{x})^2} \quad (3)$$

$$S_0 = \sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij} \quad (4)$$

where n is the number of manufacturing enterprises, x_i and y_i are the spatial coordinates of the ith manufacturing enterprise, $\bar{x}$ is the mean value, and w_{ij} is a spatial weight matrix for i and j units. The range of $Moran's\ I$ is $[-1,1]$, with absolute values approaching 1 indicating a positive correlation in space. Approaching 0 indicates a random distribution in space, and approaching -1 indicates a negative correlation in space.

Cold spot and Hotspot Analysis: *Getis–Ord G_i^**

Owing to regional heterogeneity, global autocorrelation tests cannot reflect local spatial correlation. Therefore, we further analyze the spatial clustering characteristics of county (city and district) administrative units using the Getis–Ord G_i^* index for local autocorrelation analysis. The formula is as follows:

$$G_i^* = \sum_j w_{ij} x_j / \sum_j x_j \quad (5)$$

$$Z(G_i^*) = \frac{G_i - E(G_i)}{\sqrt{VAR\ (G_i)}} \quad (6)$$

where x_j is the observation value of a spatial unit, and w_{ij} is the spatial weight matrix between units i and j. The higher the G_i^* values for each unit (i.e., Z), the more likely it is to be a hotspot. A lower Z value indicates cold spots. If the Z value approaches zero, there is no obvious spatial aggregation in the region.

Kernel Density Estimation

The kernel density method can accurately reflect the spatial agglomeration characteristics of surrounding areas through spatial point data. The formula is:

$$f_n(x) = \frac{1}{nh}\sum_{i=1}^{n} k\left(\frac{x - x_i}{h}\right) \quad (7)$$

where $k\left(\frac{x-x_i}{h}\right)$ is a kernel function, n is the number of manufacturing enterprises, $h > 0$ is bandwidth, and $x - x_i$ represents the distance from point x to x_i.

Spatial Measurement Model

Since the dependent variable is the number of manufacturing enterprises, its spatial layout has obvious discrete characteristics. The standard formula for Poisson regression used to process count variables with discrete features is as follows:

$$Ln\,\lambda_i = offset_i + \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_i x_i \quad (8)$$

The observed value y_i of dependent variable Y_i follows Poisson distribution with the parameter $P(Y_i = y_i | X_i) = (e^{-\lambda_i} \cdot \lambda_i^{y_i})/y_i$. The conditions for model establishment require that the dependent variable and the variance of the independent variable be equal. It is often difficult, however, to meet this requirement using actual data. When they are not equal, a negative binomial regression model should be used, as follows:

$$Ln\,\lambda_i = Lnk_i + offset_i + \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_i x_i \quad (9)$$

K is a super-discrete degree that follows a gamma distribution with a mean of 0 and variance of α. When α=0, this model becomes a Poisson model; when α>0, negative binomial regression is used. The larger the α, the stronger the data dispersion.

