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Spatial Pattern Evolution of the Manufacturing Industry in the Yangtze River Economic Belt and Its Impact on $PM_{2.5}$

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Abstract: Instead of being merely an important embodiment of regional productivity, the manufacturing industry also serves as a significant sector of economic operation and the supply chain system that is highly dependent on resources and the environment. Studying the spatial pattern of the manufacturing industry and its environmental effect is extremely significant for optimizing the spatial layout of urban industry, allocating production factors in a rational manner, and promoting the green transformation of industry. In this regard, this study aimed to further reveal the spatial pattern characteristics of the regional manufacturing industry and its impact on $PM_{2.5}$. Using data from micro-enterprises in the manufacturing industry in the Yangtze River Economic Belt, its spatial pattern characteristics are explored and an econometric model is constructed to analyze the impact of the manufacturing industry on $PM_{2.5}$ by comprehensively applying approaches including kernel density estimation, nearest proximity index, and Dagum Gini coefficient decomposition. Three research conclusions were drawn: (1) an obvious "core-edge" feature is present in the spatial distribution of the manufacturing industry in the studied area showing an apparent pattern of "high in the east and low in the west". The core density of the manufacturing industry in the central cities is significantly higher than that in the surrounding cities. (2) In the manufacturing industry and its subdivisions, the characteristics of spatial agglomeration are unveiled, while the agglomeration and spatial differences are diminished during the study period for the spatial equilibrium of the manufacturing industry. (3) A significantly positive impact is exerted on $PM_{2.5}$ pollution that is not limited to local cities by the manufacturing industry, which, due to the development differences within the study region, is also heterogeneous. In view of this, policy proposals for aspects such as forging a green manufacturing cluster area, establishing an industrial integration development platform, giving play to regional advantages and technological potential, etc., are put forward in this study, so as to provide a useful reference for optimizing the industrial pattern and promoting the green transformation of industries.

Keywords: manufacturing industry; spatial pattern; environmental effect; Yangtze River Economic Belt

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1. Introduction

The manufacturing industry (MI) plays a major role in producing activity. Since the strike of the 2008 financial crisis, countries across the world have placed considerable value on developing the real economy and the MI [1]. The MI, as a "barometer" of national economic development, has steady development related to improving a country's international status and competitiveness. Furthermore, the efficiency of regional resource utilization and the environmental pattern is also influenced by the geographical pattern and organization of the MI [2]. On the one hand, positive externalities like the scale economy effect and experience as well as technology sharing generated by the spatial agglomeration of the MI are conducive to improving pollution capacity and developing a circular economy with the enhancing the MI [3]. On the other hand, the unreasonable development path of the MI will lead to environmental problems corresponding to pollution industries, which will become major sources of air pollutants within the MI [4]. Therefore, when developing

the real economy with the MI at the core, scientifically mastering the spatial evolution of the regional MI and analyzing the impact of the development of the MI on air pollution are conducive to exploring the beneficial path of the development of the MI and promoting industrial transformation and upgrading. These steps also exert important theoretical and practical significance in enriching research on the spatial pattern and environmental effects of the MI.

The Yangtze River Economic Belt (YREB), while serving as an important MI base in China, is also a vital support zone for economic growth. Nonetheless, the environmental pollution effect caused by its development in the MI is relatively serious, for which the harmony between resource development and utilization and ecological protection has not been achieved. Therefore, problems such as overcapacity in low-end manufacturing, a relatively high proportion of pollution-intensive industries, and urgent promotion of the ecological process of the industry remain to be solved [5]. To develop the YREB, the environmental problems related to air pollution should be tackled. For instance, data from the Ministry of Ecology and Environment of China have revealed that from January to June 2023, Suqian, Zhenjiang, Yangzhou, and other cities located in the YREB have experienced heavy pollution weather, which not only affected the production and life of residents but also weakened the region's ability to attract talent, tourism, and investment. It has been pointed out in the national development plan and the government work reports that the green, ecological, and high-end development of the MI should be promoted. Under such a context, this study aimed to explore the spatial pattern of the MI in the YREB. The environmental effect of air pollution is not only an important topic to study in the development of the MI but is also of great significance in formulating relevant industrial policies for the region, improving industrial specialization division of labor, and driving the industries in greening and coordination.

The main contributions of this paper are reflected in the following three aspects: (1) The characteristics and evolution of the spatial pattern of the MI in the YREB are described from different perspectives such as spatial pattern, spatial agglomeration, and spatial difference. Different from existing studies, which mainly analyzed the spatial pattern characteristics of the manufacturing industry from a single perspective, this study comprehensively depicted the spatial pattern characteristics of the manufacturing industry from a variety of different perspectives. This approach provided a reference and practical guidance for identifying the evolution law underlying the regional spatial pattern of the manufacturing industry and promoting the optimization of the spatial layout of the manufacturing industry under the background of vigorously developing the real economy. (2) Based on the analysis of the spatial pattern of the MI in the YREB, an econometric model was constructed to analyze the environmental effect of the MI. Different from previous studies that focused on the impact of MI on green economic efficiency and urban environmental quality, considering that the MI is an important source of air pollution, this study focused on the impact of the MI on $PM_{2.5}$, a typical air pollutant, in order to enrich MI-related studies and provide references for promoting industrial structure upgrades and green transformation. (3) This study analyzed the impact of the MI on $PM_{2.5}$ from an empirical perspective. Considering that the development of industries is accompanied by the division of labor and cooperation among industries, the industrial development of a city may have a division of labor and relations with the industries in neighboring cities, and $PM_{2.5}$, as a typical air pollutant, has the characteristic of easy diffusion in space. A city's $PM_{2.5}$ concentration may be affected by that of a neighboring city. Therefore, this study further analyzed the spatial spillover effect of the MI on $PM_{2.5}$ when constructing the econometric model in order to provide a new perspective and thinking for the study of environmental effects in the MI and provide a reference for making strategic decisions on ecological environmental protection. Based on this analysis, the MI micro-enterprise data were used as the data source, while spatial analysis methods such as kernel density analysis, nearest neighbor index, Dagum Gino coefficient, etc., were comprehensively used to explore the spatial pattern, spatial agglomeration, spatial difference, and other characteristics of MI. In addition, a Spatial

Dubin Model was established, and the influence of the MI on $PM_{2.5}$ was analyzed from the perspective of spatial spillover.

