

Article

Spatial Agglomeration of Manufacturing in the Wuhan Metropolitan Area: An Analysis of Sectoral Patterns and Determinants

Lei Luo ^{1,2,*}, Zhenhua Zheng ¹, Jing Luo ², Yuqiu Jia ^{1,3}, Qi Zhang ^{1,4} , Chun Wu ¹, Yifeng Zhang ¹ and Jia Sun ¹

¹ Wuhan Land Use and Urban Spatial Planning Research Center, Wuhan 430014, China; zhengzhenhua@wlsp.org.cn (Z.Z.); hnun2011@126.com (Y.J.); hzbq007@gmail.com (Q.Z.); WuChun@wlsp.org.cn (C.W.); zhangyifeng@wlsp.org.cn (Y.Z.); sunjia@wlsp.org.cn (J.S.)

² School of Sociology, Central China Normal University, Wuhan 430070, China; luojing@mail.ccnu.edu.cn

³ School of Urban Design, Wuhan University, Wuhan 430072, China

⁴ The College of Architecture and Urban Planning, Tongji University, Shanghai 200092, China

* Correspondence: luolei@126.com; Tel.: +86-027-6877-5699

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Abstract: The important role of the entity economy, especially manufacturing, has been further highlighted after the outbreak of COVID-19. This study fills a research gap on manufacturing in the Wuhan Metropolitan Area by analyzing the spatio-temporal evolution patterns and characteristics of manufacturing, exploring the major location factors causing spatial reconstruction and comparing the effect intensities of the different factors in the manufacturing sector. From 2003 to 2018, the process of industrial suburbanization in the Wuhan Metropolitan Area continued to strengthen and currently the overall spatial pattern of manufacturing in the Wuhan Metropolitan Area is characterized by spreading in metropolitan areas and aggregation in industrial parks. The results of a spatial metering model showed that the dominant factors affecting the layout of manufacturing included innovation and technical service platforms, industrial parks, the number of large enterprises, living convenience, and air quality. However, the effect intensity of the different location factors varied among industries. The findings may help the government to understand the characteristics of agglomeration and spreading in the manufacturing industry and, in accordance with the dominant factors affecting the location of this industry, rationally develop ideas for adjusting the industrial layout in the post-coronavirus age.

Keywords: manufacturing agglomeration; spatio-temporal evolution patterns; negative binomial regression model; location patterns; location factors; industrial geography; Wuhan Metropolitan Area

1. Introduction

As manufacturing plays a leading role in the real economy, Western developed countries tend to have developed “remanufacturing strategies” after the financial crisis of 2007–2008 in an effort to consolidate “state economic sovereignty”. The year 2019 witnessed the outbreak of COVID-19, which led to an urgent demand for anti-epidemic materials, including masks and ventilators, which further highlighted the essential role of the manufacturing entity. In Wuhan, China, as the “eye of the storm” of the pandemic, it is important to determine the optimal way to adjust and optimize the industrial layout of manufacturing. Against the background of the COVID-19 outbreak, it is particularly meaningful to further study the spatial characteristics and factors affecting the location patterns of manufacturing in the Wuhan Metropolitan Area. This paper argues that such research can assist policy makers in effectively

guiding the spatial agglomeration and spread pattern of manufacturing in the “post-coronavirus age” so as to optimize spatial structures and functional systems.

Manufacturing agglomeration serves as an important driving force for remodeling urban spaces [1]. Its production, agglomeration [2], and the dynamic evolution process of spread directly enhance the urban economy [3] and changes in spatial patterns [4]. In return, the reshaped urban space further promotes the reform and innovation of industrial forms [5], enlarges scales [6], and accelerates the transformation and upgrading of structures [7], thereby optimizing the spatial structures and functional systems of cities and regions [8]. In the past 20 years, with the revival of new urban regionalism [9–11], metropolitan areas have become an essential space carrier in the development of the manufacturing industry. Moreover, with the transformation and upgrading of urban functional systems, the development of the manufacturing industry is becoming significant for the spatial reorganization of manufacturing clusters, showing an obvious clustering and suburbanization tendency [12]. New requirements have been listed for industrial selection and location patterns [13]. Additionally, changes have occurred in the factors affecting manufacturing agglomeration and location migration [14], which has generated new patterns of urban spatial structures.

Since the 1990s, the spatial agglomeration of manufacturing has become a hot topic in the industrial economy, spatial economy, and other economic areas. Most research focuses on the evolution and dynamic mechanism of spatial patterns of manufacturing enterprises [15], location selection and the spatial agglomeration of manufacturing [16,17], and urban spatial reconstruction [18]. Besides, other scholars have explored the migration characteristics and models and mechanisms [19] of manufacturing enterprises from the perspectives of industry classification [20] and industry agglomeration [21]. Since 2015, researchers have tended to focus on the mechanisms affecting the location of newly built manufacturing enterprises, environmental impacts (carbon emissions and smog) [22], and the relationship among producer services [23].

In China, there has been a major impetus to drive the spatial reconstruction of cities through spatial agglomeration and the spread and suburbanization of manufacturing [24]. Most studies have focused on related industries in China’s first-tier cities (e.g., Beijing, Shanghai, and Guangzhou) [25–27]. However, relatively few studies have explored location changes of manufacturing enterprises and dynamic mechanisms of urban spatial reconstruction according to the perennial micro-data of enterprises. Additionally, it is necessary to carry out further empirical research based on practices of industrial activities in specific cities so as to continuously enrich and improve theoretical frameworks. Thus, this study fills the gap on the Wuhan Metropolitan Area and analyzes case studies to investigate the interaction between the spatial reorganization of manufacturing and urban functions in this metropolitan area. We explored the spatial and temporal patterns using multi-source big data for 20 years, and in order to face new requirements and changes, innovatively focused on the impact of urban environmental impact factors on manufacturing agglomeration and spread in the Wuhan Metropolitan Area.

Taking the Wuhan Metropolitan Area as an example, this paper mainly addressed two questions: (1) What are the characteristics and processes of the spatio-temporal evolution of manufacturing companies in the Wuhan Metropolitan Area between 2003 and 2018? (2) What factors affect the agglomeration and diffusion of manufacturing in the Wuhan Metropolitan Area? This paper is composed of the following parts: Firstly, it gives a brief introduction to the research background, including the existing theories and research results; secondly, it describes the research scope, the methodology, and models used, and builds three major indicator systems—market-driving, government-driving, and urban-supporting; thirdly, it analyzes the spatio-temporal distribution patterns of the manufacturing industry in the Wuhan Metropolitan Area between 2003 and 2018, and examines the factors affecting the agglomeration and spread of manufacturing in this area; lastly, it presents conclusions, and additionally gives policy recommendations to cope with the post-coronavirus age.

2. Theoretical Background

2.1. Industrial Agglomeration and Spatial Effect

The agglomeration economy was first researched in the late 19th century by the British economist Marshall, who found that the agglomeration of the same industry facilitated knowledge spillover and technology spread among enterprises, thereby enabling the industry to prosper in cities. Additionally, he discovered that the agglomeration economy was the product of shared labor pools, input–output connections, and knowledge spillover. In the 1990s, industrial agglomeration was incorporated into the traditional analytical framework in the theory of new economic geography [28,29]. More recently, scholars have started to pay attention to the spatial effect of the agglomeration economy [30,31].

The spatial agglomeration process of manufacturing, generally called the “cumulative causation effect”, can be explained by changes in scale economy and transportation costs in the new economic geography [32]. According to the theory of new economic geography, this paper initially proposes an analytical framework for the spatial agglomeration and pattern evolution of the manufacturing industry: Due to scale economy, manufacturing first gathered in more developed central areas and pursued higher profits, leading to a spatial spillover effect [33–36]; in other words, central enterprises created external economies for peripheral enterprises. When the central and peripheral areas had developed to a specific stage, the manufacturing development in central areas faced congestion, so that constraints on the costs of transportation and production increased, which caused the development of manufacturing in the center to slow down and caused manufacturing to spread to peripheral areas. However, affected by the spatial spillover effect from central urban areas, peripheral manufacturing developed greatly and gradually caught up with the levels in central areas, which reflected the spatial convergence effect [37]. Thus, manufacturing spread to a larger peripheral area, showing a spatial pattern in which the core of the manufacturing spread from the center to multiple peripheral centers. This paper shall verify and enrich the theoretical analysis framework of the spatial agglomeration and pattern evolution of the manufacturing industry.

