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Effects of Institutions on Spatial Patterns of Manufacturing Industries and Policy Implications in Metropolitan Areas: A Case Study of Wuhan, China

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Abstract: Manufacturing space is a spatial system that combines the interaction between capital and institutions at the enterprise, industry, and spatial levels. It is also an important functional type that promotes the spatial evolution of big cities. Most studies focus on the effects of a single institutional type on the manufacturing space of big cities and lack systematic and complete exploration of the institutional mechanism. Current empirical research on typical industrial cities in China is insufficient. This study uses a GIS spatial analysis technique and a Poisson regression model to analyze the mechanism by which institutions have influenced the spatial patterns of manufacturing industries in the Wuhan metropolitan area since the 1990s. The results show that land policy, development zone policy, urban planning, transportation strategy, and eco-environmental policy all have a significant impact on the restructuring process and distribution pattern of the manufacturing industries through incentives and constraints. This study expands our understanding of the influence mechanism of manufacturing spatial patterns and proposes spatial guiding strategies and policy implications for the spatial transformation of urban manufacturing.

Keywords: institution; manufacturing industries; spatial pattern; metropolitan area; China

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1. Introduction

Since the 1990s, countries such as China have rapidly emerged as global manufacturing factories by relying on the cost advantage of land and labor as well as institutional dividends [1–4]. The formation of the global manufacturing industry in China is mainly due to the government's investment and national institutional reform. Against the backdrop of globalization, marketization, and decentralization, a series of formal institutions in China have undergone major changes. These include land reform, reform of public-owned enterprises, tax reform, and development zone policies. After experiencing adjustments to land development and spatial structures, China's big cities have started actively participating in the global production network. This has allowed China to become the main location for global manufacturing [5–11].

With the arrival of post-industrialism, manufacturing has experienced a process of suburbanization in major cities worldwide. Cities in Western countries began to suburbanize at the end of the 19th century, while Chinese cities began to do so at the end of the 20th century [12–16]. The main characteristics of suburbanization are the migration of manufacturing space and function. Scholars have conducted significant research on manufacturing spaces in big cities by focusing on three areas. The first is the characteristic of location distribution in manufacturing enterprises. The embeddedness of transnational

corporations and the rise of new technology enterprises have accelerated the spatial restructuring of manufacturing in big cities and the formation of global production networks [6–8]. The second area of focus is the spatial distribution and pattern of manufacturing industries in big cities; a spillover of land value in the inner city promoted the mass exodus of manufacturing space. Manufacturing space is dense and placed at the edge of the metropolitan area, within a radius of 15–35 km from the city center. Meanwhile, in China, the development zone has been the main manufacturing space since 1990 [9,17–19]. The third area of focus is the pattern of manufacturing spaces. Land development and the adjustment of spatial structures in big cities are driven by multiple forces, such as institutional change and market capital [9,18–21].

The location of manufacturing enterprises is not only affected by the existing market capital endowment and preference; it is also largely regulated by a series of institutional factors [22–25]. Some scholars have conducted in-depth analyses on the impact of single-type institutions and found that land policy mainly influences the geographical distribution of the manufacturing industry through paid land price, land supply, and land renewal policies [20,22,26,27]. It was also shown that development zone policy mainly influences the spatial agglomeration of the manufacturing industries through the incentives of land, taxes, talent, and other factors [17,28]. Since the 1980s, new institutional economists have formally introduced new institutional economics into spatial research and started explaining spatial problems such as industrial agglomeration and clustering from the perspective of transaction costs and division of labor [29,30]. Some scholars have explained the urban phenomenon and the influence mechanism of urban space from the perspective of new institutional economics [31–33].

Considering the existing relevant research, it is clear that they all focused on analyzing the effect of a single institutional type on the urban space in big cities. Notably, most of the research is on land policy [20,22,26]. However, there is a dearth of research that explores systematic and complete institutional mechanisms. Empirical research on China's heavily industrialized cities is also insufficient. This study proposes the hypothesis that institutions have been the most important factors affecting the spatial patterns of the manufacturing industry in China's big cities since the 1990s. Institutions have specific functional areas, ways, and internal mechanisms that need to be explored. New institutional economics also provides an analytical framework for incentives and constraints for institutional mechanisms [34]. This study puts forward an analysis of the relationship between institutions and the spatial patterns of manufacturing and explores the comprehensive mechanism. The institutions examined in this study include land policy, development zone policy, eco-environmental policy, urban planning, and transportation strategy, all of which have different effects on the spatial patterns of manufacturing industries. They affect the location choice of enterprises through incentives and constraints, thus influencing the process of suburbanization and agglomeration. Figure 1 represents the relationship between institutions and the patterns of manufacturing space.

This study uses GIS spatial analysis to identify the spatial patterns of the manufacturing industry in the Wuhan metropolitan area since the 1990s. A Poisson regression model is used to discover the institutional factors affecting the distribution of enterprises in the Wuhan metropolitan area to explore the effects of different institutions on the spatial patterns of the manufacturing industry in big cities. Finally, from the perspective of the trend of international industrial transformation, this study presents spatial guiding strategies and policy implications for the spatial transformation of manufacturing industries in big cities.