The rest of this paper is organized as follows. Section 2 reviews the literature on the spatial pattern of the MI and the environmental effects of the MI and explains the hypothesis testing completed in this study. Section 3 provides an introduction to the data sources, research methods, and relevant variables used in this study. Section 4 outlines the analysis of the characteristics of the spatial pattern of the MI in the YREB. Section 5 presents an econometric model used to empirically analyze the impact of the MI on $PM_{2.5}$. Section 6 discusses the results and policy recommendations.

2. Literature Review

2.1. Spatial Pattern of the MI

Industrial development is usually characterized by spatial agglomeration. At the end of the 19th century, Marshall analyzed the agglomeration phenomenon of enterprises and industries based on the concept of "agglomeration" and concluded that the "reservoir" effect of the labor force, economies of scale, and the technology spillover effect were the main factors of spatial agglomeration in the MI, which can be used as the foundation for relevant studies [6]. The neoclassical trade theory indicates that the spatial distribution of enterprises or industries are under the influence of resource endowment and location conditions, while Krugman argues that factors such as increasing returns to scale, transportation costs, and market demand will benefit from forming spatial agglomeration of enterprises or industries [7,8]. Based on the above theories, and focusing on the spatial agglomeration pattern of the MI, the academic community has produced much research with the following specific aspects: (1) Studies on the spatial pattern characteristics and evolution process of the MI based on multi-source data and multiple analysis methods with common data sources involving micro-enterprise database data [9], statistical data [10], field survey data [11], etc. Meanwhile, to explore the spatial distribution and change characteristics in the MI on different regional scales of state, provinces, and prefecture-level cities, approaches such as kernel density estimation, EG index, global and local spatial autocorrelation, and Theil Index are used [12–15]. The related studies indicate that the MI usually shows apparent characteristics of spatial agglomeration and spatial difference [16]. (2) Studies on the factors influencing the spatial pattern of the MI. In early research that mainly stemmed from the traditional industrial location theory, relevant studies highlighted the influence of traditional location factors such as labor, market, transportation, and land price on the spatial pattern of the MI. Following the rise and development of new economic geography, the academic community attached more importance to the influence of agglomeration economy and system on the spatial pattern of the MI. Furthermore, other empirical studies also explored the influencing factors of location choice and spatial distribution difference in the MI while centering on factors, such as environmental regulation [2], marketization level [17], infrastructure [18], and digital technology [19], by comprehensively applying fuzzy qualitative comparative analysis, factor analysis, empirical analysis, and other methods [20–22]. According to the results of previous studies, the spatial distribution of the MI has certain economic and social orientation.

2.2. Related Research on $PM_{2.5}$

Over a long period of time, with extensive and rapid urbanization, various environmental problems have emerged, among which air pollution represented by haze is typical. Compared with other atmospheric particles, $PM_{2.5}$ particles are small. They can be spread widely and remain in the air for a long time, thus constituting an important cause for haze [23]. Highly concentrated $PM_{2.5}$ will exert a serious indirect impact on physical and mental health, traffic safety, economic construction, etc. In this regard, it has been put under the spotlight of regional air pollution prevention and control. Meanwhile, its spatial pattern and influence mechanism have also gained extensive attention from the academic community, which is mainly manifested in the following aspects. The first aspect relates

to the spatio-temporal pattern and evolution law [24]. Relevant scholars have found that $PM_{2.5}$ shows a significant U-shaped, month-to-month change law in the autumn and winter and the spring and summer. In terms of spatial pattern, it also follows a certain economic and social orientation, and the population and industrial agglomeration area has become heavily polluted with $PM_{2.5}$ [25,26]. The second aspect relates to analyzing the factors that influence $PM_{2.5}$. In terms of natural factors, scholars mainly analyze the impact of natural conditions on $PM_{2.5}$ such as wind speed, precipitation, terrain, humidity, and other aspects [27]. In terms of social factors, scholars focus on the impact of energy consumption, car usage, technological innovation, and other factors on $PM_{2.5}$ [28]. Among them, the MI as an important force to promote industrialization and urbanization, and its impact on $PM_{2.5}$ has gradually attracted the attention of scholarly studies. The third aspect relates to the mutual influence of $PM_{2.5}$ among regions [29]. Previous studies have pointed out that $PM_{2.5}$ is not only affected by natural and social factors in the region but also by $PM_{2.5}$ concentration in neighboring regions, and there is a certain lag effect and rebound effect between regions [30]. When the pollution spillover effect from the regional central city is greater than its own optimization and adjustment effect, the neighboring cities will be affected by the pollution spillover of the central city. This spatial spillover effect of $PM_{2.5}$ is one of the important reasons for $PM_{2.5}$ pollution in less developed areas [31].