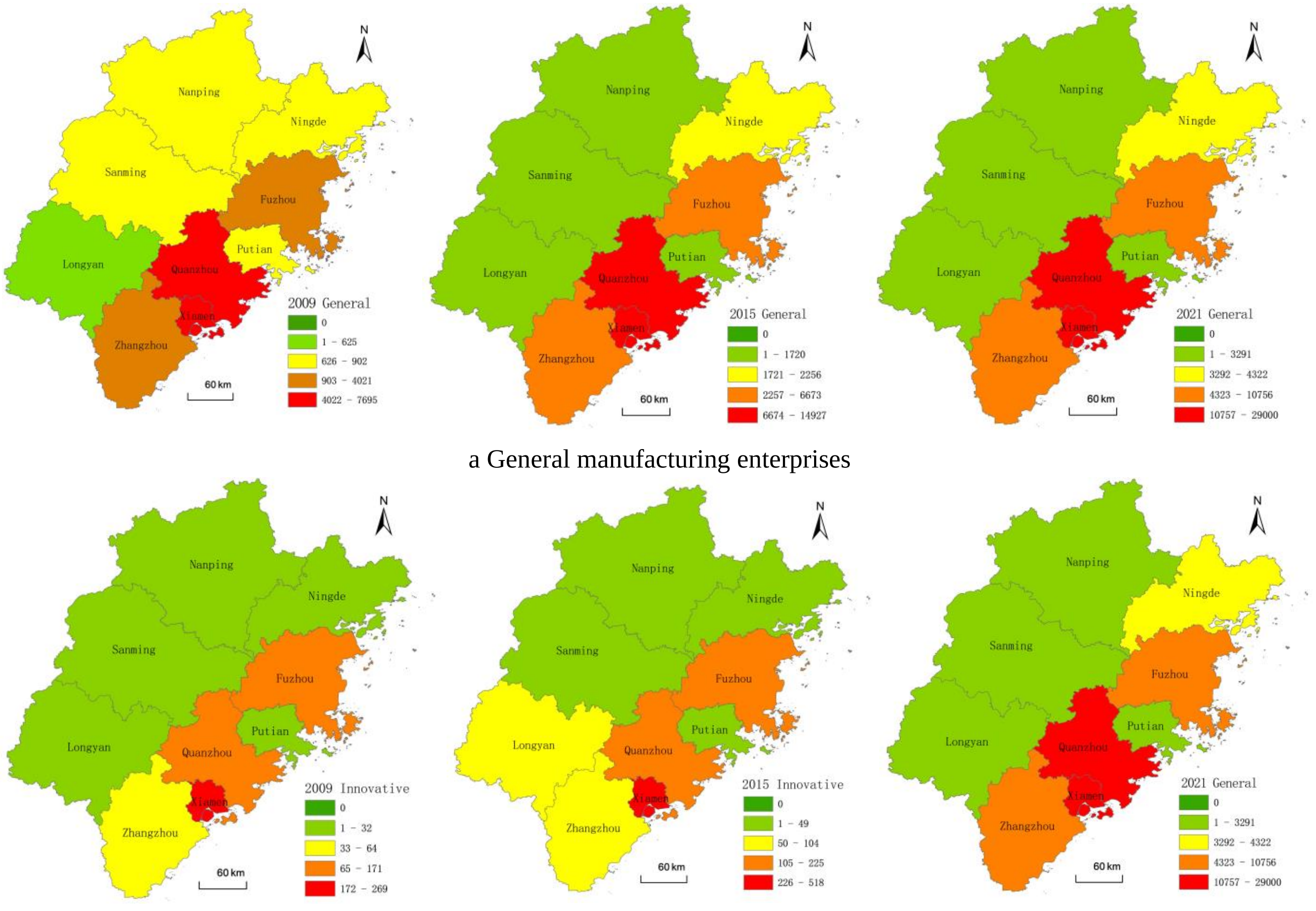
RESULTS

Overall Spatial Distribution Characteristics of Manufacturing Enterprises

Distribution characteristics of general manufacturing enterprises

Fujian's manufacturing enterprises have developed rapidly since 2008, with an increase from 24,824 in 2009 to 88,390 in 2021—a growth rate of 256%. Using ArcGIS 10.3 and the natural break classification method, we divide Fujian's manufacturing enterprises into five grades for each year (Figure 2) and draw SDEs (Figure 3) and parameter tables (Table 1). Figure 2a shows that there is obvious spatial clustering of Fujian's manufacturing enterprises, geographically concentrated on the coast of Min Dong and mainly distributed along Ningde, Fuzhou, Quanzhou, Xiamen, and Zhangzhou. Between 2009 and 2015, the grades of inland cities such as Sanming and Nanping further decreased, but the grade decrease of Putian, located on the coast of Min Dong, was unexpected. It used to be "the world shoe capital" but was greatly affected by industrial chain transfer.

Figure 3a and Table l show that Fujian's manufacturing enterprises are distributed in a southwest–northeast direction, with an approximate central axis on Longhai–Nan'an–Yongtai. The basic parallelism of this axis to the coastline is evident. The turning point 0 ranges from 34.03°to 33.87°and remains clockwise throughout the period, indicating that there has been an increasing number of manufacturing enterprises in the northeast direction. In terms of long-axis change, the standard deviation distance shortens between 2009 and 2015, suggesting that there is a polarization phenomenon along the long axis. It increases between 2015 and 2021, indicating spreading phenomena in the southwest–northeast direction. In terms of short-axis changes, there is a trend of spreading first and then clustering in Fujian's manufacturing industry between 2009 and 2021. The center points all lie within Nan'an. The coordinates of the center first move from 118.43°E, 25.16°N toward the northeastern direction at 118.44°E, 25.17°N in 2015 and then move southwestwardly to 118.42°E, 25.16°N in 2021. This indicates that as northern Fujian's new-energy vehicle industry continues to develop, the directional characteristics of Fujian's manufacturing industry become more obvious.



a General manufacturing enterprises

b Innovative manufacturing enterprises

Figure 2. The spatial distribution pattern of manufacturing enterprises in Fujian Province from 2009 to 2021

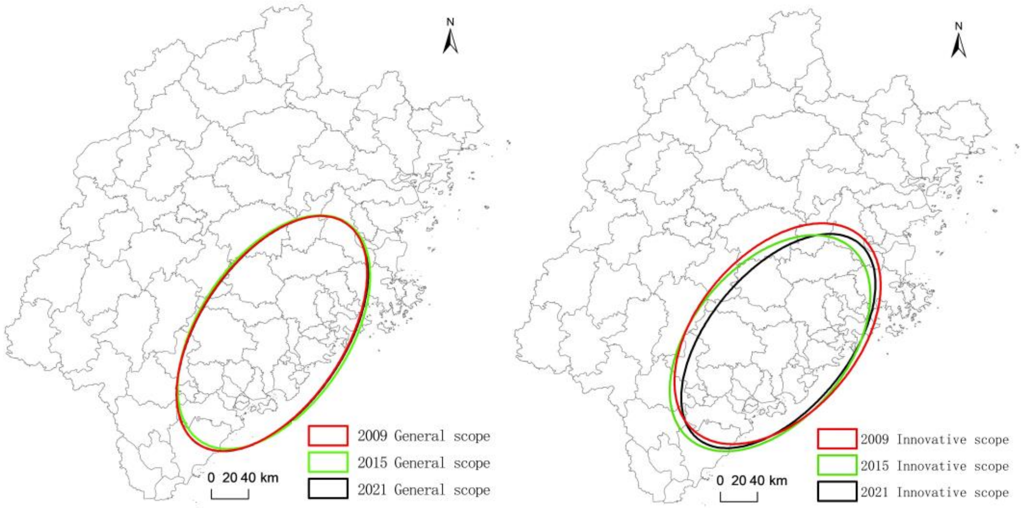


Figure 3. SDE of the Spatial Pattern of manufacturing enterprises in Fujian Province from 2009 to 2021

Table 1 SDE Parameters of Manufacturing Enterprises in Fujian, 2009–2021

Category	Date	Center Point Longitude	Center Point Latitude	Y-axis Standard Deviation	X-axis Standard Deviation	Azimuth θ(.)
General	2009	118.42558	25.156218	1.28291	0.697121	34.035486
manufacturing	2015	118.43963	25.168862	1.26479	0.722618	33.983589
industry	2021	118.41925	25.155663	1.278373	0.695914	33.870344
Innovative	2009	118.39693	25.114527	1.222748	0.671635	39.846273
manufacturing	2015	118.31637	25.093765	1.209625	0.748697	40.267037
industry	2021	118.38952	25.185385	1.23657	0.771933	40.613892

Distribution characteristics of innovative manufacturing enterprises

Figure 2b shows that the overall pattern of innovative manufacturing enterprises in Fujian Province is basically similar to that of general manufacturing, but there are significant differences in regional-level changes. Longyan’s level increases from 2009 to 2015, and Quanzhou’s level increases from 2015 to 2021, while Fuzhou’s and Longyan’s levels decrease. Statistical analysis indicates that the changes in city-level rankings are mainly attributable to an increase in the proportion of innovative enterprises in Quanzhou, rising from 22.53% in 2009 to 32.79% in 2021, thus ranking first. Further analysis shows that innovation began in 2009. The proportion of innovative manufacturing is basically consistent with that of general manufacturing, indicating that industrial agglomeration helps innovation, and innovation depends on industrial agglomeration. Innovation is not a solitary enterprise behavior; it requires interaction and competition among enterprises, which can only be achieved through enterprise agglomeration[25].