In the past five years, numerous empirical studies on industrial agglomeration have been conducted in academic circles in order to respond to the development of globalization, the fast adjustment and development of industrial structures, and their spatial agglomeration models. Relevant research includes (1) the tendency of regional industrial development and agglomeration and related factors [38,39]; (2) the relationships between the industrial agglomeration level and (i) economic development [14,40] and (ii) global value chains [41]; and (3) the relationships between the agglomeration level and (i) environmental pollution [42], (ii) carbon emissions [43,44], and (iii) productivity [45,46]. In recent years, it has been popular in academic circles to study how the ecological environment is affected by manufacturing agglomeration. According to some scholars, after reaching a certain development stage, industrial agglomeration gradually produced a negative externality, bringing about serious environmental pollution and environmental pollutants [47]. Meanwhile, several researchers held that industrial agglomeration helped alleviate environmental pollution and that the technological spillover effect allowed enterprises to extensively apply clean technologies, which was conducive to reducing energy consumption and pollution emissions [48]. The relationships between manufacturing agglomeration and environment will be discussed further later in this paper.

2.2. Location Theory and Location Factors

Enterprise location theory was first proposed in the Agricultural Location Theory of Thunen (1826), who proposed the concept of “Von Thunen’s circles”, with the city as the center and focused on the minimum transportation cost of important locations. Subsequently, Fetter (1924) and Christaller (1933) stated that dominated market demand was an essential factor to select locations for enterprises, which created a precedent for the market theory of location theory. Representatives of the location theory of industrial enterprises include Weber (1929), who theorized that places with minimum cost of raw materials, labor, and freight is the optimal location for enterprises; Palander (1935), who theorized

that enterprises emphasize the smallest sum of production expenses; and Losch (1939), who theorized that the best location for enterprises should be places with maximum profit acquired. Additionally, Ohlin (1933) pointed out in the Heckscher–Ohlin theory that different resource endowments in regions affected location choices. Moreover, the innovation theory developed by Schumpeter (1912) incorporated production factors and production conditions into the production system and influenced the location of enterprises through technological and institutional innovation. Furthermore, according to Hoover (1937), locations were determined after taking into account factors such as the natural environment, political environment, and cultural environment. Subsequent theories addressed the impact of non-economic factors on industrial locations, with representative theories including Smith's location profit marginal boundary theory and Pred's behavioral matrix.

Research has discussed the impact on enterprise location of the market, government, and globalization [49]. Undoubtedly, China's fast development in the past 30 years can be attributed to market, local, and global impetuses that drove the real economies, such as the manufacturing industry to change production locations, thereby reshaping economic–geographic structures in the country [50]. However, market competition mechanisms have failed to remove the influence of the government [51]; marketization transformation is far from complete, and decentralization has created chances for local governments to intervene in the economic activities of enterprises [52,53]. Moreover, in order to encourage enterprise transfer, local governments might accelerate industrial upgrading and adjustment by issuing a series of policies, including the construction of industrial parks, tax and credit policies [15], cheap industrial land, or stricter environmental regulations and policies [54]. Meanwhile, they could attract enterprises by improving the urban environment. According to existing studies, the quality of life [55] and the environment of neighborhood communities [56] in cities have played a crucial role in migration decisions.

Whereas most research have focused on the impact of market and government on enterprise locations [57,58], few studies have explored the impacts of urban environmental impact factors on the agglomeration and spread of the manufacturing industry. In this paper, on the basis of traditional market and government factors, urban environmental impact factors were constructed in accordance with relevant theories, existing literature, and available data. Furthermore, a count model was applied to analyze the impact factors of spatial layout for manufacturing enterprises in the Wuhan Metropolitan Area in order to study the micro-mechanism of urban spatial reconstruction.

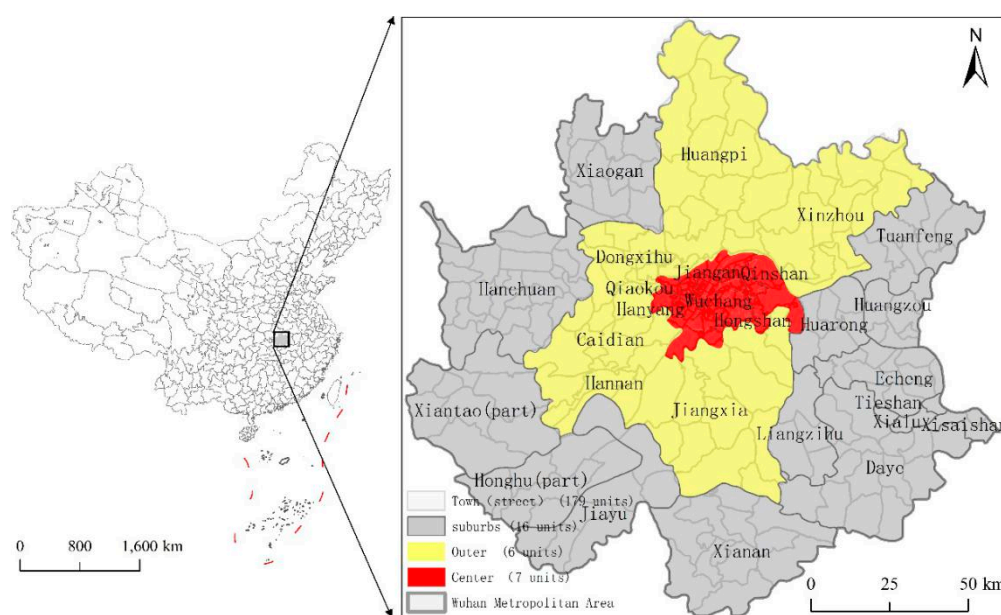
3. Materials and Methods

3.1. Study Area

In this paper, the research scope was the Wuhan Metropolitan Area defined by the Overall Urban Planning of the Wuhan Metropolitan Area (2017–2035) (Figure 1), which contains three areas: the central city, the outer city, and the suburbs (Table 1), including a total of 29 districts and 179 minimum administrative units at the town (street) level. It is worth mentioning that, in the administrative division of China, a street and town have the same administrative level; therefore, in this paper, the research units of street and town are considered to have the same level for statistical analysis. The Wuhan Metropolitan Area, with Wuhan as the leading city, is a region of coordinated economic development with surrounding areas according to the factors of industrial connection, geographical location, and other factors. It has the general characteristics of metropolitan areas in Western countries; that is, metropolitan areas are generally 60–80 km in radius and have a commuting circle of one hour [59,60]. In 2017, the Wuhan Metropolitan Area covered an area of around 21,000 km² and had a population of about 18 million.

Table 1. Zoning of the Wuhan Metropolitan Area.

Areas	Districts
Central	Jiang'an, Jianghan, Qiaokou, Hanyang, Wuchang, Qinsan, Hongshan
Outer	Dongxihu, Hannan, Caidian, Jiangxia, Huangpi, Xinzhou
Suburbs	Xiaonan, Hanchuan, Part of Xiantao, Part of Honghu, Jiayu, Xian'an, Daye, Liangzihu, Tieshan, Huangshigang, Xisaishan, Huangzhou, Tuanfeng, Huarong, Xialu, Echeng

**Figure 1.** Zoning of the Wuhan Metropolitan Area.

3.2. Data Collection

Enterprise data for 2003, 2008, 2013, and 2018 for manufacturing enterprises of medium size and above (main operation income of at least RMB 20 million) were obtained from the China Industry Business Performance Data of the National Bureau of Statistics. In order to avoid statistical errors, the locations of the enterprises were identified based on the subordinate provinces (prefecture-level cities and counties), postal code, administrative division code and name, address, and other multi-dimensional information. The API console of Baidu Maps and the Geocoding tool (<http://lbsyun.baidu.com/index.php?title=web-api/guide/webservice-geocoding>) were used to analyze the manufacturing enterprises data in batches; the latitude and longitude of the enterprises were converted to GCS_WGS_1984 coordinates and were then matched with a township vector map of the Wuhan Metropolitan Area. According to the industry classification standard of the National Bureau of Statistics (GB/T4754-2017), the number of manufacturing enterprises of medium size and above in the Wuhan Metropolitan Area was 2367, 4051, 4551, and 4904 for the years 2003, 2008, 2013, and 2018, respectively.

The manufacturing industries were classified into 31 sectors according to the national industries classification standard (GB/T4754-2017). Since some changes were made to the classification between the different study years, this paper makes some adjustment to ensure the consistency (see footnote of Appendix A: Table A1). The 31 industries were divided into four types according to the contribution of labor, capital, technology, and resource elements. The results are shown in Appendix A: Table A1.