2.3. The Impact of the MI on Air Pollution

Usually characterized by agglomeration in space, the MI's theoretical basis can be traced back to Marshall's industrial agglomeration theory, mainly emphasizing that labor sharing, intermediate input, and economies of scale brought by agglomeration can realize technology sharing and spillover and improve production efficiency, which has been expanded and developed in subsequent studies [32]. An empirical analysis is carried out based on the measurement of MI, stressing the impact of industrial agglomeration on production efficiency. The focus of existing studies is on the positive effect of the MI on improving production efficiency, while the negative effect of the MI is also attracting attention. It has been pointed out in relevant studies that the MI may cause excessive competition, and the resulting congestion effect may lead to resource misallocation and reduce production efficiency [4]. Industrial agglomeration will refine industrial division of labor and increase production links, thus increasing the relatively easy cost. To obtain competitive advantages, enterprises may monopolize key technologies, which goes against the diffusion of production technology [33]. As a result, on the one hand, agglomeration of the MI may reduce production efficiency, cause resource waste, and exacerbate pollution emission, while, on the other hand, as an important production sector, the MI is accompanied by a large number of production and transportation activities in its development, which will reduce the carrying capacity of the urban environment. Meanwhile, manufacturing agglomeration will also give rise to economic activities and population agglomeration, hence intensifying the human–land contradiction. Moreover, previous studies have also proved the negative impact of MI agglomeration on the environment [34]. For instance, after conducting an empirical study, Song et al. (2023) determined that negative effects of environmental pollution would gradually emerge along with the agglomeration of the MI reaching a certain scale [32]. Based on the existing research, Hypothesis 1 is thereby proposed.

Hypothesis 1. *The agglomeration of the MI will increase $PM_{2.5}$ pollution in the YREB.*

Furthermore, as an important part of industrial development, the MI has its evolution process presented as cyclical characteristics. When the MI is in the growth stage of incremental market development, the congestion effect of industrial development is not formed, while the development of the MI and urban ecological environment remain in a virtuous cycle [35]. Nonetheless, when the MI develops into its mature stage, competition among enterprises will be intensified by the limited market conditions, which is to the disadvantage of efficiently utilizing resources. Moreover, the dominant congestion effect

will also show up because of the limited environmental carrying capacity of industrial agglomeration areas. Hence, the nonlinear relationship between MI development and the ecological environment has gradually become the focus of related research [36]. For instance, the empirical study by Yuan et al. (2022) pointed out that MI agglomeration would exert a non-linear influence on regional green development [37]. In view of this, Hypothesis 2 is thereby proposed.

Hypothesis 2. *The agglomeration of the MI may have a nonlinear effect on $PM_{2.5}$ pollution in the YREB.*

3. Data Sources and Research Methodologies

3.1. Study Area

The YREB is an important economic corridor and ecological civilization construction area in China, with strong comprehensive strength and development potential, and is a watershed area with international influence [38]. As shown in Figure 1, the YREB covers 11 provincial-level administrative units, including two municipalities and 9 provinces. In 2021, the GDP and added value of the secondary industry accounted for 46.6% and 46.9% of China's total, respectively. The population and economic density are 2.17 times and 2.05 times China's average. The YREB is not only an important engine for China's economic growth in the new era but also a relatively concentrated area of population and environmental pollution. This is a typical area to study the contradiction between humans and land.

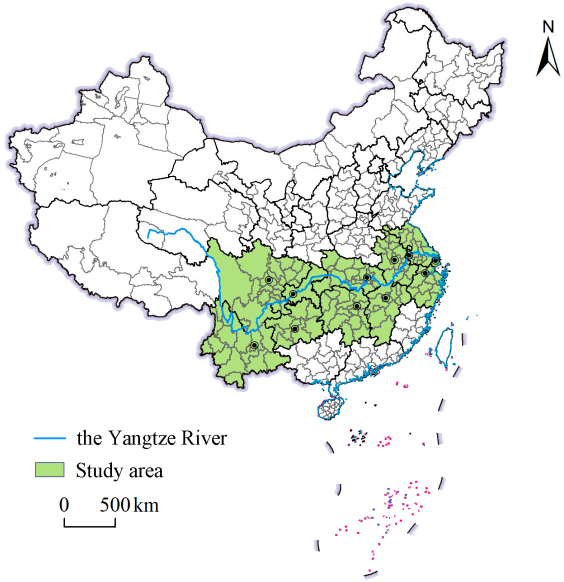

Figure 1. Study area.

3.2. Data Sources

In this paper, the spatial pattern in the MI is demonstrated based on data from micro-enterprises in the MI sourced from the third eye check platform (https://www.tianyancha.com/) and the national enterprise credit information publicity system (https://www.gsxt.gov.cn/). In terms of enterprise attributes, the enterprise name, address, time of establishment, registered capital, industry, business scope, and other information are covered. In this study, air pollution is measured with data on the average annual concentration of $PM_{2.5}$ from Dalhousie University's Atmospheric Composition Analysis Group, while the socioeconomic statistics are from the China Economic and Social Big Data Research Platform (https://data.cnki.net/) [39]. The source of the data on annual precipitation for interpreting variables is the Resource Environmental Science and Data Science at the Chinese Academy of Sciences (https://www.resdc.cn), while the source of the data on temperature inversion

is the dataset from the satellite NASA MERRA2. The data in these link was searched several times and was last accessed on 30 October 2022.

3.3. Data Processing

From the attribute data on the enterprises in the industry information, 454,718 enterprises established before 31 December 2020 in the MI with registered capital exceeding CNY 5 million (with a certain scale) are selected in accordance with the Industry Classification of the National Economy (GB/T 4754-2017) [40]. After eliminating the enterprises with addresses of wrong interpretation based on Amap API, the final number of enterprises in the MI is 453,985. Before converting the latitude and longitude coordinates into spatial data on the manufacturing enterprise using ArcGIS 10.2 the longitude and latitude coordinates of the manufacturing enterprise were queried based on the address information in the enterprise attributes, and the interpretation rate was greater than 99.8%. Then, based on the industrial intensity and referring to relevant studies, 31 MIs are categorized into labor-intensive, capital-intensive, and technology-intensive types based on industrial intensity (Table 1) [41].

Table 1. Classification of the MIs.