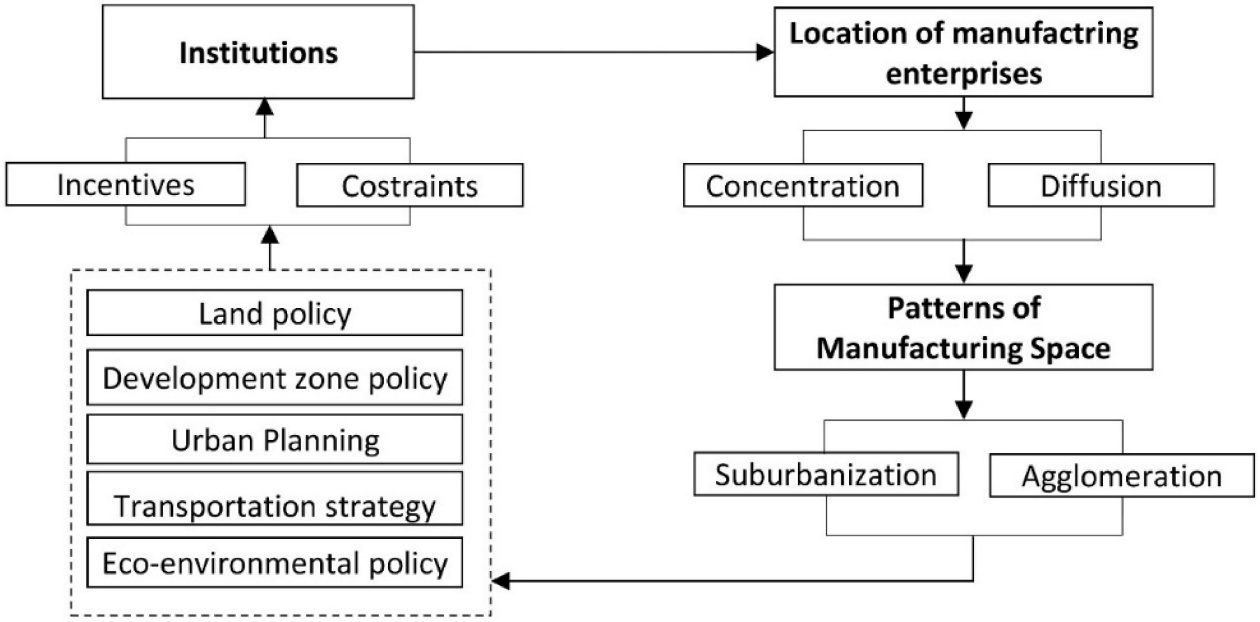
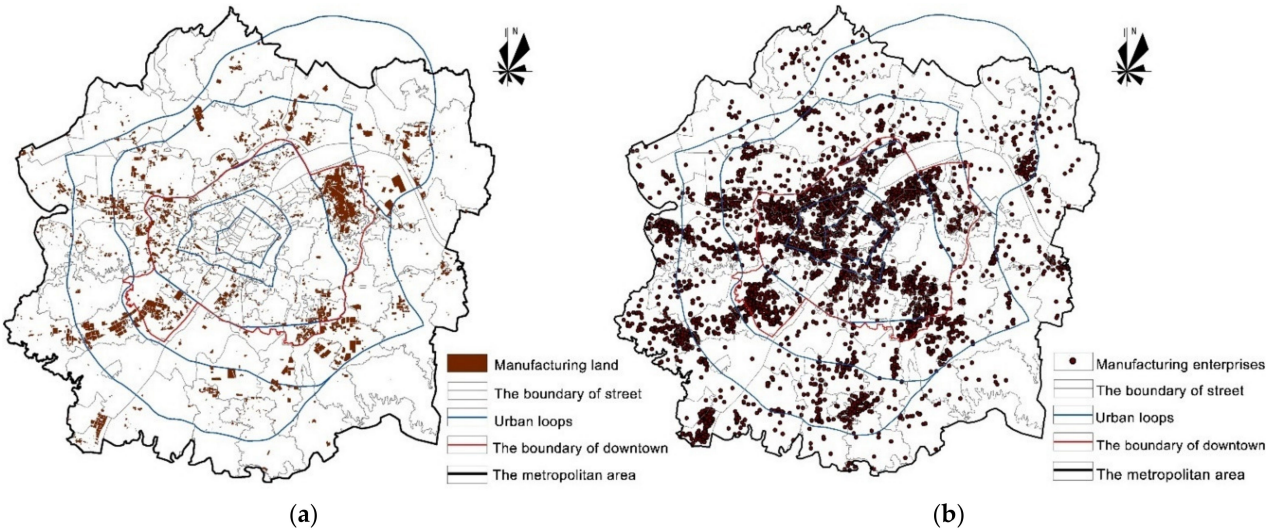


Figure 1. Framework of interpretation.

2. Study Area, Data, and Methodology

2.1. Study Area

Wuhan is the political, economic, cultural, and transportation center of Hubei Province in Central China. The resident population is approximately 10 million people and the city has a history of supporting the development of the manufacturing industry. Since the founding of the People's Republic of China, with the support of national policies, Wuhan has built 15 important heavy-industrial projects and has become a typical industrial city; it is the home to the iron, steel, automobile, machinery, and other industries. This study focuses on the Wuhan metropolitan area, which includes the main urban area and inner suburbs, a surface area of 3261 km^2. Figure 2 shows the manufacturing land and manufacturing enterprises in the metropolitan area of Wuhan.



(**a**) (**b**)

Figure 2. Object of the study: (**a**) distribution of manufacturing land in the Wuhan metropolitan area; (**b**) distribution of manufacturing enterprises in the Wuhan metropolitan area.

2.2. Data

The research data included data on land use, spatial location, and land transfer. Land-use data for 1993, 2004, 2010, and 2016 were obtained from the Wuhan Land and Planning Department. The enterprise spatial location data are from the National Third Economic Census, completed in 2013; these data include information such as the address, industry type, and number of employees. The land-transfer data include the location and area of the transferred land of manufacturing industries in Wuhan since the 1990s.

2.3. Methodology

2.3.1. Analysis of Spatial Pattern

The Global Moran's I and kernel density estimation were introduced to identify the reconstruction process and characteristics of the manufacturing space in the Wuhan metropolitan area.

(1) Global Moran's I index

The Global Moran's I index can quantitatively measure the spatial autocorrelation of the manufacturing space. In this study, the manufacturing land-use data of the Wuhan metropolitan area in four typical years (1993, 2004, 2010, and 2016) were superimposed with a geospatial grid of 1000 m × 1000 m. The Global Moran's I index was used to analyze the spatial correlation between each grid unit and its adjacent units.

(2) Kernel density estimation

A kernel density analysis uses spatial smoothing to estimate the density around the sample points according to the density of points in the buffering areas. This study divided 15,416 manufacturing enterprises into three types according to industry characteristics: capital-intensive, technology-intensive, and labor-intensive. The spatial distribution of Wuhan's manufacturing enterprises and the pattern characteristics of various manufacturing enterprises were quantitatively measured using a nuclear density analysis in GIS.

2.3.2. Identification of Institutional Factors

The spatial pattern of manufacturing industries in big cities is the outcome of choices made by many manufacturing enterprises. This study considers the number of enterprises within the administrative boundaries of sub-district offices as the dependent variable. This study applies a Poisson regression model to verify the factors influencing the location selection of manufacturing enterprises [35–38]. We then explore the effects of institutional factors on the spatial patterns of manufacturing industries in the Wuhan metropolitan area. The number of manufacturing enterprises, capital-intensive manufacturing enterprises, labor-intensive manufacturing enterprises, and technology-intensive manufacturing enterprises were counted, based on the data of the third economic census. These were taken as the dependent variables Y_1, Y_2, Y_3, and Y_4, respectively.