3.3. Methods

3.3.1. Moran's I

A total of 197 rural towns (streets) in the Wuhan Metropolitan Area were used as the calculation units, and the numbers of manufacturing enterprises in each town was calculated using the ArcGIS10.4 Spatial Statistics toolbox. Moran's I index was used to verify the overall spatial agglomeration of manufacturing in the Wuhan Metropolitan Area [61,62]. The index is defined as follows:

$$I = \frac{\sum_{i=1}^n \sum_{j=1}^n W_{ij} (X_i - \bar{X})(X_j - \bar{X})}{S^2 \sum_{i=1}^n \sum_{j=1}^n W_{ij}} \quad (1)$$

where X_i and X_j represent the number of manufacturing enterprises in the i -th and j -th towns, respectively; W_{ij} is the weight to measure spatial autocorrelation; X is the variable of interest; $\bar{X}$ is the mean of X ; and S^2 is the variance of X and $\bar{X}$. This method uses the Local Moran's I index to recognize the five spatial correlation modes that may exist at different spatial positions, namely high-high, low-low, high-low, low-high, and not significant. The positive high-high and low-low spatial correlation modes indicate significant spatial agglomeration, which also means that X_i is a high-value area, and the X_j surrounding its geographic space is also a high-value area, and vice versa.

3.3.2. Kernel Density

The global spatial autocorrelation analysis merely identified the spatial agglomeration characteristics of manufacturing in the Wuhan Metropolitan Area, rather than the distribution characteristics and forms in Wuhan City. The kernel density analysis was continuous and free from the length of the selected intervals. By endowing different weights to each element, it is possible to accurately visualize the spatial distribution of the point elements. Therefore, the kernel density estimation method was used [63], whose basic form is as follows:

$$f(x) = \frac{1}{nh} \sum_{i=1}^n K\left(\frac{x - x_i}{h}\right) \quad (2)$$

where $f(x)$ is the estimated value of f at x based on sample points; h is the bandwidth; $(x - x_i)$ is the distance between the estimated point and the sample point x_i ; and $K(z)$ is the kernel function. The Gaussian kernel function was calculated using the ArcGIS10.4 Spatial Analyst Tools, using the following formula:

$$K\left(\frac{x - x_i}{h}\right) = \frac{1}{\sqrt{2\pi}} e^{-\frac{(x-x_i)^2}{2h^2}} \quad (3)$$

3.3.3. Variables

The mechanisms that affect the location decision-making of enterprises are far from simple. In, this paper, it was deemed the location decision-making of enterprises was affected by the market, government, and urban environment. The explanatory variables of the selected Poisson regression model are described in Section 3.3.4 and the 16 independent variables are given in Table 2.

Market: The location decision-making of enterprises from the perspective of costs is mainly affected by the market economic mechanisms. In this paper, location accessibility was used to represent comprehensive transportation costs, land price was taken to mean factor input costs, and employee salary was taken to represent labor costs. Additionally, it was judged whether the transportation was convenient and accessible by measuring the distance from the center of towns (streets) to important transportation infrastructure, such as the center of Wuhan City (CBD Wuhan International Plaza), the East Lake Comprehensive Free Trade Zone (FTZ), Wuhan Tianhe International Airport (Airport), Wuhan Railway Station (Railway), and Yangluo Port (Port). The distance value was obtained using the

Euclidean distance calculation of the ArcGIS10.4 Spatial Analyst tools [64]. Additionally, the average salary of on-post staff was used to represent the variable of labor cost (Wage) in order to explore the impact of labor cost on the location patterns of manufacturing. Land cost is a significant component of factor cost [65], as well as transportation and labor costs. By introducing the land price variable (Land price) and referring to the division of benchmark land price levels (industrial purposes) in Wuhan, we divided land price into eight levels: Level 1 was the most expensive, with a value of 8, followed by Level 2, with a value of 7, and so forth until Level 8, which was the cheapest and had a value of 1.

Government policy: In consideration of the characteristics of the study area, the impact of government action mechanisms on spatial patterns of manufacturing was explored from four perspectives. First, two variables—innovation capability (number of universities and scientific research laboratories) and technical service platforms (number of technical service platforms)—were introduced to comprehensively investigate the innovation and entrepreneurial environment created by the government. Secondly, the development zone variable was introduced to examine how institutional factors (the planning and construction of development zones) guided the location of manufacturing enterprises. Specifically, a value of 5 was assigned to towns with national development zones, a value of 4 to towns with provincial development zones, a value of 3 to towns with municipal demonstration parks, a value of 2 to towns with municipal general parks and modern industrial parks, and a value of 1 to towns with high-tech small and micro enterprise parks; otherwise, a value of 0 was assigned. Thirdly, the variable “Fin”—investment and financing environment—was introduced to survey the financing environment of enterprises, which was mainly measured by the year-end balance of loans in financial institutions. Fourthly, tycoons (Leading) with an annual turnover of over RMB 10 billion were selected to study the impact of leading companies on the layout of manufacturing enterprises.

Urban environment: Since 2010, China’s emerging industries have developed rapidly, and new growth points have continued to emerge. In 2016, the State Council of China issued the “13th Five-Year Plan National Strategic Emerging Industries Development Plan”, which set the goal that the proportion of the added value of emerging industries should reach 15% of the country’s GDP by 2020. Emerging industries will become an important support for the manufacturing industry, while innovative talents and urban potential will become the primary choice for emerging industries. Therefore, it is highly necessary to introduce factors related to talents and the urban environment to study how the urban environment affects the location of emerging industries. The urban facilities are mainly represented by three factors: (1) the total number of point of interest (POI) living service facilities represents life convenience; (2) city prosperity is expressed by the total amount of social consumer goods in the statistical yearbook; and (3) environmental quality impact factors represented by the mean air concentrations of PM10 and PM2.5.

Table 2. Variables and definitions for the location of manufacturing enterprises.

Type	Variable	Sub-Variab	Definition	Source
Market	Accessibility	CBD	Distance to CBD	GIS spatial analysis tools were used to calculate Euclidean distance (this study)
		FTZ	Distance to East Lake Free Trade Zone	
		Airport	Distance to Tianhe Airport	
		Railway	Distance to Wuhan Railway Station	
		Port	Distance to Yangluo Port	
	Labor cost	Wage	Average salary of employees	National Bureau of Statistics
	Land market	Land price	Industrial land price	http://www.whtdsc.com/

Table 2. Cont.

Type	Variable	Sub-Variables	Definition	Source
Government policy	Innovation and entrepreneurial environment	Innovation	Number of universities and scientific research laboratories	http://kjt.hubei.gov.cn/
		Service Platform	Number of technical service platforms	http://www.hbsccloud.com/
	Institution	Development zone	Number of national, provincial and municipal industrial parks	http://jxt.hubei.gov.cn/
	Investment	Fin	Loans margin of financial institutions	National Bureau of Statistics
	Leading effect	Leading	Number of enterprises with annual turnover exceeding RMB 10 billion	National Bureau of Statistics
Urban environment	Convenience	Facilities	Number of shopping, dining, entertainment, accommodation, hospitals, elementary schools	Point of interest
	Prosperity	Goods	Total social consumer goods	National Bureau of Statistics
	Air quality	PM2.5	Annual average	Atmospheric monitoring stations
		PM10	Annual average	

3.3.4. Model

The negative binomial model has often been used to analyze factors influencing enterprise location [66]. The number of enterprises in each town (street) was discontinuous and had obvious discrete characteristics [67]. The model is as follows:

$$\begin{aligned}
 mi = & \beta_0 + \beta_1 \sum Accessibility_i + \beta_2 Laborcost + \beta_3 Landmarket + \beta_4 \sum Innandenv_i \\
 & + \beta_5 Institution + \beta_6 Investment + \beta_7 Leadingeffect + \beta_8 Convenience \\
 & + \beta_9 Prosperity + \beta_{10} \sum Airquality_i + \varepsilon_i
 \end{aligned} \quad (4)$$

where “mi” is the abbreviation for the entire manufacturing sector; β_1 – β_{10} are the coefficients of the above explanatory variables; β_0 is a constant term; and ε_i is the residual term.

In this paper, enterprises in each town (street) were selected as dependent variables, with 197 towns (street) as the basic unit to be studied, and the factors in Table 2 were selected as independent variables. There were 308 effective samples (Table 3). Before introducing the variables into the model, we firstly judged the correlation between the 16 independent variables. According to the calculated Pearson correlation coefficient, there was a significant correlation between the independent variable Land price and the CBD, Airport, and Railway. In order to remove multicollinearity, the above variables were respectively introduced into the regression model. First, assuming that the number of enterprises in each town (street) conforms to the Poisson distribution, the STATA14 software (<https://www.stata.com/stata14/>) was used to execute the Poisson regression; it was found that the mean and variance of the dependent variable are unequal (Appendix B: Tables A2 and A3); therefore, the STATA14 software was further used to select the negative binomial regression model fitting equation and the negative binomial regression was carried out through stepwise regression, with the confidence level set as 90%. The regression results of the negative binomial model for the whole manufacturing industry (Appendix B: Table A4), different industries, and different types of enterprises were obtained, respectively (Appendix B: Tables A5–A8), and the accessory parameter was significantly non-zero, which proved the rationality of using the negative binomial model in the estimates.

Table 3. Descriptive statistics of the research sample data.