Classification	Manufacturing Industries
Labor intensive	(13) agricultural and sideline food processing industry; (14) food manufacturing industry; (15) wine, beverage and refined tea manufacturing industry; (16) tobacco products industry; (17) textile industry; (18) textile, clothing, and apparel industry; (19) leather, fur, feathers, and their products and footwear industry; (20) wood processing and wood, bamboo, rattan, brown, and grass products industry; (21) furniture manufacturing industry; (22) paper and paper products industry; printing and recording media reproduction industry; (24) culture, art, sports, and entertainment products manufacturing industry
Capital intensive	(25) petroleum, coal, and other fuel processing industry; (28) chemical fiber manufacturing industry; (29) rubber and plastic products industry; (30) non-metallic mineral products industry; (31) ferrous metal smelting and rolling processing industry; (32) non-ferrous metal smelting and rolling processing industry; (33) metal products industry
Technology intensive	(26) chemical raw materials and chemical products manufacturing industry; (27) pharmaceutical manufacturing, industry; (34) general equipment manufacturing industry; (35) special equipment manufacturing industry; (36) automobile manufacturing industry; (37) railways, ships, aerospace, and other transportation equipment manufacturing industry; (38) electrical machinery and equipment manufacturing industry; (39)computers, communications, and other electronic equipment manufacturing industry; (40) instrumentation manufacturing, comprehensive utilization of waste resources, repair of metal products, machinery and equipment industry

3.4. Research Method

3.4.1. Nuclear Density Analysis

The nuclear density analysis method used in this study to describe the spatial outcome of the MI in the YREB is one of the commonly used spatial interpolation methods to estimate the spatial agglomeration and dispersion levels of variables based on sample point data, where the kernel density value is directly proportional to the spatial agglomeration level of the sample data [42]. It is mainly implemented using ArcGIS 10.2 and its calculation process is as follows:

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

Based on this equation, the larger the $f(x)$ value, the higher the nuclear density value. $x - x_i$ refers to the distance between the estimated point and the sample point, h stands for

the search radius of the kernel density estimate, n represents the number of sample points in the range of h, and $K\left(\frac{x-x_i}{h}\right)$ is the kernel function.

3.4.2. Nearest Neighbor Index

The nearest neighbor index (*NNI*) measures the spatial distribution pattern of manufacturing enterprises in YREB based on a ratio calculated as the average distance between each manufacturing enterprise and its nearest manufacturing enterprise divided by the average distance between each manufacturing enterprise under a random distribution [43]. In this study, the *NNI* is used to characterize the spatial agglomeration characteristics of the MI. It was mainly implemented using ArcGIS 10.2 in the calculation process as follows:

$$NNI = \frac{D_N}{D_R} = \left(\frac{1}{n}\sum_{i=1}^{n} d_i\right) / \left(\frac{1}{2}\sqrt{A/n}\right) \quad (2)$$

In the equation, d_i is the actual distance between an enterprise and its nearest neighbor, A represents the area of the YREB, and n is the number of prefecture-level cities i. An $NNI = 1$ indicates the random distribution of manufacturing enterprises in the YREB. An $NNI < 1$ means that the manufacturing enterprises in the YREB tend to be clustered. And an $NNI > 1$ demonstrates that the manufacturing enterprises in the YREB tend to be distributed randomly.

3.4.3. Dagum Gini Coefficient

The Dagum Gini coefficient method is widely used for measuring regional differences to reflect the differences in the geographic concentration index of the MI in the upper, middle and downstream range of a study area, as well as the differences in the MI in the upper, middle, and downstream range of a study area. In this study, the Gini coefficient (G) for the whole YREB is decomposed into an intra-regional difference contribution G_w, an inter-regional net difference contribution G_{nb}, and a super-variable density contribution G_t. To limit the length of this paper, this computational procedure is not listed. The method was mainly calculated using Matlab 2018b referring to the specific calculation [44].

3.4.4. Spatial Durbin Model

On the basis of spatial pattern analysis, using the annual average $PM_{2.5}$ concentration of each county as the explanatory variable and the geographical concentration index of manufacturing enterprises as the core explanatory variable, an economic model is established to analyze the environmental impact of air pollution from the perspective of empirical analysis. Considering that air pollution such as $PM_{2.5}$ may be affected by adjacent areas, the spatial Durbin model (SDM) is thereby selected for estimation [45]. The model was mainly constructed using Stata 17 with the calculation formula:

$$Y_{it} = \beta X_{it} + \rho\sum_{j=1}^{n} W_{ij}X_{jt} + \delta\sum_{j=1}^{n} W_{ij}Y_{jt} + u_i + \lambda_i + \varepsilon_i \quad (3)$$

$$W_{ij}\begin{cases} \frac{1}{d_{ij}}(i \neq j) \\ 0(i = j) \end{cases} \quad (4)$$

$$W_{ij} = \begin{cases} \frac{1}{\left|pgdp_i - pgdp_j\right|}(i \neq j) \\ 0(i = j) \end{cases} \quad (5)$$

In the equation, X_{it} and Y_{jt} are the observed values of the explanatory and explained variables for cities i and j in period t, respectively; β is the coefficient of the explanatory variable; and W_{ij} represents the spatial weight matrix. Equation (4) is the geographical distance matrix, where d_{ij} is the distance from city i to city j. Equation (5) is the economic distance matrix, where pgdp is per capita GDP. In this paper, Equation (4) is selected as the

spatial weight matrix for the main regression results, and Equation (5) is selected for the robustness test. ρ is the spatial regression coefficient; δ is the spatial lag coefficient; u_i and λ_i are spatial and temporal effects, respectively; and ε_i is the disturbance term. When $\rho = 0$ and $\delta \neq 0$, Equation (3) corresponds to the SLM model. When $\rho = -\beta\delta$, Equation (3) is the SEM model.