According to the probability density function of the Poisson distribution, the probability that the number of enterprises in a street/township y is

$$P(Y_i = y_i|X_i) = \frac{e^{-\lambda}\lambda_i^{y_i}}{y_i!} \quad (1)$$

$$\lambda_i = e^{\beta x_i}(i = 1, 2, 3, 4 \ldots\ldots) \quad (2)$$

The maximum likelihood estimators (MLE) of parameter β can be obtained using the following log-likelihood function:

$$L(\beta) = \sum_{i=1}^{N}[y_i\lambda_i - \lambda_i - In(y_i!)] \quad (3)$$

An important feature of the Poisson model is that the conditional mean and conditional variance of the dependent variable are equal to λ_i.

$$Var(Y_i|X_i,\beta) = E(y_i|X_i,\beta) = m(X_i,\beta) = \lambda_i = e^{\beta x_i} \quad (4)$$

If the number of enterprises *Y*i observed in the unit of *i* obeys the Poisson distribution with parameter λ_i, the variance is estimated using the log-likelihood function mentioned above. The estimated value ($\hat{y}_i$) is obtained, and an auxiliary regression is developed:

$$(y_i - \hat{y}_i)^2 - y_i = \alpha \hat{y}_i^2 + \tau \quad (5)$$

In the above formula, τ is the residual error. Finally, we obtained regression coefficients and tested their significance. The variable statistics are shown in Table 1.

Table 1. List of explanatory variables.

Institutional Factors	Variables	Description
Land policy	Land price	The price based on "Land Grade and Benchmark Land Price Update in Wuhan"
	Land supply	The leased area of the land within the unit
Development zone policy	Whether it is a development zone	Yes is 1; no is 0
Urban planning	Whether it is a development zone	Yes is 1; no is 0
	Whether it is the central urban area	Yes is 1; no is 0
Traffic strategy	Whether it is an industrial strategic area	Yes is 1; no is 0
	Presence of the shoreline of the Yangtze River	Yes is 1; no is 0
Eco-environmental policy	Proportion of the eco-environmental area	Ratio of eco-environmental area to unit area in a unit

3. Results

3.1. Spatial Reconstruction Process and Pattern Characteristics

As shown in Table 2, this study addresses the areas of manufacturing land in different expressway loops of the Wuhan metropolitan area from 1993 to 2016. Manufacturing land areas within the second loop decreased from 13.25 km^2 in 1993 to 3.71 km^2 in 2016, while the manufacturing land area outside the second loop increased from 40.13 km^2 in 1993 to 175.74 km^2 in 2016. In this process, the area of manufacturing land from the third to the fifth loop increased the most. Therefore, the suburbanization trend of manufacturing space in the Wuhan metropolitan area has been apparent since the 1990s.

The Global Moran's I index was used to further analyze the suburbanization process of manufacturing space in the Wuhan metropolitan area since the 1990s. The results show that the manufacturing space has undergone obvious reorganization from 1993 to 2016. From 1993 to 2004, the highly concentrated areas of manufacturing land in the inner city gradually shifted to suburban areas. From 2005 to 2010, the agglomeration of industrial sectors, dominated by the iron, steel, and chemical industry, was further strengthened in northeast Wuhan, and three obvious agglomeration areas were initially formed in the northwest, southwest, and southeast. In 2016, manufacturing agglomerations were formed in the northeast, northwest, southwest, and southeast areas (Figure 3).

Table 2. Change of manufacturing land in the Wuhan metropolitan area since the 1990s.

Spatial Range	1993		2004		2010		2016	
	Area (km^2)	Proportion (%)	Area (km^2)	Proportion (%)	Area (km^2)	Proportion (%)	Area (km^2)	Proportion (%)
Within first loop	3.96	6.78	1.71	1.59	0.9	0.57	0.67	0.37
From first loop to second loop	9.29	15.91	8.71	8.10	4.06	2.59	3.04	1.69
Second loop to third loop	21.97	37.63	24.2	22.51	30.93	19.73	27.67	15.42
Third loop to fifth loop	18.16	31.11	72.91	67.80	120.84	77.10	148.07	82.51
sum	58.38	100	107.53	100	156.73	100	179.45	100