Figure 3b and Table 1 show that, compared with general manufacturing enterprises, innovative manufacturing enterprises also present a southwest–northeast orientation, but the angle of rotation is between 39.85° and 40.61°, and it always rotates clockwise. This indicates that the directionality of innovative manufacturing gradually spreads outward, and its centrifugal force decreases. From the change in the long axis, the standard deviation distance first shortens and then lengthens, showing a “first polarization and then diffusion” trend along the long axis. From the change in the short axis, innovative manufacturing continues to spread. From the center point, all are within Nan’an, and the central coordinates move from 118.4E, 25.11°N toward the southwest in 2009 to 118.32E, 25.09°N in 2015 and then northeastward to 118.39°E, 25.19°N in 2021. This indicates that there has been a significant increase in the number of innovative manufacturing enterprises in the northeastern direction.

Spatial Association and Agglomeration Evolution of Manufacturing Enterprises

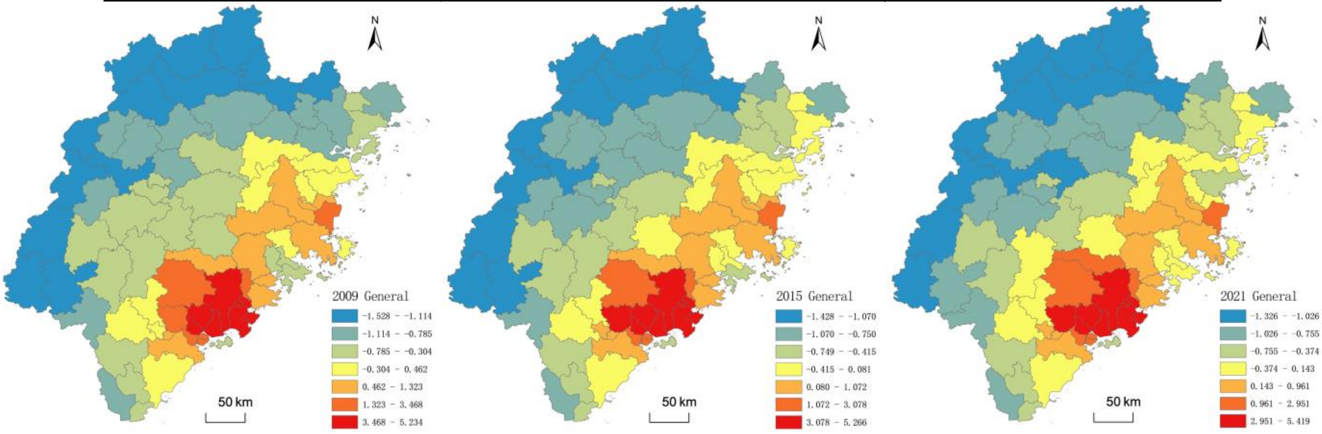
Spatial agglomeration analysis

To explore the spatial agglomeration characteristics of manufacturing enterprises in Fujian Province, Moran's I is calculated for each year (Table 2). The results show that the Moran's I of general and innovative manufacturing industries is significantly positive each year, indicating that Fujian's manufacturing industry has obvious spatial agglomeration and path dependence. From a temporal perspective, however, the Moran's I of general manufacturing enterprises gradually decreases over time, declining from 0.522 in 2009 to 0.477 in 2021. This suggests that the spatial aggregation index of Fujian's manufacturing enterprises is weakening. Moreover, the Moran's I of innovative manufacturing enterprises remains relatively stable, reflecting higher spatial aggregation.

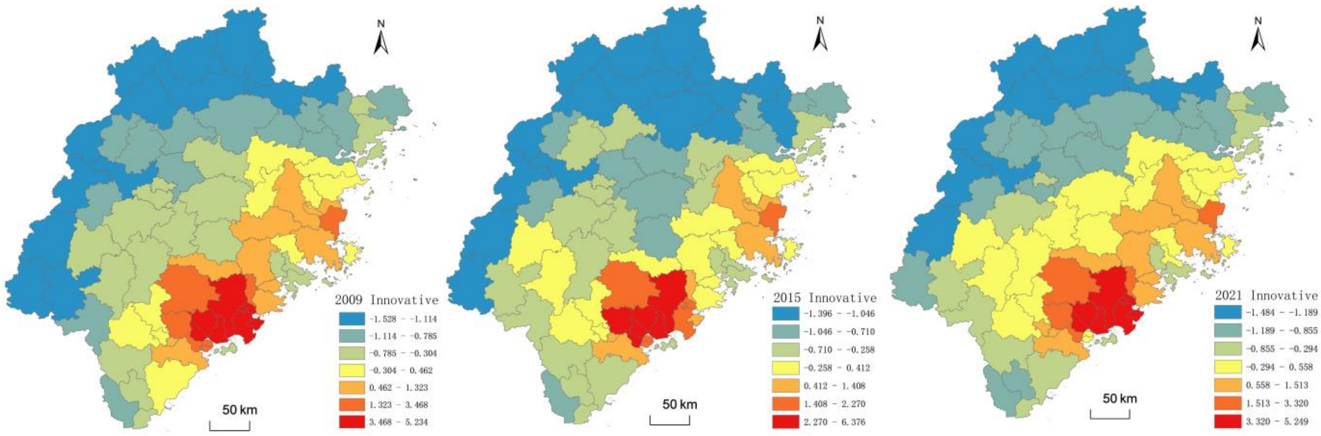
To further analyze the spatial distribution trend of manufacturing enterprises in Fujian at the county level, we calculate the Z-value of the G statistic for each year using the hotspot analysis module in ArcGIS 10.3 and divide it into seven grades using the natural breaks classification method. On that basis, we draw a cold–hot map of manufacturing industry distribution in different years (Figure 4).