4. Spatial–Temporal Pattern of the MI

4.1. Spatial Pattern of the MI

According to the kernel density estimation method, the spatial pattern of the 4-year characteristic MI is plotted (Figure 2. As can be seen from Figure 2: (1) the core density of MI increased from 28,575.3 in 2005 to 132,480 in 2020, indicating a development trend in the spatial agglomeration of the MI. (2) The core density of MI is characterized by the spatial pattern of "the downstream is higher than the upstream, and the central city is higher than the surrounding areas", and the spatial distribution has obvious economic and social direction. The downstream region forms a centralized and interconnected manufacturing cluster in the Yangtze River Delta region. Due to the advantages of central cities, such as Wuhan, Changsha, Chongqing, and Chengdu, in their economic and social development, transportation and communication infrastructure, and human capital, a "high value island" with a discrete distribution of nuclear density values is formed in the region. In the periphery of the central city, the core density of the MI showed a spatial distribution pattern of circular decline.

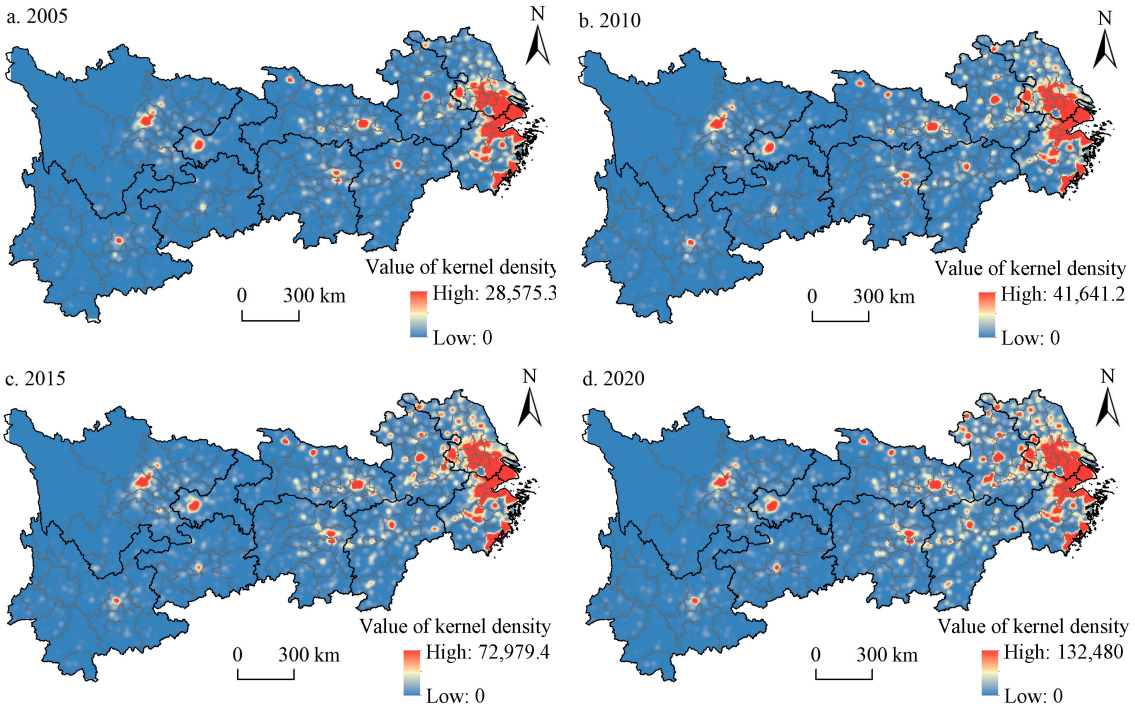

Figure 2. Kernel density map showing the MI.

The graph in Figure 3 further describes the labor-intensive, capital-intensive, and technology-intensive MI. The spatial pattern characteristics of labor-intensive, capital-intensive, and technology-intensive manufacturing industries are consistent with the spatial pattern characteristics of the whole sample manufacturing industry, and its spatial distribution has an economic–social orientation and significant "core-edge" characteristics. In terms of the kernel density value, the kernel density value for technology-intensive MIs is greater than that for the labor-intensive and capital-intensive manufacturing industries. Compared with labor-intensive and technology-intensive manufacturing industries, the high-value areas with technology-intensive MIs core density are more concentrated in the

Yangtze River Delta region, with an active flow of innovation factors and strong innovation ability. Considering the Yangtze River Delta as the core area, the core density value for the labor-intensive and capital-intensive manufacturing industries is based on the middle and upper reaches of the central cities, forming a spatial pattern of "small agglomeration and multi-center".