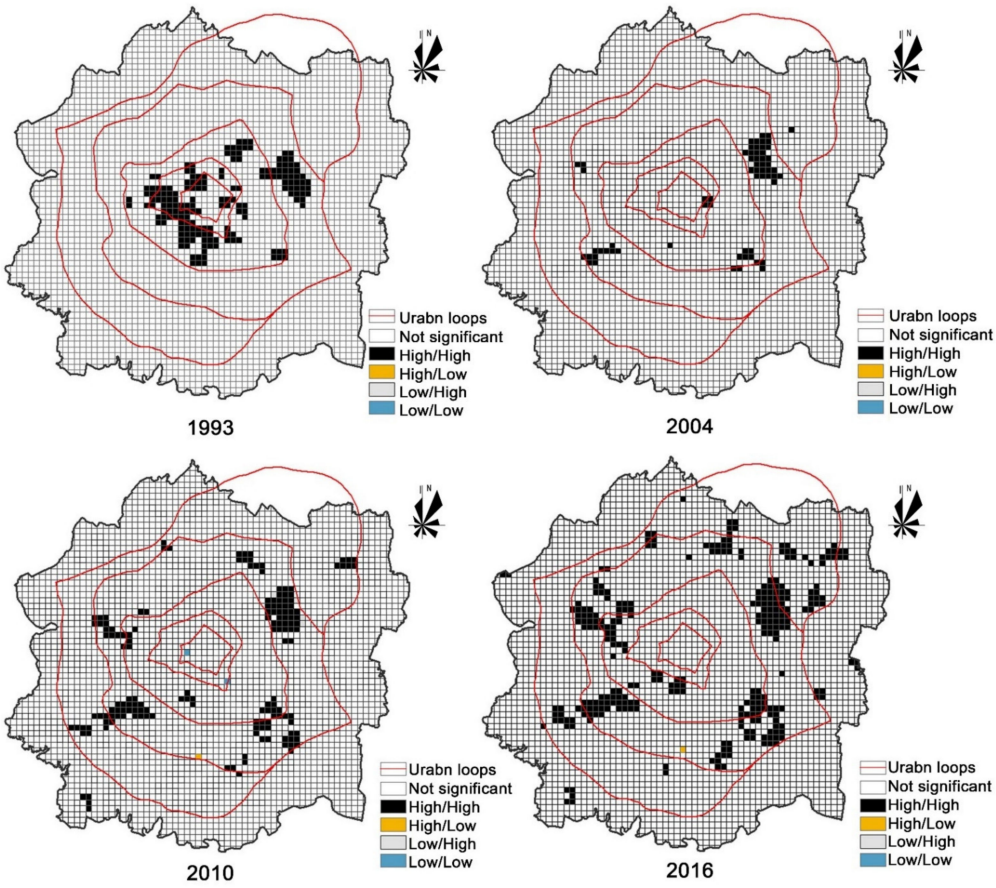


Figure 3. Clustering and outlier analysis of manufacturing land in the Wuhan metropolitan area since the 1990s.

Based on the data from the third economic census in Wuhan, the spatial distribution of different types of manufacturing industries was analyzed using a kernel density analysis (Figure 4). The results reveal that (1) capital-intensive industries are generally characterized by the coexistence of both agglomeration and dispersion, which are concentrated at the edge of the metropolitan area and dispersed finger-like to the outer suburbs along the traffic axis. For example, the iron, steel, and petrochemical industries have obvious spatial agglomeration characteristics, in which agglomeration has a strong traffic direction. Furthermore, their distribution pattern is similar to the overall distribution pattern of manufacturing enterprises in Wuhan, indicating that capital-intensive heavy enterprises have caused the spatial pattern of the manufacturing industry in Wuhan. We also see that (2) labor-intensive industries are mainly concentrated in the inner city within the third expressway loop. The number of enterprises is generally small, showing the spatial

characteristics of agglomeration of the inner city and dispersion of surrounding areas. Further, (3) technology-intensive enterprises have the highest degree of concentration, and a strong agglomeration center exists in the Wuhan East Lake High-Tech Development Zone in the east of the Wuhan metropolitan area.

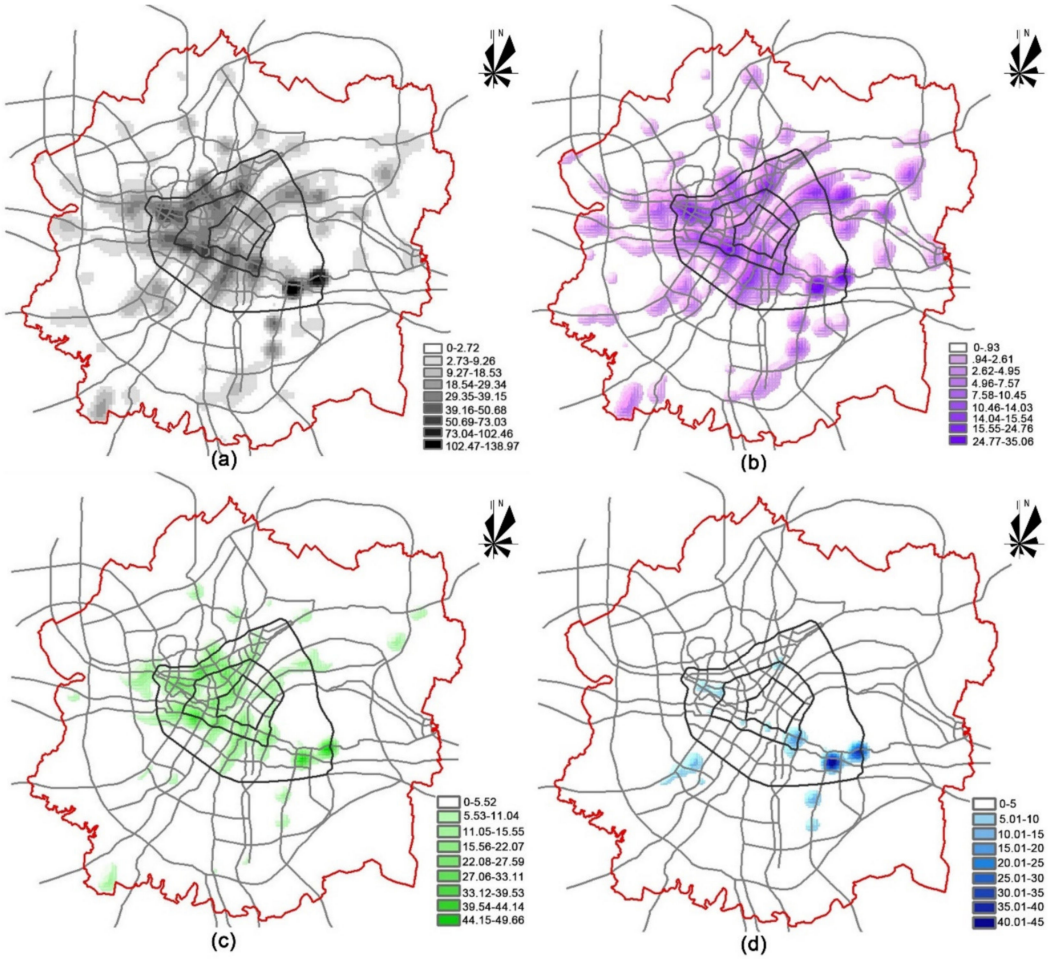


Figure 4. Spatial patterns of different manufacturing enterprises in the Wuhan metropolitan: (**a**) all manufacturing enterprises; (**b**) capital-intensive enterprises; (**c**) labor-intensive enterprises; (**d**) technology-intensive enterprises.

The results of Poisson model are shown in Table 3.

3.2. Land Policy

The land factor is an irreplaceable input for manufacturing spatial layout [20], especially in the case of the market-oriented reform of China's land policy since the 1990s. China's paid land use reform has accelerated the marketization of urban land. Furthermore, the establishment of land price institutions promoted the distribution of urban land prices in a decreasing pattern, from the center to the suburbs [22]. To reduce land costs, enterprises tend to locate and cluster in the suburbs, where land prices are relatively low. However, the land reserve and land expropriation institutions provided a guarantee of land supply on the periphery of urban areas. This further promoted the suburbanization of the manufacturing spaces.