Table 2 Global Moran's I of Manufacturing Enterprises in Fujian

Index	General Manufacturing Industry			Innovative Manufacturing Industry		
	2009	2015	2021	2009	2015	2021
Moran's I	0.522	0.486	0.477	0.541	0.549	0.526
E(I)	−0.009	−0.009	−0.009	−0.009	−0.009	−0.009
Z-score	8.327	7.814	7.789	8.251	8.597	8.218
p-value	0.000	0.000	0.000	0.000	0.000	0.000



a General manufacturing enterprises



b Innovative manufacturing enterprises

Figure 4. Spatial hotspots distribution of manufacturing enterprises in Fujian Province from 2009 to 2021

Figure 4a shows that from 2009 to 2021, the spatial agglomeration characteristics of general manufacturing enterprises in Fujian are relatively stable. The hotspots present a cluster aggregation pattern, and the hotspot areas are mainly concentrated on the continuous urban belt along the southeast coast of Fujian Province, including Fuzhou, Quanzhou, Xiamen, and Zhangzhou. The cold spot areas are mainly focused in the border area between northwest Fujian and Jiangxi Province. In general, the hotspots and cold spots tend to be aligned along the southwest–northeast direction. In terms of hotspot evolution trends, since 2009, Fujian's manufacturing industry has been steadily maintained by nine primary hotspots: Tong'an District, Jimei District, Xiang'an District, Nanan, Jinjiang, Shishi, Fengze District, Licheng District, and Changtai District. The core of the large hotspots is the Xiamen–Zhangzhou–Quanzhou hotspot zone, and the core of the medium hotspots is the Fuzhou hotspot zone centered on Changle District. The only change is that Changtai District rises from a secondary hotspot to a primary hotspot during 2009–2015, showing an agglomeration distribution around the extreme value zones of the manufacturing enterprise hotspots. In terms of cold spot evolution, it generally maintains a north–south F-shaped first-level continuous cold spot belt starting at Wuping County and ending at Pucheng County. However, there are only two changes during this period: Shanghang County and Songning County change from first-level cold spots to second-level cold spots. Under the influence of the trickle-down effect of the two hotspots and the rapid development of Ningde's new-energy industries, Zhangping County and Dehua County change from being third-level cold spots to being insignificant ones, and Ningde reduces its number of cold spots from seven to five without any first-level cold spots.

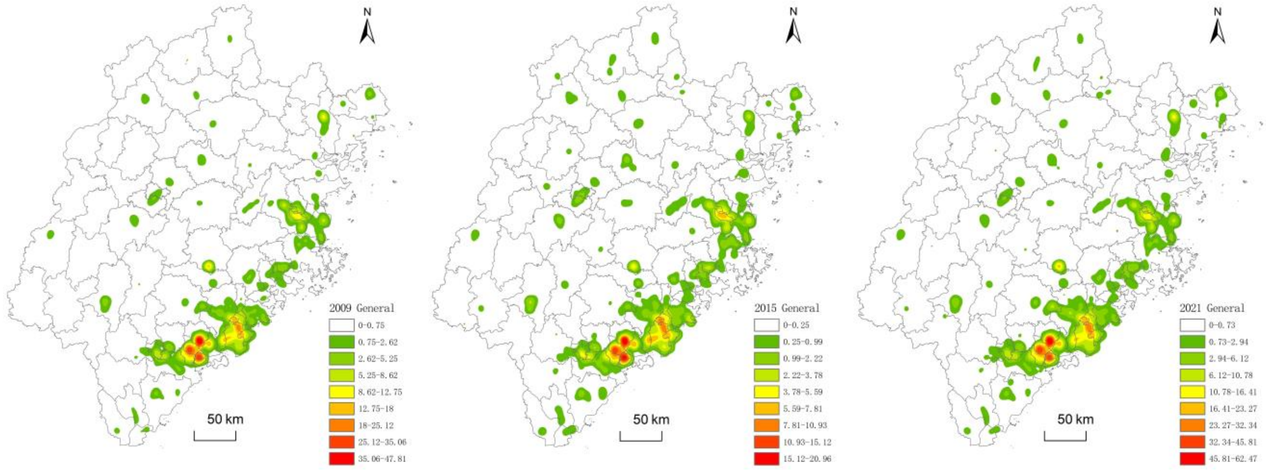
Figure 4b shows that Fujian's innovative manufacturing industry hotspot distribution pattern is basically similar to that of general manufacturing industries but presents stronger polarization and diffusion phenomena. In terms of hotspot distribution, from 2009 to 2015, the number of first-level hotspots in the large Xiamen–Zhangzhou–Quanzhou hotspot area change from five in Quanzhou and three in Xiamen to four in Xiamen, one in Quanzhou, and one in Zhangzhou, with Xiamen becoming the core. In addition, the medium hotspot zone in Fuzhou also further converges. Two hotspot zones gather together, reducing regional connectivity. From 2015 to 2021, the first-level hotspots in the large Xiamen–Zhangzhou–Quanzhou hotspot area return to five in Quanzhou and three in Xiamen, strengthening regional connectivity and forming a stable industrial innovation chain for Fujian's manufacturing industry. In terms of cold spot distribution, there is an initial trend of dispersion followed by concentration between 2009 and 2021, with the number of cold spots decreasing from 45 to 38, mainly concentrated around the two hotspot areas. Since 2009, Putian has not appeared in any hotspots. This indicates that low-end contract manufacturing industries face huge risks of industrial transfer, and the manufacturing industry still faces difficulties in recovering its aggregation and scale effects.

Spatial evolution analysis

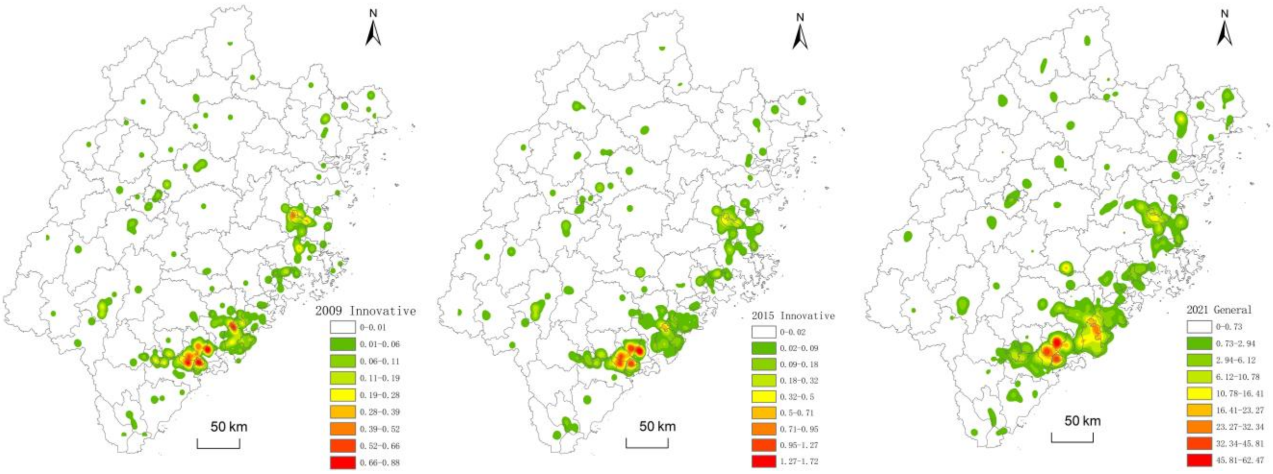
Based on SDE, Moran's I, and hotspots analysis, we can depict the overall distribution pattern of Fujian's manufacturing industry at the provincial, prefectural city, and county-district levels. To further explore the spatial pattern evolution of Fujian's manufacturing industry in counties and cities, we use kernel density analysis and divide it into nine levels according to the natural break method, drawing three-year kernel density maps (Figure 5).