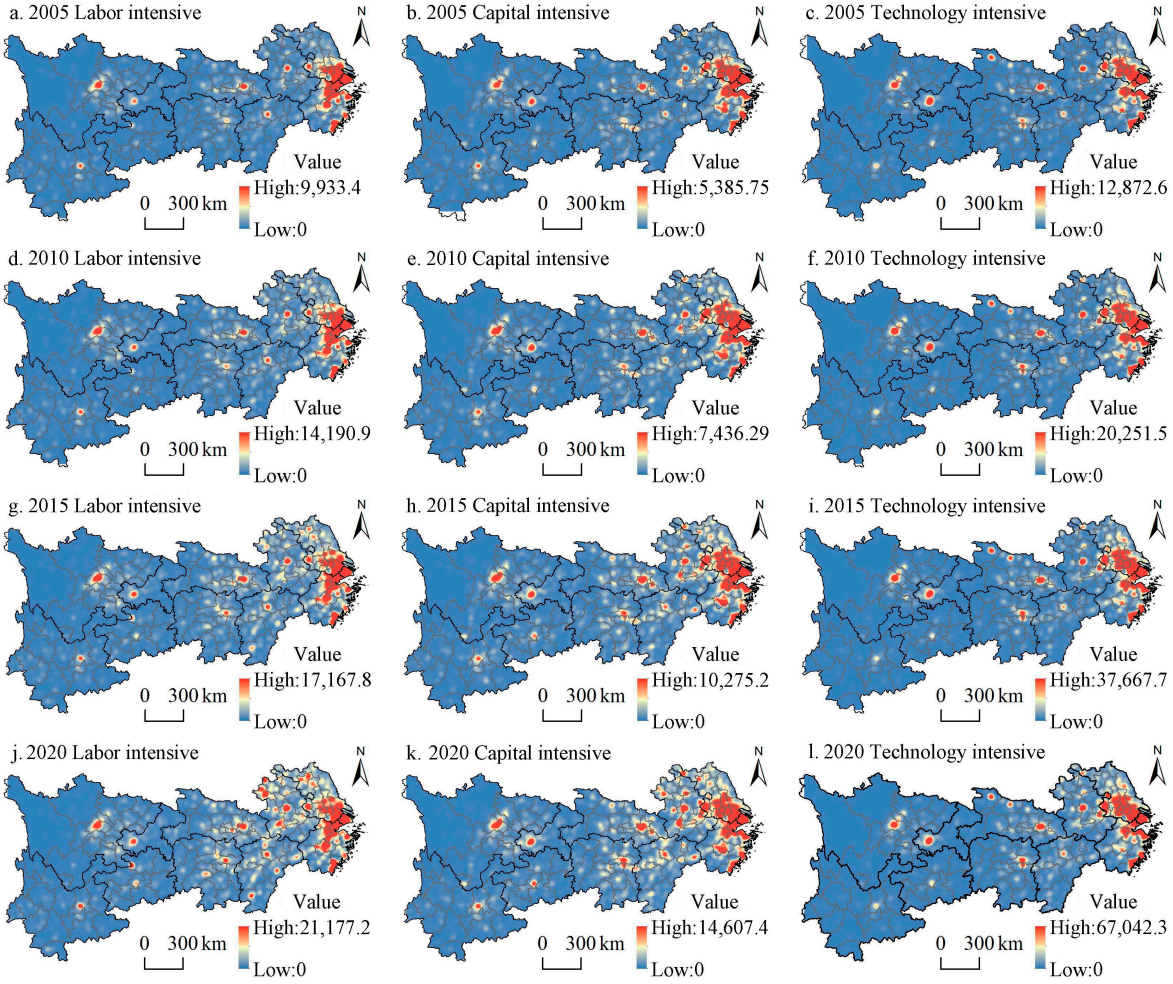

Figure 3. Distribution of nuclear density for the different types of MI.

4.2. Characteristics of Spatial Agglomeration of MI

Based on the kernel density analysis, the nearest neighbor index (*NNI*) is used to explore the spatial distribution and agglomeration characteristics from the perspective of overall industries and sub-industries (Table 2). As can be seen from Table 2 the NNI values in 2005, 2010, 2015, and 2020 are 0.178, 0.171, 0.167, and 0.156, respectively, with a continuous decrease of much less than 1, indicating that the MI in the studied area shows the characteristics of an agglomeration distribution. Meanwhile, the NNI value for each subsector in the MI is also less than 1, which is characterized by an agglomeration distribution, but there are some differences in the agglomeration of various industries. The industries with significant improvement in the agglomeration level, such as the (34) general equipment MI, (35) special equipment MI, and (36) automobile MI, are concentrated in technology-intensive manufacturing industries. The agglomeration level of labor-intensive MIs, such as the agricultural and sideline food processing industry and food MI, is significantly lower than that of the technology-intensive MIs, indicating that the agglomeration level of technology-intensive and other high-end MIs is continuously improving, the process of upgrading the MI is further advancing, and the production factors such as technology and knowledge are flowing and spreading among industries.

Table 2. Distribution of nuclear density for different types of MIs.

Name of Manufacturing Industry	2005	2010	2015	2020	Color Classification
(13) Farm and sideline food processing industry	0.391	0.374	0.362	0.360	0.156~0.180
(14) Food manufacturing industry	0.402	0.385	0.363	0.333	0.181~0.215
(15) Wine, beverage, and refined tea manufacturing industry	0.435	0.415	0.413	0.379	0.216~0.245
(16) Tobacco industry	0.499	0.563	0.492	0.475	0.246~0.272
(17) Textile industry	0.195	0.189	0.179	0.165	0.273~0.311
(18) Textile clothing, clothing industry	0.225	0.231	0.230	0.227	0.312~0.360
(19) Leather, fur, feathers, and their products and footwear industry	0.280	0.289	0.273	0.272	0.361~0.411
(20) Wood processing and wood, bamboo, rattan, palm, and grass products industry	0.367	0.375	0.363	0.339	0.412~0.563
(21) Furniture manufacturing industry	0.329	0.300	0.279	0.253	
(22) Paper and paper products industry	0.328	0.319	0.286	0.271	
(23) Printing and recording media reproduction industry	0.271	0.263	0.249	0.252	
(24) Culture and education, industrial beauty, and sports and recreational goods manufacturing	0.246	0.245	0.236	0.210	
(25) Petroleum, coal, and other fuel processing industry	0.501	0.495	0.458	0.485	
(26) Chemical raw materials and chemical products manufacturing industry	0.278	0.262	0.269	0.276	
(27) Medicine manufacturing industry	0.318	0.292	0.268	0.244	
(28) Chemical fiber manufacturing industry	0.424	0.427	0.407	0.322	
(29) Rubber and plastic products industry	0.236	0.218	0.212	0.216	
(30) Manufacturing of non-metallic mineral products industry	0.324	0.304	0.308	0.292	
(31) Ferrous metal smelting and calendering processing industry	0.361	0.340	0.330	0.310	
(32) Non-ferrous metal smelting and rolling processing industry	0.380	0.330	0.318	0.282	
(33) Metal products industry	0.254	0.239	0.219	0.208	
(34) General machinery manufacturing industry	0.180	0.173	0.165	0.156	
(35) Special equipment manufacturing industry	0.256	0.209	0.206	0.186	
(36) Motor industry	0.217	0.188	0.181	0.165	
(37) Manufacturing of railway, ship, aerospace, and other transportation equipment industry	0.251	0.220	0.180	0.165	
(38) Electrical machinery and equipment manufacturing industry	0.259	0.214	0.169	0.161	
39 Manufacturing of computers, communications, and other electronic equipment industry	0.214	0.218	0.207	0.180	
(40) Instrument manufacturing industry	0.215	0.211	0.217	0.213	
(41) Other manufacturing industry	0.323	0.291	0.287	0.262	
(42) Comprehensive utilization of waste resources industry	0.466	0.437	0.446	0.380	
(43) Metal products, machinery, and equipment repair industry	0.392	0.363	0.341	0.313	
Manufacturing industry as a whole	0.178	0.171	0.167	0.156	