Table 3. Regression results of manufacturing industry location in the Wuhan metropolitan area.

Institutional Factors	Variable	Number of All Manufacturing Enterprises	Number of Labor-Intensive Enterprises	Number of Technology-Intensive Enterprises	Number of Capital-Intensive Enterprises
Land policy	Land price	−0.7317 ***	−0.6799 ***	−0.1853	−0.3935 ***
	Land supply	0.6452 ***	0.6349 ***	0.2356	0.4586 ***
Development zone policy	Whether it is a development zone	0.2859 **	0.2518 **	0.5332 ***	0.1867 *
Urban planning	Whether it is the central urban area	−0.3673 **	−0.3758 ***	−0.3833 **	−0.3572 **
	Whether it is an industrial strategic area	0.2643 **	0.0298 *	0.3789 **	0.3244 **
Traffic strategy	Presence of a shoreline of the Yangtze River	0.1929 *	0.1783 *	0.2121 *	0.2398 ***
	Presence of a highway or expressway crossing	0.3895 ***	0.3717 ***	0.3831 **	0.3335 ***
	Distance from the Tianhe airport	−0.0391	−0.0502	−0.0295	−0.1353
Eco-environmental policy	Proportion of the eco-environmental baseline area	−0.0666 **	−0.0721 *	−0.3135 ***	−0.229 *

Note: * significant at 0.1 level, ** significant at 0.05 level, *** significant at 0.01 level.

This study focuses on land prices and land supply to discuss the relationship between land policy and the spatial distribution of manufacturing industries. As shown in Figure 5, land prices in the Wuhan metropolitan area show a decreasing trend from the center to the suburbs. Similarly, land prices in central urban areas are much higher than those in peripheral urban areas. In contrast, with the support of land reserve and land expropriation institutions, the land supply on the periphery of the city is much larger than in the downtown area. All these factors lead to a concentration of manufacturing enterprises in suburban areas. The results also show that the land price has a significant negative correlation with the number of manufacturing enterprises (−0.7317 ***), indicating that the number of manufacturing enterprises decreases as the land price increases. Land supply is significantly positively correlated with the number of manufacturing enterprises in each area (0.6452 ***). This indicates that the number of manufacturing enterprises increased as the land supply of the unit increased. Therefore, land policy has a significant impact on the location choice of manufacturing enterprises and the spatial patterns of manufacturing industries. Furthermore, market-oriented reform of land policy affects the spatial differentiation of urban land prices and land supply, thereby affecting the location decision of manufacturing enterprises and promoting and accelerating the suburbanization process of manufacturing space. However, in the model, the correlation between the number of technology-intensive enterprises and land price (−0.1853), as well as between the number of technology-intensive enterprises and land supply (0.2356) is not significant. This indicates that land policy has little effect on the location choice of technology-intensive enterprises.

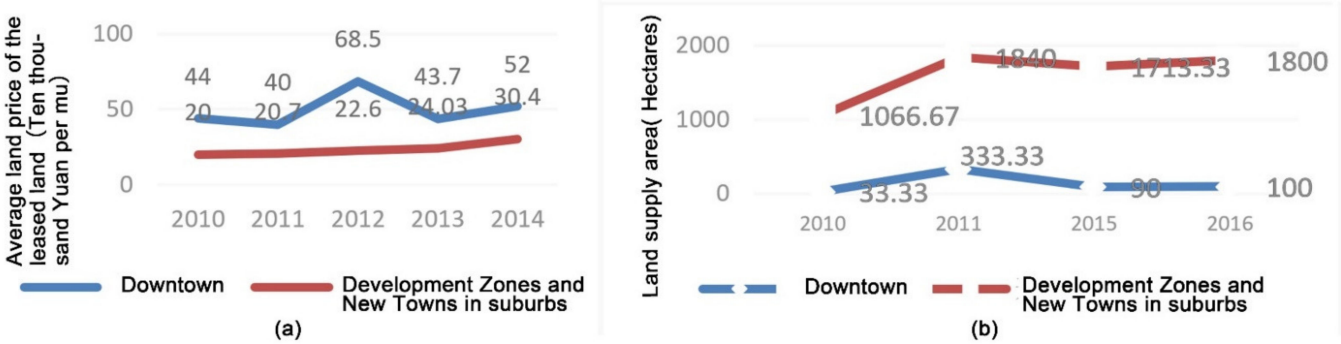


Figure 5. Analysis of manufacturing land transfer in the Wuhan metropolitan area: (**a**) average land price of the leased land; (**b**) land supply area.

3.3. Development Zone Policy

As a new mode of industrial spatial organization, the development zone has been an important factor in industrial transformation and urban spatial expansion since China's reform and opening-up [17,22]. The development zone policy mainly affects special industrial organizations through a series of incentives. These include preferential land price, tilt of land indicators, financial and tax support, and talent awards. This reduces production costs and provides a superior institutional environment for enterprises to attract them to the development zone.

This study discusses the relationship between the development zone policy and the spatial distribution of the manufacturing industry through the index "whether it is a development zone". As shown in Figure 6, 2016 saw 73.84% of manufacturing enterprises in the Wuhan metropolitan area to be distributed throughout various types of development zones, and enterprises continued to agglomerate in development zones. The results also show that the index "whether it is a development zone or not" (0.2859 **) is positively correlated with the number of manufacturing enterprises; this indicates that the planning and construction of the development zone helps attract manufacturing enterprises to Wuhan. For example, technology-intensive enterprises (0.5332 ***) tend to gather in development zones with rich science and education resources and a superior institutional environment.

3.4. Urban Planning

Urban planning is based on developing functional zones and land-use planning, while accounting for eco-environmental protection, transportation, and other aspects of special planning necessary to formulate strategic directions for urban development. Urban planning allows the coordination of land development and space utilization for various types of constructions.