Figure 5a shows that from 2009 to 2021, Fujian's manufacturing industry consistently presents a "point-axis" spatial pattern dominated by one axis. The main belt is distributed along the coastal urban chain of Xiamen–Zhangzhou and Quanzhou–Fuzhou, while the point distribution mainly occurs at the city districts of inland cities in northwest Fujian. Since 2009, manufacturing industries have become increasingly concentrated along the coastal areas and have connected to form a chain-like pattern. Furthermore, they have gradually expanded toward Ningde's and Zhangzhou's southwest direction. However, the various clusters of inland cities are still far apart from each other, showing an increasing tendency toward self-bundling development.

Figure 5b shows that Fujian's innovative manufacturing industries also present a "point-axis" spatial distribution similar to that of general manufacturing industries, which gradually spreads outward. However, there are significant differences in the evolutionary trends. From 2009 to 2021, the main axis evolves from a "one core, two subordinates" pattern centered on Xiamen and Zhangzhou, with Quanzhou and Fuzhou as subordinates, to a "three cores parallel" spatial structure. Both ends also rapidly spread towards the northeast of Ningde and the southwest of Zhangzhou. From 2015 to 2021, benefiting from the rapid development of the ceramics industry, Dehua County has significantly increased its innovative manufacturing industries, showing obvious aggregation effects.



a General manufacturing enterprises



b Innovative manufacturing enterprises

Figure 5. The kernel density distribute of manufacturing enterprises in Fujian Province from 2009 to 2021

Factors Affecting Spatial Differentiation Evolution in Fujian's Manufacturing Enterprises

Variables and Processing

The factors affecting the spatial evolution of manufacturing are complex and diverse. Based on the literature, Fujian's actual situation, and data availability, we select general manufacturing enterprises and innovative manufacturing enterprises as independent variables. We further select 10 representative indicators from the four dimensions of society, economy, transportation, and innovation (Table 3) as dependent variables to explore their effect on the spatial evolution of Fujian's manufacturing industry. 1) Population size. The urban population is a foundation for labor resources and provides support for market potential. Manufacturing industries located in areas with abundant human resources are more likely to obtain suitable workers; the unit-area population[26] is selected as an indicator. 2) Industrialization level. A well-structured industry can effectively improve enterprise efficiency. The evolution of the industrial structure is closely related to spatial development. We select the proportion of secondary industry as an indicator. 3) External development level. Based on China's process of industrialization as well as related research results, manufacturing development can be considered closely related to foreign direct investment (FDI). The actual utilization of FDI per year is selected as an indicator[27]. 4) Number of development zones. Development zones that carry out pilot programs attract and guide industrial agglomeration owing to their preferential policies and complete infrastructure conditions[28]. However, different development zone levels have varying effects on the location choice of manufacturing industries; thus, they are assigned different values accordingly. 5) Economic development level. The higher the regional economic development level, the greater its attractiveness for populations and resources, usually representing a larger market scale. We select per capita GDP as an indicator[27]. 6) Labor cost. Traditional locational theories suggest that labor costs significantly affect the spatial patterns of manufacturing industries. We select the average wage of employees as an indicator[29]. 7) Financial support. Difficulties with financing and high financing costs are key factors restricting industrial development; we select the average GDP financing amount as an indicator. 8) Transportation accessibility. Convenient transportation infrastructure greatly reduces transport costs and enhances market accessibility. Road density is selected as an indicator[30]. 9) Distance from cities to major ports. Fujian Province's total exports reached RMB 1.12 trillion in 2022, over 80% of which included industrial products. Fujian still mainly relies on an outward-oriented economy. Maritime transport is the most cost-effective mode of transportation for international trade, and the distance between county-level city centers and five main ports in Fuzhou, Xiamen, Putian, Quanzhou, and Zhangzhou is selected as an indicator. 10) Patent R&D. New economic geography theory suggests that technological innovation is an important factor affecting the spatial distribution of industries. Patents are the primary outcomes of technological innovation. We select the number of patent applications per 10,000 people each year as an indicator based on common practices in the literature[31].

Table 3 Variable Selection and Explanation of Factors Influencing the Spatial Pattern Evolution of Manufacturing Enterprises in Fujian

Variable Type	Variable Name	Variable Code	Variable Description
Social dimension	Population size	PDEN	Population per unit area (10,000/km^2)
	Industrialization level	INDUS	Proportion of the output value of secondary industry to GDP (%)
	External development level	OPEN	Actual utilization of foreign capital (USD 10,000)
	Number of development zones	DPA	Located in special economic zones, national new areas, national-level development zones, and provincial-level development zones, they are assigned values of 10, 8, 6, and 4, respectively
Economic dimension	Economic development level	PGDP	Per capita Gross Domestic Product (RMB 10000/person)
	Labor cost	WAGE	Average salary of employees in the region (10,000 yuan)
	Financial support	FIN	Average GDP financing amount (yuan)
Transportation dimension	Accessibility by transportation	TRA	Highway density, highway mileage/area (km/km^2)
	Accessibility by transportation	PORT	Closest distance from the regional center of mass to Fuzhou, Xiamen, Putian, Quanzhou, and Zhangzhou ports (km)
Innovation ability	Patent R&D	PAF	Number of patent applications per 10,000 people in the region that year

Regression results analysis

First, we perform O tests on the dependent variable and find that the sample variance is much higher than the sample mean. For example, in 2009, the average value and variance of the general manufacturing industry model are 299.084 and 200,877.029, respectively. The sample data have super-dispersive characteristics and do not meet the prerequisite assumptions for Poisson regression. Moreover, α's 95% confidence interval at a significance level of 1% is (0.497, 0.271), which rejects the original hypothesis that alpha = 0. Therefore, we use negative binomial regression models for analysis (Table 4).