Stats	Max	Min	Mean	SD	N
mi	238	0	22.22	35.49	197
CBD	126	6.1	62.24	29.34	197
FTZ	139.9	17.55	76.82	29.02	197
Airport	159.7	27.76	87.03	31.42	197
Railway	160.6	11	96.21	29.97	197
Port	179.1	36	113.4	31.88	197
Land price	1391	195.8	459.6	178.8	197
Wage	111,987	39,623	57,054	13,109	197
Development zone	10	0	0.35	1.171	197
Innovation	409	0	5.096	32.55	197
Fin	194	0	2.569	18.08	197
Service Platform	58	0	1.03	6.027	197
Leading	16	0	0.249	1.53	197
Facilities	23,325	8.05	655	2201	197
Goods	1100	0.75	39	135.2	197
PM2.5	71.35	59.61	65.73	3.077	197
PM10	96.58	72.66	82.53	4.145	197

4. Results

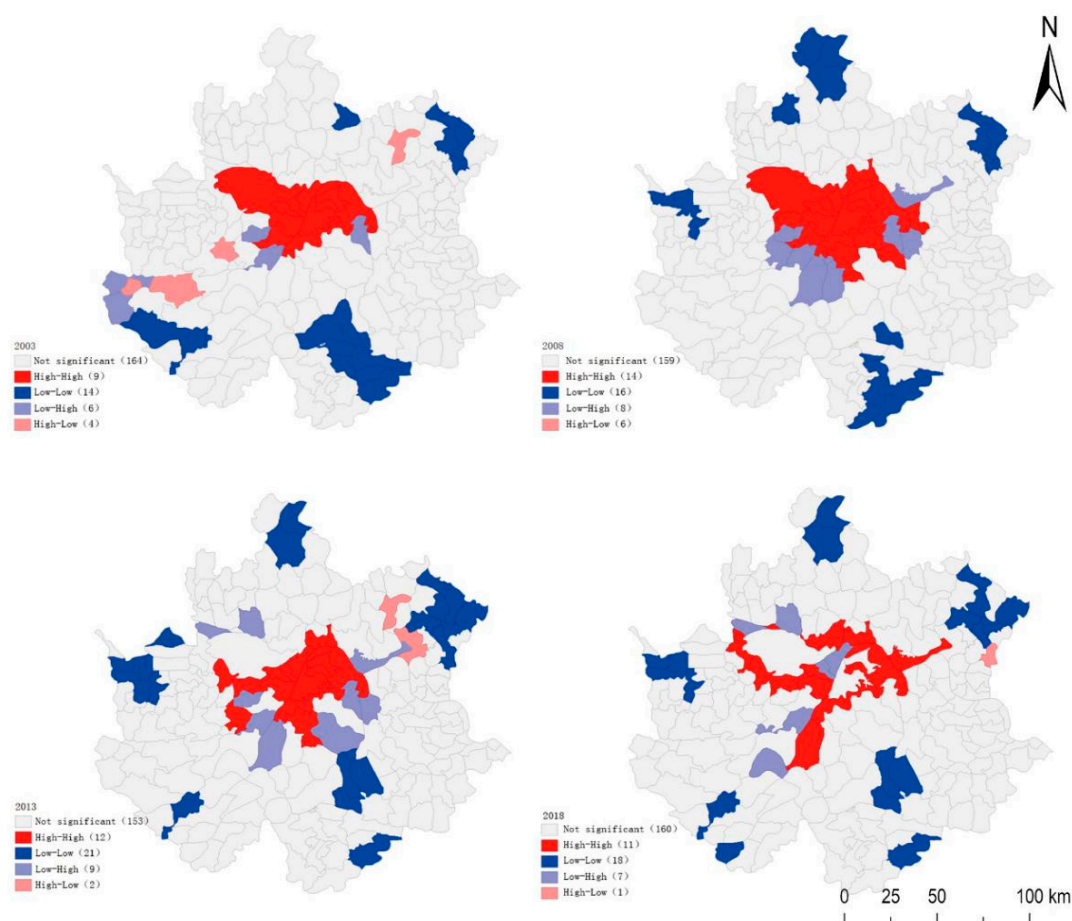
4.1. Temporal Evolution of Manufacturing Agglomeration

GeoDa1.14 software (<http://geodacenter.github.io/>) was used to calculate the Moran's I index for 2003, 2008, 2013, and 2018. All of the Moran's I indexes were greater than 0, and the normal statistics value Z was greater than the critical value (2.58) at the $p < 0.01$ significance level, indicating a significant positive autocorrelation in the spatial distribution of manufacturing in the Wuhan Metropolitan Area. As shown in Table 4, the correlation between manufacturing enterprises in the Wuhan Metropolitan Area and the space was firstly enhanced and then declined. This also implies that enterprises in the Wuhan Metropolitan Area did not rely on space so much, but rather attached great importance to technological innovation, talents, and industrial policy, etc. [68]. In summary, the results suggest that there was a spatial spillover effect in factors affecting the spatial layout of manufacturing enterprises in the Wuhan Metropolitan Area, which shall be further proved by the spatial Poisson regression model.

By further analyzing the spatial correlation of the manufacturing enterprises between 2003 and 2018 (Figure 2), we may find that in 2003 and 2008, urban centers were high-high agglomerations areas for manufacturing enterprises, and this was the legacy of developing a “production city” under the planned economy [69]. In 2013 and 2018, high-high agglomerations areas dispersed towards the periphery and new towns (streets), such as Guanshan, Zhifang, Zhuankou, Caitian, and Tianhejie. The potential reason is that these new towns were governmentally planned with priority given the development of manufacturing. Between 2003 and 2018, the low-low agglomeration areas mainly existed in suburban areas (e.g., Yaojiajie, Xugu, Xinyan, and Tujianao), which is because these towns are mainly agricultural areas. Outer periphery areas showed the agglomeration of low-high and high-low agglomeration, such as Shuangliu, Zhengdian, Jinkou, and Junshan streets. Manufacturing companies in these regions are distributed discretely, with large spatial differences. In addition, high-high and low-low agglomeration indicate the existence of two-pole agglomeration of manufacturing enterprises in space. It also implies the existence of spatial spillover effects in neighboring townships; that is, the development level of a certain township manufacturing industry depends on the development level of neighboring township manufacturing industries, which verified the theoretical analysis framework of the spatial agglomeration and pattern evolution of the manufacturing industry (2.1).

Table 4. Comparison of the Moran's I index of manufacturing enterprises in the Wuhan Metropolitan Area.

Year	2003	2008	2013	2018
Moran's I	0.342	0.401	0.208	0.120

**Figure 2.** Local indicators of spatial association of manufacturing enterprises in townships in the Wuhan Metropolitan Area in 2003, 2008, 2013, and 2018.

4.2. Manufacturing Suburban Agglomeration and Reconstruction is Significant

This paper further examines the spatial distribution characteristics of manufacturing by means of a kernel density estimation to explore the influence of urban centers, outer areas, and suburbs in 2003, 2008, 2013, and 2018, respectively. As shown in Figure 3, between 2003 and 2018, the manufacturing center of the Wuhan Metropolitan Area has gradually transferred from the urban center to the suburbs, and has expanded from a single center to multiple centers. In 2003, the manufacturing in the Wuhan Metropolitan Area displayed a “one-pole agglomeration” trend and tended to be spatially polarized. In 2008, the manufacturing center turned to Hongshan from Qiaokou. Later, in 2011, Wuhan issued the “Industrial Doubling Plan”, which accelerated the new industrialization, comprehensively promoted the transformation and upgrading of industry, and further facilitated the spread and suburbanization of manufacturing. In the same year, a spatial spillover effect was demonstrated, driving industrial development in Dongxihu, Caidian, and the surrounding Ezhou, Hanchuan, and Huangshi.

In 2013, the spatial distribution of the manufacturing industry was characterized by declining agglomeration in the central area, strong aggregation in the outer area, and slight aggregation in the suburbs. Enterprises spread quickly to the outer areas, which became the center of manufacturing. Furthermore, there were four manufacturing clusters in the four diagonal directions of east, west, south, and north, respectively, including the Qingshan Economic Development Zone, which is dominated

by iron and steel, chemical, and machinery manufacturing enterprises; the Wujiashan Economic and Technological Development Zone, which is dominated by food, clothing, and home appliances enterprises; the Wuhan Economic and Technological Development Zone, which is dominated by automobiles and parts and electrical equipment manufacturing; and the East Lake High-Tech Development Zone, which is dominated by optoelectronic information, biomedicine, modern equipment manufacturing, energy and environmental protection, and new materials enterprises. In 2018, manufacturing enterprises further spread to the east, west, south, and north with high density. In particular, manufacturing developed dramatically in the Wuhan–Ezhou–Huanggang–Xiaogan region due to structural advantages and competitiveness.