The effects of urban planning are as follows. First, urban planning has promoted the gradient relocation of manufacturing industries by implementing urban renewal strategies. For example, the comprehensive planning of Wuhan (2010–2020) proposed to move the traditional industries out of the downtown and developed the tertiary industry, which provided a policy basis for the functional relocation of manufacturing industries. Second, previous planning determined the urban industrial spatial structure and clarified the layout of the manufacturing space. For example, the comprehensive planning of Wuhan (2010–2020) focused on the suburbs for urban spatial expansion and proposed a layout pattern of "a main urban area and six new town groups". The industrial space focuses on the periphery of new town groups, thus forming the spatial pattern of several development zones and multi-industry clusters in suburban areas (Figure 7).

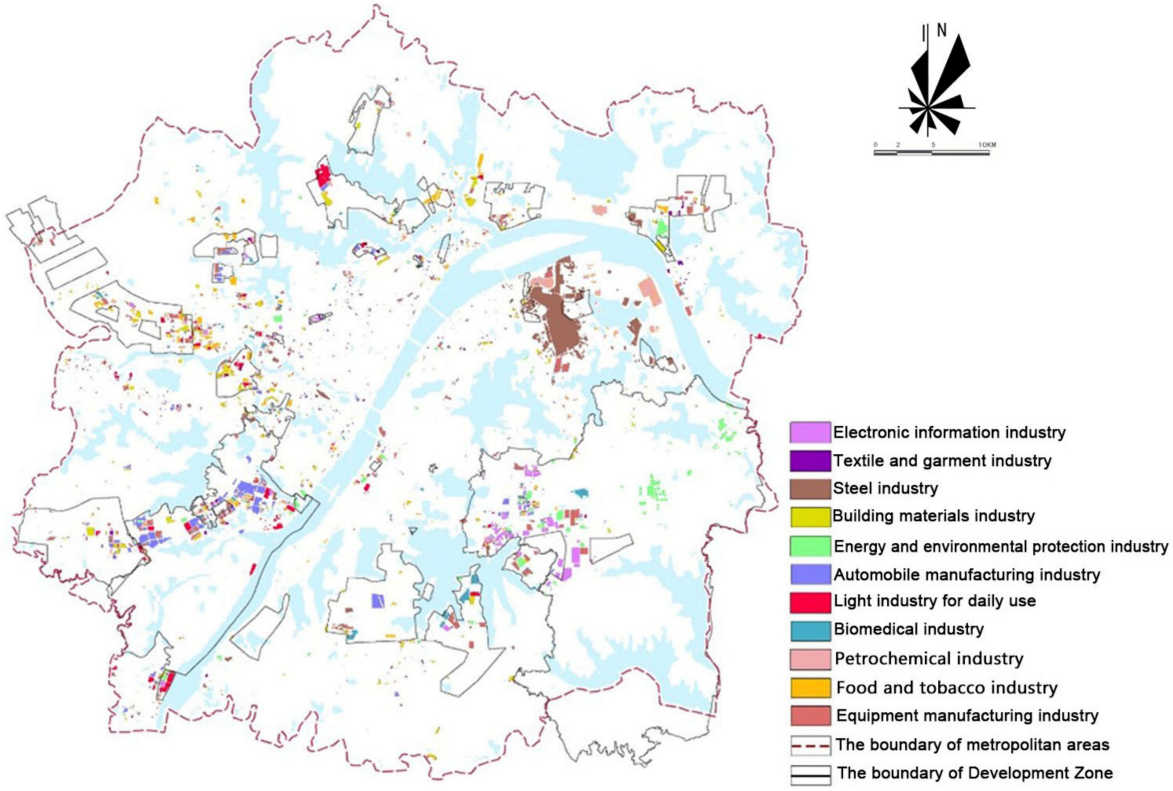


Figure 6. Relationship between manufacturing industry and Development Zone distribution.

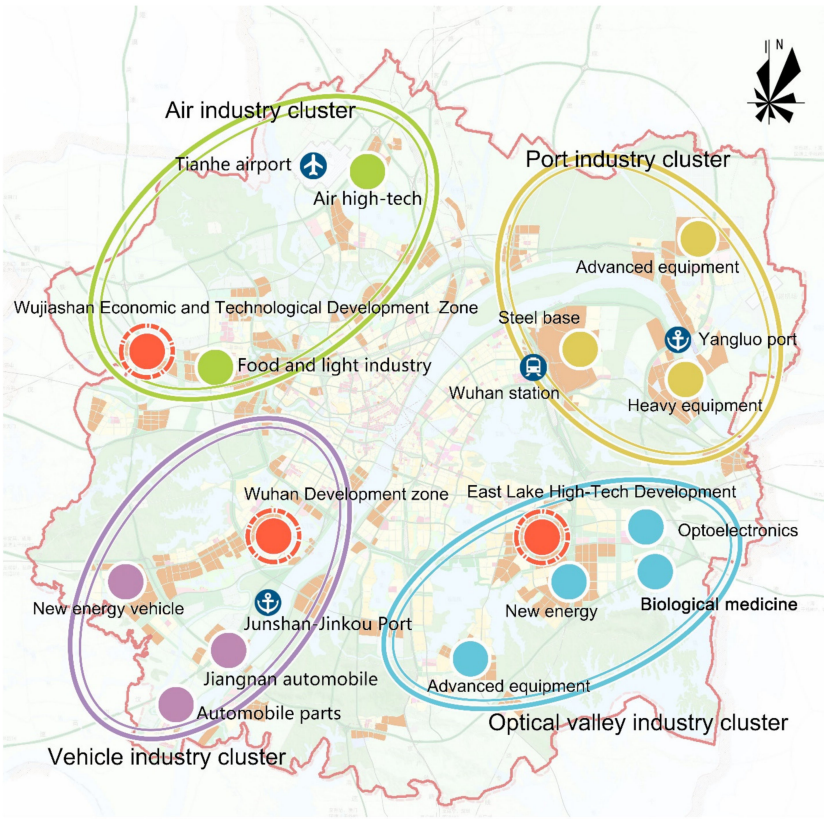


Figure 7. Distribution of industrial strategic areas in the Wuhan metropolitan area.

This study discusses the relationship between urban planning and the spatial pattern of manufacturing industries in terms of two indexes: "whether it is the central urban area" and "whether it is an industrial strategic area." The results show that the index of "whether it is the central urban area" (−0.3673 **) is negatively correlated with the number of manufacturing enterprises. This indicates that the urban renewal strategy has an obvious impact on the location selection of manufacturing industries in Wuhan; moreover, it promotes the migration of manufacturing industries to the suburban area. The index of "whether it is an industrial strategic area" (0.2643 **) is positively correlated with the number of manufacturing enterprises. This shows that the location of manufacturing enterprises strictly follows the strategic positioning and layout of the manufacturing space in the comprehensive planning of Wuhan.