Table 4 Negative Binomial Regression Results for the Spatial Pattern Evolution of Fujian's Manufacturing Enterprises

Variable	General Manufacturing Industry		Innovative Manufacturing Industry	
	2009	2021	2009	2021
PDEN	0.759** (2.287)	1.722*** (5.496)	1.263*** (3.433)	1.109*** (2.858)
INDUS	1.924** (2.455)	2.448*** (3.761)	3.254*** (3.234)	1.799** (2.231)
OPEN	0.543*** (3.75)	0.052 (1.33)	0.322** (2.08)	−0.046 (−0.995)
DPA	0.025 (1.097)	0.028** (2.13)	0.018 (0.747)	0.042*** (2.593)
PGDP	0.099 (1.103)	−0.074*** (−3.853)	0.149 (1.368)	−0.02 (−0.841)
WAGE	−0.167 (−0.743)	0.266*** (4.747)	0.024 (0.084)	0.185*** (2.778)
FIN	0.675*** (3.579)	0.729*** (5.056)	0.721*** (3.177)	0.742*** (4.53)

TRA	0.624** (2.514)	1.154*** (8.712)	0.595** (2.128)	0.981*** (6.519)
PORT	−7.584*** (−5.583)	−4.056*** (−3.323)	−8.517*** (−4.047)	−5.145*** (−3.386)
PAF	0.041 (0.92)	0.019*** (5.113)	0.081 (1.613)	0.046*** (5.484)
Sample size	83	83	83	83
Alpha	0.384	0.262	0.419	0.344
Alpha confidence interval	(0.497,0.271)	(0.339,0.185)	(0.621,0.216)	(0.458,0.23)
Constant	−3.498*** (−5.076)	−5.762*** (−9.002)	−8.429***(−9.085)	−8.023***(−9.903)

Note: ***, *, * represent 1%, 5%, and 10% significance levels; Z-values in parentheses.

Regression model results for general manufacturing enterprises

In 2009, distance to main ports, financial support, and openness level are the main factors driving the spatial evolution of Fujian's manufacturing industry. PORT, FIN, and OPEN all pass the significance tests at the 1% level, with PORT having a significantly negative regression coefficient, while the other two show positive coefficients. This indicates that Fujian's manufacturing industry has a strong port orientation and FDI dependence, which are closely related to its outward-oriented economy. In 2009, the external dependency rate of Fujian's economy reaches 45.54%, and coastal manufacturing mainly relies on exports. Financing support has a significantly positive effect coefficient, suggesting that a good financing environment is an important factor affecting the spatial agglomeration of manufacturing industries. Population, industrialization degree, and transportation accessibility are important factors influencing the spatial evolution of Fujian's manufacturing industry. PDEN, INDUS, and TRA all pass the significance tests at the 5% level, showing positive regression coefficients. This indicates that population density, labor force availability, industrialization level, and structural integrity, as well as transport accessibility, have positive effects on the development and agglomeration of manufacturing industries. The number of economic development zones, economic development levels, and patent R&D do not show significant effects on the spatial evolution of Fujian's manufacturing industry, possibly owing to their close relationship with high reliance on FDI. Foreign capital policy incentives offset the benefits brought by economic development zones, weakening innovation drive. Labor cost does not show significant effects on the spatial evolution of Fujian's manufacturing industry, contrary to previous studies. This is mainly because it is associated with the mountainous and hilly terrain along the coast. Although inland areas have low labor costs, they lack advantages compared with coastal regions in terms of sea freight convenience, completeness of the industrial structure, and labor force availability.

The results of the regression model for general manufacturing in 2021 are significantly different from those in 2009. Except for openness level, which is not significant, the other nine variables have a significant effect on the spatial evolution of Fujian's manufacturing industry. Among them, only DPA passes the significance test at the 5% level, while the others pass the significance test at the 1% level. Although distance to major ports remains the most important factor, the regression coefficient changes from −7.58 to −4.056, indicating that the influence degree has decreased. Moreover, openness level does not show a significant effect, suggesting that the port orientation and FDI dependence of Fujian's manufacturing industry have declined. According to calculations, the external dependence of Fujian's manufacturing industry in 2021 was only 37.80%, a decrease of about 8 percentage points from 2009. The second to fifth most influential factors are industrialization level, population size, transportation accessibility, and financial support strength. Among them, industrial structure has become increasingly prominent, with a regression coefficient of 2.448. This indicates that new enterprises tend to be located in related industry areas to reduce investment risks and improve production efficiency, while relevant industry clusters have also become more obvious. Labor cost is significantly positively correlated, with a regression coefficient of 0.266. This indicates that as the "population dividend" gradually disappears, the shortage of manufacturing workers has an increasing influence on the manufacturing sector. Only by increasing wages can enough workers be recruited. This also indicates that places with richer human resources more easily attract the clustering of manufacturing enterprises, whose regression coefficient reaches 1.722 and passes the significance test at the 1% level. The number of development zones begins to produce a significant positive effect. This indicates that after rectifying FDI-funded enterprises' super-national treatment and development zone chaos, infrastructure and policy dividends, such as tax exemption, financing support, and labor subsidy, attract manufacturing enterprises to settle. The patent application variable passes the significance test at the 1% level. This indicates that with the development of manufacturing and complex competition between countries, it is difficult to obtain advanced technology through "borrowing," and technological progress tends to derive from original innovative ability.

Regression model results for innovative manufacturing enterprises

In 2009, distance to main ports, industrialization level, population size, and financial support are the core factors affecting the spatial evolution of innovative manufacturing in Fujian. All four variables (PORT, INDUS, PDEN, and FIN) pass the significance test at the 1% level. Similar to general manufacturing enterprises, PORT also has the strongest effect on the spatial evolution of innovative manufacturing enterprises. Larger regression coefficients indicate that these enterprises are more dependent on international markets and have a stronger port orientation. Financing support is significantly positive but with a slightly enlarged coefficient. This suggests that an easy financing environment can promote enterprise investment in technological innovation. The difference lies in higher significance levels for INDUS and PDEN, as well as higher regression coefficients. This indicates that regions with higher industrialization levels, better industrial structures, and richer human resources have a stronger capacity for technological innovation. Openness level and transportation accessibility are important factors influencing the spatial evolution of innovative manufacturing enterprises in Fujian. Compared with general manufacturing enterprises, the significance level and coefficient of OPEN decrease, while the effect of PAF on innovation capability is not significant. This indicates that domestic innovative enterprises' technological innovation capabilities have benefited from the technology spillover effects of FDI-funded enterprises to some extent, and their original innovation capabilities need further strengthening. Additionally, the number of development zones, regional economic development level, and labor cost have no significant effect on the spatial evolution of innovative enterprises in Fujian Province.