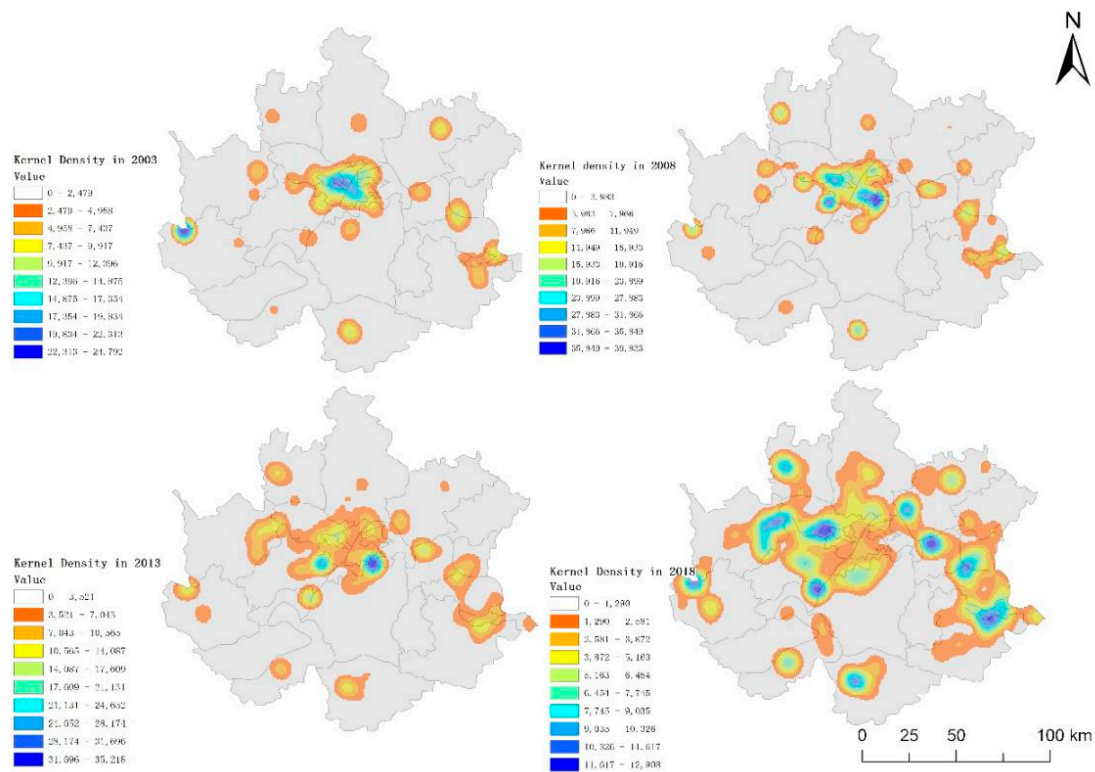


Figure 3. Kernel density of manufacturing enterprises in the Wuhan Metropolitan Area in 2003, 2008, 2013, and 2018.

According to the kernel density analysis of four major manufacturing industries (Figure 4), resource-intensive enterprises were mainly distributed in Daye and Huangshi, with the leading industry being non-ferrous metal metallurgy. Most labor-intensive enterprises were established in cities, and were mainly concentrated in Hanchuan City and the Qiaokou District of Hankou, showing a trend of large-scale agglomeration and dispersion. The largest number of high-tech enterprises were located in the Guanshan Subdistrict of the East Lake Technology Development Zone, followed by the Zhuankou Subdistrict of Hanyang. Moreover, the kernel density characteristics of the capital-intensive enterprises were basically consistent with those of the manufacturing enterprises in the Wuhan Metropolitan Area, signifying that capital-intensive heavy chemical enterprises laid the basic framework for spatial patterns of manufacturing. Capital-intensive heavy chemical enterprises gathered with high density in Qingshan and spread continuously towards the suburbs along the traffic axis.

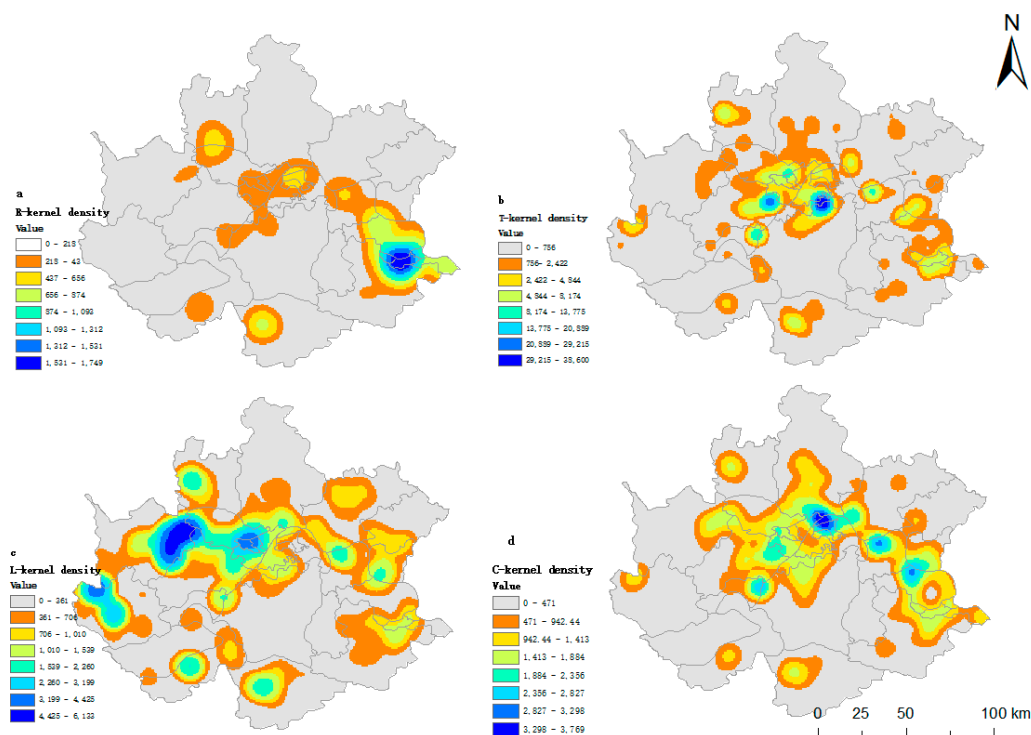


Figure 4. Kernel density of different types of manufacturing enterprises in the Wuhan Metropolitan Area in 2018: (a) kernel density of the resource-intensive industry (R); (b) kernel density of the technology-intensive industry (T); (c) kernel density of the labor-intensive industry (L); (d) kernel density of the capital-intensive industry (C).

4.3. Analysis of Factors Influencing Manufacturing Agglomeration

The regression results for all manufacturing enterprises signified that, after 2003, the traditional market driving factors were no longer key factors leading to the acceleration of agglomeration, and that, by contrast, enterprises preferred government policy and urban environmental factors more and more in layouts. According to the regression results (Table 5), factors including innovation and technical service platforms, industrial parks, number of large enterprises, life convenience, and PM2.5 passed the T-test at the 90% significance level, while all other variables did not produce significant effects.

Specifically, the location choice was significantly affected by innovation and technical service platforms factors, indicating that manufacturing enterprises tend to quarter in areas with competitive capabilities in innovation and technology conversion. According to the regression results, technical service platforms had a more significant impact on manufacturing agglomeration, passing the T-test at the 99% significance level; however, the regression coefficient is negative, indicating that the agglomeration of manufacturing enterprises is negatively correlated with the spatial distribution of technical service platforms. The reason for the negative correlation between the agglomeration of manufacturing enterprises and the spatial distribution of technical service platforms may be that the manufacturing industry has expanded to agglomeration in the suburbs, while technical services belonging to the producer service industry are mainly distributed in urban centers. Undoubtedly, innovation and technical service platforms directly reflect cities' innovative impetus and the driving force that facilitates the sustainable development of industrial transformation [70]. In 2018, Wuhan was equipped with 89 universities, 121 research institutions, 68 academics, 13 national-level laboratories, and the largest number of college students of any city in the world (about 1.3 million). Therefore, a good talent reserve, and a sound innovation and entrepreneurship environment were conducive to stimulating the innovative vitality and creativity of the market entities, providing effective technical support and service platforms for the sustainable development, transformation, and upgrading of manufacturing in the Wuhan Metropolitan Area.