4.3. Characteristics of Spatial Differences in the MI

Differences in the characteristics of the spatial distribution of MIs are further described, and a decomposition analysis is conducted from the perspectives of the upper, middle, and lower reaches using the Dagum Gini coefficient method (Table 3). As can be seen

from Table 3, the overall Gini coefficient for the MI in 2005–2020 decrease, while the upstream, middle, downstream, intra-group, and inter-group decreased, indicating that the number of manufacturing enterprises was gradually unbalanced. It may be that in recent years, national strategic policies have been launched to coordinate, promote, and actively construct industrial transfer demonstration areas, which effectively promoted the quality of regional industrial development, improved the quality of industrial development in the middle and downstream regions, and actively stimulated development vitality in the middle and upstream regions. In terms of intra-regional differences, a significant difference in the manufacturing agglomeration levels in the upper, middle, and lower reaches of the three regions is presented, in which the highest degree of internal disequilibrium is in the upper reaches, while the highest degree of equilibrium is in the middle reaches. Considering the contribution rates of the regional difference, the average contribution rates of the three indexes to the overall regional difference from small to large are supervariable density, intra-group gap, and inter-group gap, among which the contribution rate of inter-regional difference accounts for the largest proportion and gradually increases, while the contribution rate of intra-regional difference is small and constantly decreases, indicating that the spatial pattern difference in the manufacturing industry should reduce. In this regard, it is not only necessary to pay attention to the coordinated development within the region but also to the coordinated development between regions.

Table 3. Decomposition of the Dagum Gini coefficient for manufacturing.

Year	Total	Upstream	Midstream	Downstream	Intra-Class	Interblock	Supervariable Density	Rate of Contribution (%)		
								Intra-Class	Interblock	Supervariable Density
2005	0.696	0.640	0.383	0.596	0.189	0.432	0.075	27.124	62.084	10.792
2010	0.650	0.609	0.360	0.526	0.169	0.413	0.069	25.942	63.465	10.594
2015	0.608	0.572	0.342	0.477	0.154	0.387	0.067	25.263	63.707	11.030
2020	0.573	0.557	0.329	0.406	0.135	0.380	0.057	23.638	66.330	10.032

5. Environmental Effects of Air Pollution in the MI

5.1. Variable Selection and Description

5.1.1. Explained Variable

$PM_{2.5}$ was the explained variable in this study. This study plots the spatial–temporal pattern changes in $PM_{2.5}$ based on its average annual concentration in prefecture-level cities in the YREB (Figures 4 and 5). Plots a and b in Figures 4 and 5 divide the mean $PM_{2.5}$ concentration in the YREB into five levels: above 0~20, 20~35, 35~50, 50~70, and 70 $\mu g/m^3$, with reference to the division standard in the Code for Monitoring Ambient Air Quality (Trial). Plots c and d in Figure 5 calculate the difference in $PM_{2.5}$ concentration in different years (visualized by subtracting the previous year from the following year) to analyze the spatial–temporal pattern in $PM_{2.5}$ in the YREB. It can be seen from Figure 3 that the average annual concentration of $PM_{2.5}$ in prefecture-level cities in the YREB is mainly in the range of 35–50 and 50–70, indicating relatively serious air pollution. However, the average annual $PM_{2.5}$ concentration shows a downward trend as a whole with an increasing number of cities falling in the range of 20–35. According to Figure 4, the concentration of $PM_{2.5}$ in the YREB shows a trend change from "high in the middle and low in the east and west" to "high in the north and low in the south", and its spatial distribution is generally consistent with the level of economic development and the intensity of human activities, reflecting that there is a certain correlation between social and economic activities, such as economic agglomeration and industrial development and the spatial distribution of $PM_{2.5}$. However, there is a significant decrease in the $PM_{2.5}$ concentration in the central region of the YREB in 2020 compared to 2012, which is due to the implementation and promotion of space pollution-related prevention and control policies.

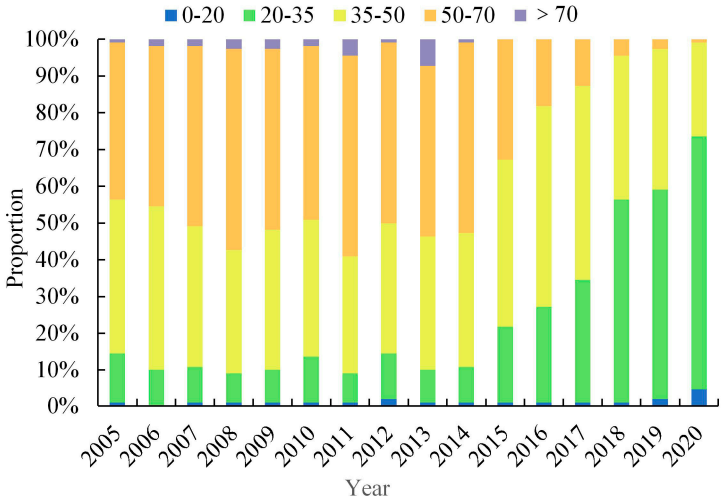

Figure 4. Variation trend in $PM_{2.5}$ concentration among prefecture-level cities in the YREB from 2005 to 2020.