The results for the innovative manufacturing regression model in 2021 are significantly different from those in 2009. Among 10 variables, only openness and regional economic development level have a significant effect on the spatial evolution of Fujian's manufacturing industry. Among the eight other variables, only INDUS passes the significance test at 5%, while others pass at 1%. However, compared with general manufacturing industries in 2021, there is little difference except that the significance levels and coefficients of DPA and PAF increase, while those of INDUS decrease. This indicates that after more than 10 years of rapid development, Fujian's manufacturing industry has gradually occupied leading positions in some fields, such as modern textiles, new-energy batteries, and automobile glass. This means that enterprises' product value will more rapidly shift toward high added value from low added value. Moreover, innovation models have also transitioned from imitative and cooperative innovation to independent innovation and knowledge innovation, requiring higher original innovation ability. These results correspond well with the fact that PAF becomes highly significant; its coefficient greatly exceeds those of general manufacturing industries, and OPEN does not become highly significant. At the same time, the attractiveness of industrial parks increases, and the influence of industrial structure decreases, indicating that innovative enterprises need greater agglomeration effects and information and knowledge demand.

RESULTS

Taking data for manufacturing enterprises in Fujian Province from 2009 to 2021, we use SDE, spatial autocorrelation, kernel density, and negative binomial regression to study the spatial distribution pattern of Fujian's manufacturing industry and the related factors. The main conclusions are as follows: 1) The spatial distribution of manufacturing enterprises in Fujian is uneven and tends to be concentrated on the southeast coast of Fujian Province. Most are distributed along a coastal urban belt centered on Ningde, Fuzhou, Quanzhou, Xiamen, and Zhangzhou. The proportion of inland enterprises has slowly declined since 2009. Since then, general manufacturing has been centered on Quanzhou–Xiamen, while innovative manufacturing centers have shifted from Xiamen to Quanzhou. 2) The samples of general and innovative manufacturing enterprises both show significant spatial agglomeration characteristics. There are large hotspot areas centered on Xiamen–Zhangzhou–Quanzhou and medium hotspot areas centered on Fuzhou. However, innovative manufacturing shows stronger polarization and diffusion phenomena. 3) In terms of spatial evolution trends, both general and innovative manufacturing firms gradually evolve from "point-axis" to "point-cluster," where the coastal axis continuously links up and diffuses into cluster belts, while the scattered point distribution patterns remain unchanged in the interior area. However, innovative enterprises exhibit stronger spillover effects. 4) The regression results indicate that the distance to ports, industrialization level, financial support, transportation accessibility, and population size significantly affect different sequences and types at different times, but the coefficient of distance to ports decreases sharply. External development level changes from having a significant positive effect to not have an effect. Labor cost, number of development zones, and patent R&D change from having no effects to having significant positive effects. The number of patents and development zones have more significant coefficients for innovative manufacturing enterprises. Moreover, the economic foundation has an insignificant effect.

DISCUSSION

Compared with other coastal areas in eastern China, Fujian's manufacturing industry has rapidly gathered along the coast and has expanded. In the complex domestic and international environment after COVID-19, the sustainable development of Fujian's manufacturing industry still has a long way to go. First, we should continue to strengthen the maritime strategy; leverage the role of the Maritime Silk Road; establish multilevel land, sea, and air transport systems; and become further integrated into global industrial chains. At the same time, we should focus on improving inland areas' export paths for manufacturing industries and reduce the negative effects caused by being far away from ports. Second, clustering is important for technological innovation. We should scientifically integrate various levels of development zones; improve infrastructure, preferential policies, and the financial market system; and guide manufacturing development zones toward intensive, clustered, high-end development. Third, we should provide a more favorable environment and conditions for scientific and technological innovation. Cultivate high-quality laborers; talent is the driving force of innovation. Universities and research institutions should optimize the construction of basic and frontier disciplines by integrating science education and talent training mechanisms. Coordinate tax, finance, and fiscal policy support; encourage enterprises to increase R&D investment; enhance the core competitiveness of industrial chains; protect intellectual property rights; promote close integration between academia, industry, and research; and accelerate the conversion efficiency of scientific research results. Fourth, pay attention to the overall design of the manufacturing industry chain, overcome administrative barriers between regions, promote the free flow of all types of factors, and promote the coordinated innovative development of each region's manufacturing industry. Fifth, we should manage the psychological well-being of workers to alleviate anxiety caused by industrial competition. A healthy mindset is crucial for the development of the manufacturing industry

This study does have some limitations. First, regarding the time frame, since this study focuses on the spatial patterns and related factors of general and innovative manufacturing enterprises under the global reshaping of manufacturing, we only use data from 2009 to 2021 for negative binomial regression analysis. We do not involve a longer time series. Second, regarding factors, owing to the difficulty of obtaining data, factors such as industrial land costs and environmental factors are not included. Many studies have shown that those two factors are also important. More in-depth research will be conducted in the future after collecting more comprehensive data.

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REFERENCES

[1] JIANG H, LI Y. Change of spatial structure of manufacturing industry in the Beijing-Tianjin-Hebei region and its driving factors. Progress in Geography, 2021, 40(5): 721-735, doi: 10. 18306/dlkxjz.2021.05.001.

[2] MA X, ZHANG Z, GONG W, et al. Spatial pattern evolution and driving factors identification of manufacturing industry in Lanzhou. Scientia Geographica Sinica, 2023, 43 (3) : 51 9-529, doi:10.13249/j.cnki.sgs.2023.03. 014.

[3] ZHU D, CHANG H. Marxist economic research on the hollowing out of industry. Contemporary Economic Research, 2020 (11) : 15 -25, doi:10.3969/j.issn.1005-2674.2020.11.00 3.

[4] Fujian Provincial Bureau of Statistics Fujian Statistical Yearbook. Beijing: China Statistical Publishing House, 2010-2022.

[5] LUO C, ZHENG B, LIU L. Spatial evolution and influencing factors of the manufacturing industry on metropolitan areas: A case study of Changsha. Tropical Geography, 2022, 42 (5) :773-787, doi:10.13284/j. cnki.rddl.00348 4.