Furthermore, the regression coefficient between manufacturing and industrial parks was 0.597, illustrating that for manufacturing enterprises, location choice was also significantly affected by industrial parks. In China, by implementing preferential policies, such as those related to land and taxation, the government created good infrastructure and specialized government services, which attracted a large number of manufacturing enterprises to move to industrial parks [71]. In the Wuhan Metropolitan Area, in 2018, there were 12 national-level industrial parks (accounting for 63% of the national-level industrial parks in Hubei Province), 18 provincial-level industrial parks, and 43 municipal-level industrial parks. From 2003 to 2018, 85.6% of the manufacturing enterprises were located in those industrial parks. The spatial coverage of the manufacturing industry was further expanded and reorganized [72] due to the construction of industrial parks, which revealed that, between 2003 and 2008, administrative power was more effective at promoting the expansion of the manufacturing industry than the industry itself.

The number of large enterprises (leading effect) passed the T-test at a significance level of 99%; however, the regression coefficient is negative, indicating that the number of large enterprises significantly affected the location choice of the industrial agglomeration, but the large enterprises and other manufacturing enterprises show a negative relationship in spatial location. Studies have found that the dominant position of a small number of large companies in a region will limit the agglomeration economy and ultimately weaken the economic performance of enterprises in the industry, especially small enterprises [73]. Moreover, most large enterprises are located in self-built independent industrial parks, which obviously repel the aggregation of other manufacturing enterprises in the same spatial location. However, large enterprises have a complete industrial chain, which can drive the spatial agglomeration of related enterprises in the industrial chain. Therefore, actively attracting large enterprises is vital to the development of manufacturing in the Wuhan Metropolitan Area.

Life convenience (Facilities), the urban environment factor, had a significant effect on manufacturing agglomeration, implying that supporting living facilities were essential in the Wuhan Metropolitan Area. In return, the improvement of facilities effectively facilitates urban balance between work and living and promotes the integration of industries and the city. The regression coefficient of air quality (PM_{2.5}), another urban environment factor, was negative, illustrating that the more significant the manufacturing agglomeration, the worse the air quality. In other words, a significant spatial correlation was found between manufacturing agglomeration and environmental pollution [74], which means that smog pollution would be aggravated as manufacturing become more agglomerated [75]. In this regard, the Chinese government has reinforced the implementation of environmental protection policies and improved environmental regulation capabilities while promoting the agglomeration of manufacturing, and has also impressed upon enterprises that the pursuit of economic growth should not be at the expense of the environment [76].

According to the results of the regression analysis of the sub-samples (Table 5), in the study period, technology-intensive industries (T) paid more attention to government policy and the urban environment during agglomeration and emphasized innovation and the entrepreneurial environment to a greater extent than other industries. Therefore, in order to achieve transformation, upgrade infrastructure, and high-quality developments, it was necessary to focus on improving the innovation and entrepreneurship atmosphere of cities and accelerate the transformation of the technological achievements into productivity. Similarly, according to the regression results of labor-intensive industries (L), the influences of labor cost (Wage) and development zone (Development zone) were most significant, which shows that labor cost was an important factor affecting industrial agglomeration, especially in industrial parks. The layout of capital-intensive industries (C) was mainly affected by traffic location (Airport) and urban prosperity (goods). Since the development of capital-intensive technologies is attributed to a higher material and technological foundation and adequate financial support, these technologies demanded high economic strength and a high level of prosperity. Just as for the other three types of enterprises, during aggregation, resource-intensive enterprises (R) attached great importance to industrial parks (development zones) and the leading effect of large enterprises, and preferred locations with higher urban environment convenience and prosperity.

Table 5. Regression results for the driving factors of manufacturing enterprises.

	(1) Mi	(2) Ti	(3) Li	(4) Ci	(5) Ri
CBD	0.004 (0.011)	0.019 (0.014)	−0.005 (0.012)	−0.026 (0.022)	0.008 (0.014)
FTZ	−0.009 (0.009)	−0.024 ** (0.011)	−0.003 (0.010)	−0.009 (0.016)	−0.017 (0.012)
Airport	0.011 (0.009)	0.003 (0.011)	0.007 (0.010)	0.053 *** (0.019)	0.005 (0.012)
Railway	−0.015 (0.012)	−0.027 * (0.015)	−0.013 (0.014)	0.006 (0.021)	−0.010 (0.016)
Port	−0.002 (0.013)	0.014 (0.015)	0.011 (0.014)	−0.028 (0.021)	−0.005 (0.015)
Wage	−0.062 (0.011)	−0.078 (0.019)	−0.107 ** (0.021)	−0.056 (0.045)	−0.007 (0.001)
Land price	0.001 (0.001)	0.002 (0.002)	0.003 (0.001)	0.001 (0.002)	0.002 (0.002)
Innovation	0.092 * (0.049)	0.171 *** (0.064)	0.076 * (0.042)	0.015 (0.039)	0.032 (0.049)
Service platform	−0.415 *** (0.136)	−0.708 *** (0.177)	−0.307 * (0.121)	−0.229 (0.153)	−0.289 ** (0.134)
Development zone	0.597 *** (0.159)	0.804 *** (0.197)	0.515 *** (0.17)	0.265 (0.235)	0.661 *** (0.19)
Fin	0.012 (0.012)	0.011 (0.014)	0.017 (0.011)	0.020 (0.015)	0.015 (0.013)
Leading	−0.298 *** (0.116)	−0.539 *** (0.146)	−0.098 (0.109)	−0.241 (0.179)	−0.354 *** (0.131)
Facilities	0.002 *** (0.001)	0.003 *** (0.001)	0.001 (0.001)	0.002 ** (0.001)	0.002 ** (0.001)
Goods	−0.002 (0.003)	−0.003 (0.004)	0.002 (0.003)	−0.009 ** (0.004)	−0.008 ** (0.003)
PM2.5	−0.110 ** (0.047)	−0.156 *** (0.056)	0.081 * (0.049)	−0.146 * (0.078)	−0.161 * (0.057)
PM10	−0.025 (0.024)	−0.015 (0.028)	−0.045* (0.026)	−0.020 (0.041)	−0.014 (0.030)
Constant	11.08 *** (3.85)	11.671 *** (4.472)	1.461 (4.046)	9.797 (6.142)	13.48 *** (4.65)
lnalpha	0.026 (0.102)	0.282 ** (0.127)	0.099 (0.123)	0.717 *** (0.185)	0.299 ** (0.141)
Observations	197	197	197	197	197
r ² _p	0.056	0.102	0.044	0.057	0.065

Standard errors are in parentheses. Note: *** means $p < 0.01$, ** means $p < 0.05$, * means $p < 0.1$. Mi is the abbreviation of the entire manufacturing sector, Ti is the abbreviation of all technology-intensive industries, Li is the abbreviation of all labor-intensive industries, Ci is the abbreviation of all capital-intensive industries, and Ri is the abbreviation of all resource-intensive enterprises.

5. Discussion and Conclusions

5.1. Discussion

Because of limited data availability, this paper, while exploring factors affecting the layout of manufacturing, failed to carry out a profound study from the perspectives of producer services and industrial chain layout. Briefly, producer services and industrial chains are closely related to manufacturing, in that their progress contributes to the transformation and upgrading of manufacturing industries and high-quality developments. This paper is of significance to further research on the spatial exclusion of large enterprises and enterprises above a designated size.

The spatial pattern of the Wuhan Metropolitan Area has been characterized by the spreading of the Metropolitan Area and agglomeration in industrial parks, as has occurred in Shanghai, Beijing, and Nanjing. According to studies on the spatial agglomeration and suburbanization of the software industry in the Shanghai Metropolitan Area [77], software enterprises were spatially “spread in the metropolitan area and re-aggregated in parks”. However, in terms of influencing factors, it was found that location selection was dramatically affected by traffic accessibility, the construction of science and technology parks, and an industrial foundation, which differs from the conclusions of this paper.

Similarly, Zhang explored the spatial pattern evolution and influencing factors of manufacturing in Beijing [78] and discovered the same agglomeration characteristics, and held that the manufacturing industry's location was mainly affected by traffic accessibility, the agglomeration economy, the planning of science and technology parks, and policy guidance. Additionally, a study on co-location in the service industry and manufacturing industry concluded that manufacturing was mainly located in new towns and national development zones, and the distribution of manufacturing was shown to be influenced by the joint effects of agglomeration economics and land price [23]. Therefore, due to the special economic background, institutional environment, and the construction of industrial parks, in China, it has been common to guide manufacturing to move from urban centers and re-aggregate in industrial parks. However, the factors that affected the location of manufacturing were diverse due to differences in the regional environment, local forces, and the capabilities of urban governance. In summary, when encountering similar research problems, the authors suggest that scholars should, in view of the realities of each city, select targeted indicators to analyze practical influencing factors.

The year 2019 saw the concentrated outbreak of COVID-19 in the Wuhan Metropolitan Area, and, as of 30 August 2020, confirmed cases there accounted for 88.5% of the confirmed cases in the Hubei Province. The epidemic undoubtedly dramatically affected manufacturing, especially the automobile industry and electronic information industry, for instance delaying the resumption of work and necessitating export restrictions and the blocking of transportation and logistics, which led to a decline in manufacturing capacity and consumer demands. Accordingly, an urgent issue is how to cope with the COVID-19 crisis in an orderly manner, which requires the government to provide systematic macro-guidance and implement targeted policies.