3.5. Transportation Strategy

Transportation strategies have promoted the construction of regional transportation facilities such as high-speed railways, highways, airports, and city loops. They also reduced the time and economic costs of transportation and changed the traditional location selection of enterprises, encouraging manufacturing enterprises to be located along the traffic axis. This study discusses the relationship between transportation strategy and the spatial pattern of manufacturing industries using three indexes: "whether there is a shoreline of the Yangtze River", "whether there is a highway or expressway crossing", and "distance from the Tianhe airport".

As shown in Figure 8, the construction of expressways, airports, ports, urban loops, and intercity railways has promoted the relocation of manufacturing industries. The industrial agglomeration area is formed according to the construction of transportation facilities in the suburban area of Wuhan. For example, relying on the Tianhe airport, industrial agglomeration has formed dominated by aviation logistics, the high-tech industry, and a headquarters economy in northwest Wuhan. In addition, the multidirectional traffic pattern promotes the spatial decentralization of the manufacturing industry in the Wuhan metropolitan area.

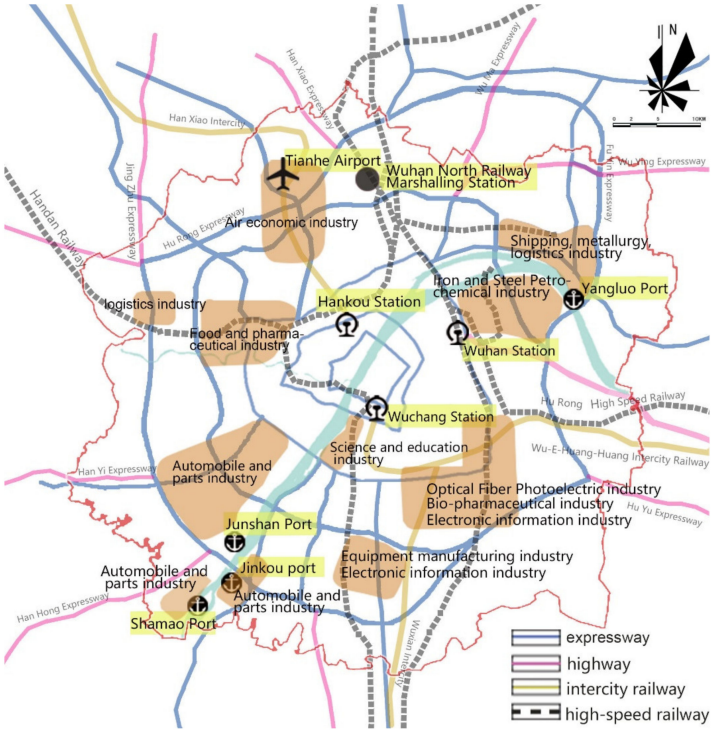


Figure 8. Distribution of important traffic facilities and manufacturing agglomerations in the Wuhan metropolitan area.

The statistical results show that the index of "whether there is a high-speed/expressway crossing" (0.3895 ***) has a significantly positive correlation with the number of manufacturing enterprises. In particular, the positive correlation between labor-intensive manufacturing industries (0.3717 ***) and capital-intensive manufacturing industries (0.3335 ***) is very high, indicating that access to transportation attracts manufacturing enterprises to Wuhan. The index of "whether there is a shoreline of the Yangtze River" (0.1929 *) also has a significantly positive correlation with the number of manufacturing enterprises, with the capital-intensive manufacturing industry (0.3335 ***) having an especially high degree of positive correlation. This indicates that capital-intensive enterprises are highly dependent on water transport. However, the correlation between "Distance from the Tianhe airport" (−0.0391) and the number of manufacturing enterprises is not obvious, mainly because the airport development zone is still in its infancy.

3.6. Eco-Environmental Policies

With China's big cities gradually entering post-industrialism, economic growth at the expense of the environment is no longer viable. The protection of the environment is becoming increasingly important. As a constrained institution, the urban eco-environmental space is protected and controlled by the eco-environmental red line. In 2015, "the Regulations on Basic Eco-environmental Control Line of Wuhan" were promulgated, indicating that eco-environmental control and management had finally become law in Wuhan. While eco-environmental policies restrict the location selection of new manufacturing enterprises in ecologically sensitive areas, they also push enterprises to relocate away from ecologically sensitive areas.

This study also discusses the relationship between eco-environmental policies and the spatial patterns of manufacturing industries using the index of "proportion of the eco-environmental area". As shown in Figure 9, the current manufacturing land in the Wuhan metropolitan area is not within the area defined by the eco-environmental red line. The statistical results also show that the proportion of eco-environmental areas (0.0666 **) has a significant negative correlation with the number of manufacturing enterprises. This indicates that eco-environmental policies place obvious constraints on the location of enterprises and spatial patterns of manufacturing industries in the Wuhan metropolitan area. The effect of eco-environmental policies on the location of technology-intensive enterprises (−0.3135 ***) is the most obvious, implying that technology-intensive industries have a high awareness of eco-environmental protection. Overall, the constraining effect of eco-environmental protection policies on manufacturing space will increase in the future, which will provide a clear spatial access threshold for the location selection of manufacturing enterprises.



Figure 9. Overlap of the area within the eco-environmental bottom line and current manufacturing land in the Wuhan metropolitan are.

4. Policy Implications

The results of our analyses show that land policy, development zone policy, urban planning, transportation strategy, and eco-environmental policies all had significant effects on the spatial patterns of manufacturing industries in the Wuhan metropolitan area since the 1990s. Institutions are an important means of urban spatial governance that affects the spatial restructuring of the manufacturing industry through incentives and constraints. Furthermore, land policy, transportation strategy, and development zone policy reduce the cost of production and external transactions for enterprises through a series of incentives [33]. Using "profit-orientation", enterprises gathered in suburban areas, development zones, transportation trunk lines, and hub areas. However, urban planning and eco-environmental policies regulated the location of enterprises and reduced externalities by means of spatial control and eco-environmental control to promote the orderly reconstruction of manufacturing space.