[6] HOLL A. Manufacturing location and impacts of road transport infrastructure: Empirical evidence from Spain. Regional Science and Urban Economics, 2004, 34 (3) : 341-363, doi:10. 1016/S0166-0462(03)00059-0.

[7] NAKAMURA R. Agglomeration economies in urban manufacturing industries: A case of Japanese cities. Journal of Urban Economics, 2006, 17 (1) : 108-124, doi:10.1007/s00168-0 14-0627-z.

[8] SRIDHAR K, WAN G. Firm location choice in cities: Evidence from China, India, and Brazil. China Economic Review, 2010, 21 (1) : 11 3-122, doi:10.1016/j.chieco.2009.11.003.

[9] WALKER R. Industry builds the city: The suburbanization of manufacturing in the San Francisco Bay Area, 1850-1940. Journal of Historical Geography, 2001, 26 (1) : 36-57, do i:10.1006/jhge.2000.0268.

[10] LEE K. Intra-urban location of manufacturing employment in Colombia. Journal of Urban Economics, 2010, 9 (2) : 222-241, doi:10.1016 /0094-1190(81)90042-5.

[11] VERNON R. International investment and investment trade in the product cycle. Quarterly Journal of Economics, 1966, 80 (2) : 190-207, doi:10.1002/tie.5060080409.

[12] SMITH D, FLORIDA R. Agglomeration and industrial location: An econometric analysis of Japanese affiliated manufacturing establishments in automotive-related industries. Journal of Urban Economics, 1994, 36 (1) : 23-41, doi:10.1006/juec.1994.1024.

[13] WHEELER D, MODY A. International investment location decisions: The case of US firms. Journal of International Economics, 1992 (33) : 57-76, doi:10.1016/0022-1996(92) 90050-T.

[14] HE C, HU X. Evolution of Chinese industrial geography since reform and opening-up. Acta Geographica Sinica, 2019, 74 (10) : 1962-197 9, doi:10.11821/dlxb201910002.

[15] SHI M, YANG J, LONG W, et al. Changes in geographical distribution of Chinese manufacturing sectors and its driving forces. Geograph ical Research, 2013, 32 (9) : 1708-1720, doi:10.11821/dlyj201309013.

[16] LIU H, FAN J, ZHANG H, et al. Dynamics of manufacturing industry and change of its spatial pattern in the Pearl River Delta urban agglomeration. Progress in Geography, 2020, 39 (2) : 195-206, doi:10.18306/dlkxjz. 2020.02.0 02.

[17] ZHANG J, TANG G. Spatial differentiation pattern of manufacturing industry in Zhejiang and its influencing factors. Scientia Geographica Sinica, 2018, 38 (7) : 1107-1117, doi:CNK I:SUN:DLKX.0.2018-07-012.

[18] CHEN N. Labor intensive industries change with the times. Textile Science Research, 2020 (08): 18-19, doi:CNKI:SUN: JJYD. 0.2014-06 -022.

[19] CHEN S, CHEN J, WEI S. The integrated transportation accessibility in Fujian Province and its correlation with the spatial distribution of manufacturing. Scientia Geographica Sinica, 2012, 32 (7) : 807-815, doi:10.13249 /j. cnki .sgs.2012.07.807.

[20] ZENG L, WEI S, GENG J. The analysis of spatial structure and its change of manufacturing in Fujian. Economic Geography, 2011, 31 (10) : 1680-1685, doi:CNKI:SUN:JJDL.0.201 1-10-015.

[21] WANG C, LIU S, CHEN Y. The evolution characteristics of the industry spatial structure in Fujian Province based on the enterprise location. Journal of Changchun Normal University, 2018, 37 (10) : 101-105, doi:CNKI:SU N: CCSS.0.2018-10-023.

[22] ZHU Meiqi, Zhai Guofang. Analysis of spatiotemporal differentiation and influencing factors of high-tech enterprises in new cities: taking five new cities in Shanghai as an example. Shanghai Urban Planning, 2021 (6): 134-144, doi:10.11982/j. supr. 20210619.

[23] YAN D, WU Q. Spatial-temporal Evolution and Driving Factors Study of the Growth of High-tech Enterprises in the Yangtze River Delta. Journal of Nantong University (Social Sciences Edition), 2020, 36 (4): 41-49, doi:10. 3969/j.issn.1673-2359.2020.04.006.

[24] XION F, REN J, WU M, etc. The Spatiotemporal Evolution and the Influence Mechanism of High-Tech Enterprise Locations in China during the Twenty-First Century. Economic Geography, 2018, 38 (2): 27-35, doi:10.15957 /j.cnki.jjdl.2018.02.004.

[25] SUN Y. Thoughts on the Development of National Advertising Industry Parks: Based on the Theory of Industrial Agglomeration. Today Media, 2022,30 (02): 16-19, doi:10.3969 /j.issn.1672-8122.2022.02.006.

[26] HE C, WEI H. Information Cost, Agglomeration Economy, and the Location of Foreign Investment in China China Industrial Economy, 2001 (9): 38-45, doi:10.3969/j.issn.1006 -480X.2001.09.005.

[27] XU W, ZHANG X, LIU C. Spatial distribution pattern and influencing factors of manufacturing enterprises in Yangtze River Delta: Scale effects and dynamic evolution. Geographic Research, 2019, 38 (05): 1236-1252, doi: 10. 11821/dlyj020170859.

[28] ZHANG X, LIU W. Role of Development Areas in Urban Spatial Changes in China: Types and Dynamics. Geographic Science, 2003 (2): 142-149, doi:10.3969/j.issn.1000-0690.2003. 02.003.

[29] T Ozawa. Pax Americana-led macro-clustering and flying geese style catch up in East Asia: mechanisms of regionalized endogenous growth. Journal of Asian Economics, 2003,13(6):699-713, doi:10.1016/S1049-0078 (02)00180-X.

[30] YANG H, SUN L, WU A. Research on Changing Trend of China's Manufacturing Industrial Agglomeration Degree and Its Affecting Factors. China Industrial Economics, 2008 (4): 64-72, doi:CNKI:SUN:GGYY.0.2008-04-007.

[31] Fujita M. Towards the new economic geography in the brain power society. Regional Science and Urban Economics, 2007, 37(4):482-490, doi:10.1016/j.regsciurbeco.2007.04.004.