5.2. Conclusions

This paper employed multiple spatial analysis methods (i.e., Moran's I, kernel density) at the Wuhan Metropolitan Area scale to comprehensively explore the distribution and spatial evolution process of manufacturing from 2003 to 2018. It further used a negative binomial regression model to account for the factors influencing the spatial distribution of manufacturing.

The research demonstrated that manufacturing presented an obvious trend of suburbanization; this process of suburbanization is similar to that of Western Metropolitan [79,80]. However, affected by policies and industrial parks, manufacturing had significant differences in spatial distribution and suburbanization processes. Between 2003 and 2018, the spatial pattern of the manufacturing industry in the Wuhan Metropolitan Area was characterized by spreading from the center to the suburbs, mainly spreading east, west, south, and north, and regrouping in industrial parks. The spatial distribution of the manufacturing companies shows a trend of high-low-low-low distribution, and there is a significant autocorrelation. The correlation between manufacturing companies and space first rises and then declines, which means that these companies will not rely too much on space, and pay more attention to other factors.

A regression model was applied to test the major location factors resulting in the spatial reconstruction of manufacturing and to determine the intensities of these impact factors in the entire manufacturing industry and among different manufacturing industries. As estimated with the negative binomial regression model, the spatial evolution mechanism of manufacturing in the Wuhan Metropolitan Area involves a market economy mechanism guided and planned by the government. Additionally, the government has imposed new requirements for manufacturing enterprises in order to protect the urban environment. The main impact factors include innovation and technical service platforms, industrial parks, number of large enterprises, life convenience, and PM2.5 concentration. However, the effect intensity of the different location factors varies among industries.

Based on the conclusions of this paper, we suggest to make improvements from three perspectives: first, give full play to the decisive role of industrial parks in industrial agglomeration, increase the construction of industrial parks, introduce policies serving the real economy, and enhance the environment for innovation and entrepreneurship, including financial support, tax relief, and the

reduction and deferred payment of other expenses. The government should focus on facilitating the division of labor at the industrial-chain level, adjusting the industrial layout, and establishing an integrated industrial system in the Wuhan Metropolitan Area. Secondly, the leading effect should be exploited to form a spatial pattern of manufacturing featuring staggered development and give full play to the role of large enterprises in the leading scale of the industrial chain so as to enhance the regional production capacity and accelerate industrial agglomeration. There are 25 enterprises worth over RMB 10 billion in the Wuhan Metropolitan Area, forming an industrial landscape with the automobile manufacturing industry led by Dongfeng Honda and SAIC-GM; the steel machinery manufacturing industry led by the Wuhan Iron and Steel (Group) Company; and the pharmaceutical industry led by Humanwell Healthcare (Group). It is essential to fully support the orderly resumption of production, especially for leading enterprises, as well as the restoration of production capacity, in order to promote coordinated work resumption in the upstream and downstream links of the industrial chain and accelerate economic recovery. Thirdly, attention should be paid to improving capabilities in the urban environment and governance, rationally allocating public services during the spatial agglomeration and diffusion of manufacturing, avoiding blind investment, and achieving the organic integration of spatial reorganization and the optimization of urban functions. More importantly, efforts should be made to optimize the industrial layout and promote industrial upgrading through technological and institutional innovation in order to enhance urban spatial quality.

Finally, the conclusions and methodologies of this paper are also suitable for fields such as territory development planning, industrial development planning, and economic and social research.

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Appendix A

Table A1. Classification of manufacturing industries.

Classification Due to Factor Intensive	Manufacturing Industries
Labor-intensive Industry (L)	Processing of food from agricultural products (C13), manufacture of food (C14), manufacture of beverages (C15), manufacture of textiles (C17), manufacture of textiles and apparel (C18), manufacture of leather, furs, feathers, and related products (C19), manufacture of furniture (C21), manufacture of paper and paper products (C22), printing and reproducing of recording media (C23), manufacture of articles for culture, education, and sport activities (C24), other manufacturing (C41).
Capital-intensive Industry (C)	Processing of petroleum, coking, and nuclear fuel (C25), manufacture of rubber and plastic (C29), manufacture of non-metallic mineral products (C30), manufacture of metallic products (C33).
Technology-intensive industry (T)	Manufacture of raw chemical materials and chemical products (C26), manufacture of medicines (C27), manufacture of general purpose machinery (C34), manufacture of special purpose machinery (C35), manufacture of automobile (C36), manufacture of railway, vessel, aerospace, and transport equipment (C37), manufacture of electrical machinery and equipment (C38), manufacture of computers and communications equipment (C39), manufacture of instruments (C40), comprehensive utilization of waste resources (C42), metal products, machinery, and equipment maintenance industry (C43).

Table A1. Cont.

Classification Due to Factor Intensive	Manufacturing Industries
Resource-intensive industry (R)	Manufacture of tobacco (C16), processing of timber and manufacture of wood, bamboo, rattan, palm, and straw products (C20), manufacture of chemical fibers (C28), smelting and pressing of ferrous metals (C31), smelting and pressing of non-ferrous metals (C32).

Notes: In 2003, the 28 manufacturing industries selected were C13–C41, without C38. Since changes were made in classification of national economic industries after 2011, in 2013, manufacturing industries C13–C40 were selected for analysis according to the new classification standard (GB/T4754-2011). Similarly, in 2018, manufacturing industries C13–C43 were analyzed according to the new classification standard (GB/T4754-2017). Moreover, due to changes in the statistical caliber of the industrial enterprises above the designated size since 2011, the storage standard was adjusted from a main operation income of RMB 5 million to a main operation income of RMB 20 million. For the sake of comparison, adjustments were made in accordance with the new statistical caliber of the zoning codes for the statistics and urban-rural codes issued by the National Bureau of Statistics.

Appendix B

Firstly, a Poisson regression was carried out.

Table A2. The results of the Poisson regression.

Mi	Coef.	St. Err.	t-Value	p-Value	(95% Conf	Interval)	Sig
CBD	−0.002	0.009	−0.26	0.794	−0.02	0.015	
FTZ	−0.003	0.01	−0.34	0.733	−0.023	0.016	
Airport	0.017	0.01	1.76	0.078	−0.002	0.036	*
Railway	−0.022	0.013	−1.66	0.097	−0.049	0.004	*
Port	0.001	0.011	0.09	0.926	−0.021	0.023	
Land price	−0.001	0.001	−0.83	0.407	−0.003	0.001	
Wage	−0.002	0.004	−0.18	0.86	−0.013	0.017	
Development zone	0.5	0.112	4.46	0	0.28	0.719	***
Innovation	0.03	0.019	1.55	0.12	−0.008	0.068	
Fin	0.016	0.004	4.07	0	0.008	0.024	***
Service platform	−0.192	0.064	−3.02	0.003	−0.317	−0.067	***
Leading	−0.131	0.074	−1.78	0.076	−0.276	0.014	*
Facilities	0.001	0	2.53	0.012	0	0.002	**
Goods	−0.003	0.002	−1.67	0.095	−0.007	0.001	*
PM20.5	−0.024	0.036	−0.65	0.514	−0.095	0.047	
PM10	−0.047	0.026	−1.79	0.073	−0.098	0.004	*
Constant	8.763	3.386	2.59	0.01	2.127	15.399	***
Mean dependent var		22.223		SD dependent var		35.488	
Pseudo r-squared		0.427		Number of obs		197.000	
Chi-square		876.750		Prob > chi2		0.000	
Akaike crit. (AIC)		4336.904		Bayesian crit. (BIC)		4399.285	

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Secondly, one of the premises of using Poisson regression is that the expectation of the explained variable is equal to the variance. The results show that the sample variance differs greatly from the sample mean.

Table A3. The results of the sample variance and the sample mean.

Variables	Obs	Mean	Std. Dev.	Min	Max	p1	p99	Skew.	Kurt.
mi	197	22.223	35.488	0	238	0	234	3.757	20.644

Lastly, to relax this assumption, a negative binomial regression was used. In this paper, the negative binomial regression was carried out by the stepwise regression method, and the confidence level was set as 90%. The regression results of the negative binomial model for the whole manufacturing

industry, different industries, and different types of enterprises were obtained, respectively, and the accessory parameter α was significantly non-zero, which proved the rationality of using the negative binomial model for the estimation.

Table A4. The result of overall manufacturing by negative binomial regression.