Different types of institutions also played unique leading roles in the different periods of Wuhan's history. From 1993 to 2004, both the land policy and development zone policy had an important effect on the spatial development of the manufacturing industries in Wuhan. They promoted the retreat of manufacturing industries from the inner city and accelerated the agglomeration to development zones in suburban areas. From 2005 to 2010, under the guidance of an urban planning and transportation strategy, development zones and multi-industry clusters appeared in suburban areas. The process of manufacturing suburbanization was reinforced, which contributed to the spatial decentralization of the manufacturing industries in Wuhan. Since 2011, local governments have played increasingly important roles in developing manufacturing spaces, and the role of eco-environmental policies and urban planning has been strengthened. The total quantity of manufacturing land has increased sharply, while major manufacturing agglomeration areas have formed in the suburbs. Finally, due to the different types of manufacturing industries, their needs and sensitivities to the institution and the degrees of influence also differ. According to the results, labor-intensive enterprises are the most sensitive to land price (−0.6799 ***) and traffic accessibility (0.3717 ***). Technology-intensive enterprises are more inclined to cluster in development zones (0.5332 ***). Capital-intensive enterprises are highly dependent on water transport (0.2398 ***), and eco-environmental control constraints have the most obvious effect on technology-intensive enterprises (0.3135 ***).

Since the global financial crisis of 2008, globalization has entered a new stage. The concept of "reindustrialization" with intelligent manufacturing at the core has proved important for developed countries to adjust their industrial structure. For example, the United States has proposed a strategy for American leadership in advanced manufacturing and encouraged the worldwide withdrawal of some high-tech manufacturing links. "German Industry 4.0" focused on the intellectualization and virtualization of Germany's original advanced industrial model, with the help of the information industry, and gave primacy to the formulation and promotion of new industry standards. The "Made in China 2025" plan proposed to focus on industrial innovation and continued to implement an innovation-driven strategy to enhance core competitiveness. In the context of tightening production factors and weakening globalization, the development of manufacturing industries in developing countries represented by China has entered a critical period, from factor- and investment-driven development to innovation-driven development; thus, institutional supply is also in need of urgent transformation and innovation. It is therefore necessary to further explore spatial transformation and propose institutional innovation, considering the transformation of the global manufacturing industry.

From the perspective of spatial transformation, given the opportunity of a new round of technological and industrial revolution, innovative industries, such as high-tech industries and emerging strategic industries, will play an important role in big cities, and the spatial demand of innovative industries will increase further. Complying with the upgrading trend of international manufacturing industries, the future spatial patterns of manufacturing industries will focus on the innovative manufacturing industrial areas and

be based on the industry's characteristics and spatial needs. At the same time, in selecting locations, manufacturing industries in big cities will pay more attention to regional traffic conditions, the innovation environment, and collaborative patterns of regional industrial space [39]. For example, Wuhan will focus on the development of artificial intelligence, Internet of Things technology, 3D printing technology, and personalized customization in the future. It will then foster world-class manufacturing industrial clusters in optoelectronic communications and general transport equipment manufacturing. In this way, traditional manufacturing will be transformed into intelligent manufacturing and the global competitiveness of the manufacturing industry will be enhanced. The manufacturing space will also form a multi-node and modular regional production network with the surrounding cities in the Wuhan metropolitan area.

From the perspective of institutional innovation, on the one hand, reasonable incentive and restraint mechanisms should be established with the evolution of manufacturing industry development. For example, the institutional incentives of the land policy, development zone policy, and industrial development policy should be oriented away from dependence on low-cost elements to high-end industries, high-tech, high-quality talents, and other innovative elements. The eco-environmental protection policy should require a stricter bottom line of protection and establish a stricter "negative list" mechanism for industries. On the other hand, to cater for the spatial transformation of manufacturing industries and promote the transformation of manufacturing space to a high-quality and high-efficiency level, it is essential to promote institutional reform and innovation. For example, land policy should explore new ways of developing stock land and new models of land supply for innovation industries. The relevant departments may allow various flexible modes of land supply, such as "transfer by stages", "lease first and then grant", and "combination of lease and concession", to meet the space demand of innovative industries. Development zone policy should reward aspects such as talent and technological innovation. Relevant departments may encourage strategic emerging industries through preferential land prices, taxation, finance, talent, and technology.

5. Conclusions

Institutions are important variables that affect the evolution of spatial structures in large cities. A rational, specialized layout of a manufacturing space is the main focus when optimizing the use of land. It is necessary to consider institutions as factors when studying the mechanism of manufacturing spaces in big cities in China.

This study uses GIS spatial analysis and a Poisson regression model to analyze the spatial pattern characteristics of manufacturing industries in the Wuhan metropolitan area, discusses the effect of institutions since the 1990s, and proposes an optimization strategy along with institutional innovation suggestions to deal with the evolution of the international manufacturing industries. The results show that land policy, development zone policy, urban planning, transportation strategy, and eco-environmental policies have all had significant impacts on the spatial pattern of manufacturing industries in the Wuhan metropolitan area since the 1990s. Institutions mainly affect the spatial restructuring process and distribution pattern of the manufacturing industry in metropolitan areas of big cities through incentives and constraints.

The effects on the enterprises location and spatial layout of manufacturing industries are multifaceted and complex, such as globalization, capital, transportation, enterprise strategy, government behavior, etc. However, the institutions should be regarded as the fundamental factor, which has different degrees of cross-influence on other factors. Therefore, it needs to be noted that institutional factors can be taken as one of the independent variables or research perspectives in this paper, and the research results can explain the institutional influence on location selection of manufacturing enterprises, rather than all the influences. This study has some limitations. First, an institution is a large, complex system. The five types of institutions proposed in this study cannot fully reflect the effect that all institutions have on the spatial pattern of manufacturing industries in big cities.

Subsequent studies can further investigate and supplement other types of institutions. Second, this study mainly analyzes the special pattern of manufacturing industries in big cities from the macro level but fails to address the main problems, such as low land use efficiency of manufacturing, which are very important for institutional innovation and need to be further improved.

In the future, we can further study the industrial characteristics and spatial demands of innovative manufacturing industries in the context of global manufacturing transformation. Combined with the current problems of manufacturing land use, this study further examines the content of institutional innovation to cope with the spatial transformation of the manufacturing industry, to guide spatial strategies and institutional innovation suggestions for the spatial transformation and development of the manufacturing industry in contemporary big cities.

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