Mi	Coef.	St. Err.	z	p > z	(95% Conf	Interval)	Sig
CBD	0.004	0.011	0.35	0.727	−0.018	0.026	
FTZ	−0.009	0.009	−1.02	0.308	−0.027	0.008	
Airport	0.011	0.009	1.18	0.24	−0.007	0.029	
Railway	−0.015	0.012	−1.25	0.213	−0.04	0.009	
Port	−0.002	0.013	−0.15	0.88	−0.027	0.023	
Land price	0.001	0.001	0.43	0.665	−0.002	0.003	
Wage	−0.062	0.011	−0.66	0.511	−0.012	0.006	
Development zone	0.597	0.159	3.76	0	0.286	0.909	***
Innovation	0.092	0.049	1.86	0.063	−0.005	0.188	*
Fin	0.012	0.012	1.01	0.311	−0.011	0.034	
Service platform	−0.415	0.136	−3.06	0.002	−0.681	−0.149	***
Leading	−0.298	0.116	−2.58	0.01	−0.524	−0.071	***
Facilities	0.002	0.001	3.47	0.001	0.001	0.003	***
Goods	−0.002	0.003	−0.85	0.394	−0.008	0.003	
PM20.5	−0.1	0.047	−2.14	0.032	−0.192	−0.008	**
PM10	−0.025	0.024	−1.07	0.285	−0.072	0.021	
Constant	11.08	3.85	2.88	0.004	3.535	18.625	***
lnalpha	0.026	0.102	.b	.b	−0.173	0.226	
Mean dependent var		22.223		SD dependent var		35.488	
Pseudo r-squared		0.056		Number of obs		197.000	
Chi-square		90.408		Prob > chi2		0.000	
Akaike crit. (AIC)		1551.113		Bayesian crit. (BIC)		1616.777	

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table A5. The result of the technology-intensive industry (T) by negative binomial regression.

Ti	Coef.	St. Err.	z	p > z	(95% Conf	Interval)	Sig
CBD	0.019	0.014	10.42	0.155	−0.007	0.046	
FTZ	−0.024	0.011	−2.23	0.026	−0.046	−0.003	**
Airport	0.003	0.011	0.27	0.785	−0.018	0.024	
Railway	−0.027	0.015	−1.82	0.068	−0.057	0.002	*
Port	0.014	0.015	0.97	0.331	−0.015	0.043	
Land price	0.002	0.002	1.07	0.286	−0.001	0.005	
Wage	−0.078	0.019	−0.44	0.663	−0.017	0.021	
Development zone	0.804	0.197	4.07	0	0.417	1.191	***
Innovation	0.171	0.064	2.66	0.008	0.045	0.298	***
Fin	0.011	0.014	0.78	0.434	−0.017	0.039	
Service platform	−0.708	0.177	−4.01	0	−1.054	−0.362	***
Leading	−0.539	0.146	−3.68	0	−0.826	−0.252	***
Facilities	0.003	0.001	4.60	0	0.002	0.004	***
Goods	−0.003	0.004	−0.91	0.364	−0.01	0.004	
PM20.5	−0.156	0.056	−2.80	0.005	−0.266	−0.047	***
PM10	−0.015	0.028	−0.52	0.6	−0.07	0.041	
Constant	11.671	4.472	2.61	0.009	2.907	2.435	***
lnalpha	0.282	0.127	.b	.b	0.033	0.532	
Mean dependent var		8.802		SD dependent var		22.745	
Pseudo r-squared		0.102		Number of obs		197.000	
Chi-square		119.163		Prob > chi2		0.000	
Akaike crit. (AIC)		1088.771		Bayesian crit. (BIC)		1154.435	

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table A6. The result of the labor-intensive industry (L) by negative binomial regression.

Li	Coef.	St. Err.	t-Value	p-Value	(95% Conf Interval)	Sig
CBD	−0.005	0.012	−0.42	0.676	−0.029	0.019
FTZ	−0.003	0.01	−0.36	0.722	−0.022	0.015
Airport	0.007	0.01	0.67	0.505	−0.013	0.027
Railway	−0.013	0.014	−0.90	0.369	−0.04	0.015
Port	0.01	0.014	0.71	0.478	−0.017	0.036
Land price	0	0.001	−0.03	0.976	−0.002	0.002
Wage	−0.107	0.121	−1.47	0.141	−0.23	0.029
Development zone	0.515	0.17	3.03	0.002	0.182	0.848
Innovation	0.076	0.042	1.78	0.074	−0.007	0.159
Fin	0	0.011	−0.03	0.979	−0.021	0.021
Service platform	−0.307	0.121	−2.53	0.011	−0.545	−0.069
Leading	−0.098	0.109	−0.90	0.368	−0.313	0.116
Facilities	0.001	0.001	1.59	0.112	0	0.002
Goods	0.002	0.003	0.77	0.439	−0.004	0.008
PM20.5	0.081	0.049	1.65	0.099	−0.015	0.177
PM10	−0.045	0.026	−1.72	0.086	−0.095	0.006
Constant	1.461	4.046	0.36	0.718	−6.469	9.391
lnalpha	0.099	0.123	.b	.b	−0.142	0.34
Mean dependent var		5.929		SD dependent var		9.134
Pseudo r-squared		0.044		Number of obs		197.000
Chi-square		49.140		Prob > chi2		0.000
Akaike crit. (AIC)		1105.194		Bayesian crit. (BIC)		1170.858

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.**Table A7.** The result of the capital-intensive industry (C) by negative binomial regression.

Ci	Coef.	St. Err.	t-Value	p-Value	(95% Conf Interval)	Sig
CBD	−0.026	0.022	−1.18	0.24	−0.068	0.017
FTZ	−0.009	0.016	−0.58	0.562	−0.041	0.022
Airport	0.053	0.019	2.80	0.005	0.016	0.09
Railway	0.006	0.021	0.27	0.79	−0.036	0.047
Port	−0.028	0.021	−1.33	0.182	−0.07	0.013
Land price	0.001	0.002	0.25	0.799	−0.004	0.005
Wage	−0.056	0.045	−0.17	0.862	−0.034	0.015
Development zone	0.265	0.235	1.13	0.259	−0.195	0.724
Innovation	0.015	0.039	0.38	0.705	−0.062	0.091
Fin	0.02	0.015	1.38	0.168	−0.009	0.049
Service platform	−0.229	0.153	−1.50	0.134	−0.528	0.071
Leading	−0.241	0.179	−1.35	0.178	−0.593	0.11
Facilities	0.002	0.001	2.29	0.022	0	0.003
Goods	−0.009	0.004	−2.05	0.041	−0.018	0
PM20.5	−0.146	0.078	−1.88	0.06	−0.298	0.006
PM10	−0.02	0.041	−0.48	0.63	−0.1	0.061
Constant	9.797	6.142	1.60	0.111	−2.241	21.834
lnalpha	0.717	0.185	.b	.b	0.354	1.08
Mean dependent var		1.518		SD dependent var		3.033
Pseudo r-squared		0.057		Number of obs		197.000
Chi-square		35.204		Prob > chi2		0.009
Akaike crit. (AIC)		626.305		Bayesian crit. (BIC)		691.969

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table A8. The result of the resource-intensive industry (R) by negative binomial regression.

Ri	Coef.	St. Err.	t-Value	p-Value	(95% Conf	Interval)	Sig
CBD	0.008	0.014	0.56	0.575	−0.019	0.034	
FTZ	−0.017	0.012	−1.50	0.135	−0.04	0.005	
Airport	0.005	0.012	0.47	0.636	−0.017	0.028	
Railway	−0.01	0.016	−0.63	0.527	−0.04	0.021	
Port	−0.005	0.015	−0.30	0.765	−0.034	0.025	
Land price	0.002	0.002	1.01	0.313	−0.001	0.005	
Wage	−0.007	0.001	−0.15	0.884	−0.021	0.024	
Development zone	0.661	0.19	3.48	0	0.289	1.033	***
Innovation	0.032	0.049	0.64	0.519	−0.065	0.128	
Fin	0.015	0.013	1.22	0.223	−0.009	0.04	
Service platform	−0.289	0.134	−2.16	0.031	−0.552	−0.027	**
Leading	−0.354	0.131	−2.71	0.007	−0.611	−0.098	***
Facilities	0.002	0.001	3.30	0.001	0.001	0.003	***
Goods	−0.008	0.003	−2.46	0.014	−0.015	−0.002	**
PM20.5	−0.161	0.057	−2.81	0.005	−0.273	−0.049	***
PM10	−0.014	0.03	−0.48	0.634	−0.074	0.045	
Constant	13.48	4.65	2.90	0.004	4.367	22.594	***
lnalpha	0.299	0.141	.b	.b	0.022	0.576	
Mean dependent var		4.832		SD dependent var		7.571	
Pseudo r-squared		0.065		Number of obs		197.000	
Chi-square		65.508		Prob > chi2		0.000	
Akaike crit. (AIC)		984.929		Bayesian crit. (BIC)		1050.593	

*** $p < 0.01$, ** $p < 0.05$.

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