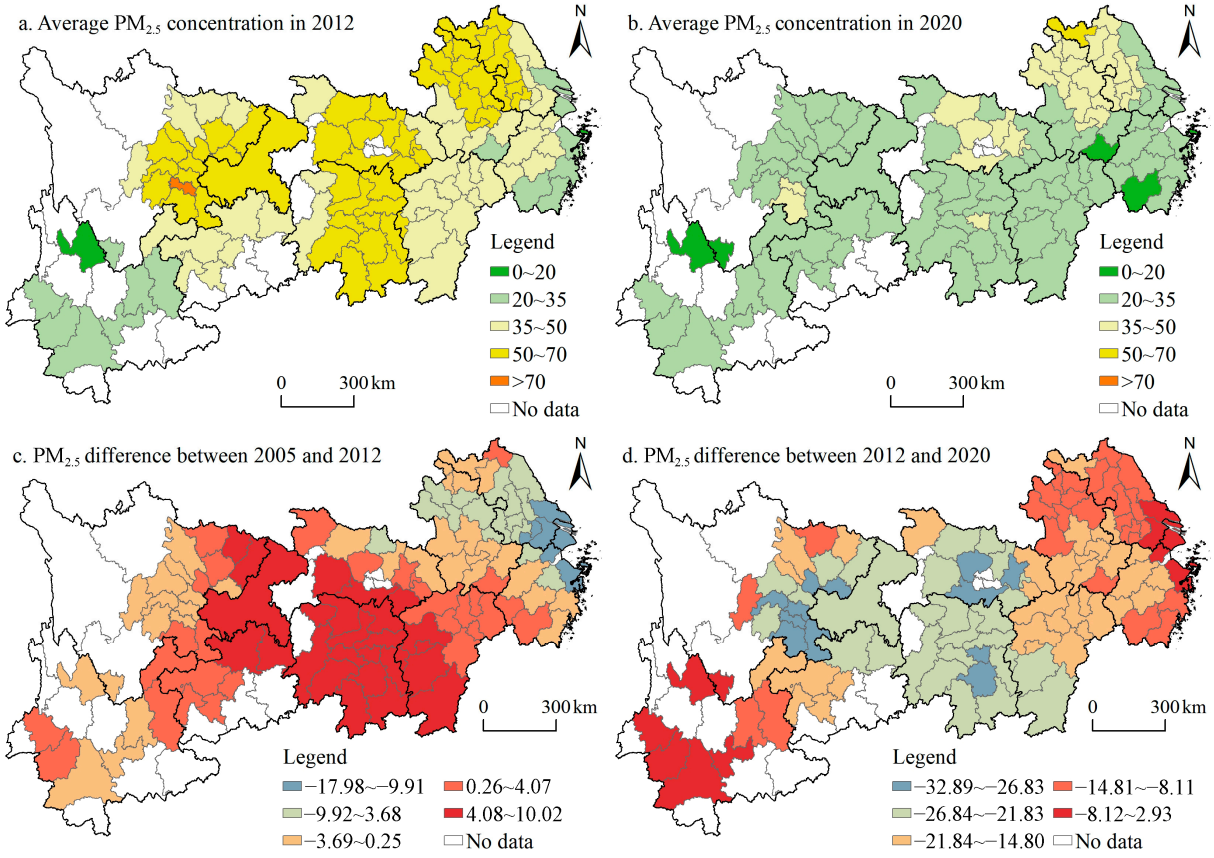

Figure 5. Spatial pattern and change trend in mean $PM_{2.5}$ concentration in prefecture-level cities in the YREB.

5.1.2. Explanatory Variable

Natural factors such as average annual precipitation and average annual temperature inversion, along with social and economic factors such as per capita GDP and environmental regulations, are incorporated into the same econometric model, while the number of manufacturing enterprises in prefecture-level cities is used as the core explanatory variable to explore its impact on $PM_{2.5}$.

(1) Core explanatory variable: manufacturing industry (MI). The number of manufacturing enterprises in prefecture-level cities in the MI, that is, the main industry responsible for air pollution emissions and carbon emissions, is selected as the core explanatory variable in this study. An econometric model is constructed for analyzing the impact of the MI on air pollution.

(2) Control variables: Considering the possibility that $PM_{2.5}$ pollution may be affected by both natural and socioeconomic factors, and referring to relevant studies, some natural, economic, and social factors are selected as control variables, including annual average precipitation (*Rain*), annual average temperature inversion (*Ainve*), per capita GDP (*Pgdp*), environmental regulation (*Enr*), science and technology expenditure (*Tech*), and level of opening up (ln*Open*). Meanwhile, with reference to the research achievements of Liu et al. (2022), three indexes for industrial wastewater, industrial SO_2, and industrial smoke and dust emissions are selected for environmental regulation (*Enr*) to calculate the comprehensive indexes of environmental regulation. In addition, a science and technology expenditure (*Tech*) variable is selected with the science and technology expenditure in the fiscal expenditure for the measurement [46]. The level of opening to the outside world is represented by the amount of foreign capital actually utilized.

The scatterplot and fitted line for the full sample of the manufacturing industry, its various classified industries, and $PM_{2.5}$ pollution are shown in Figure 6, which directly reflect the relationship between the MI and $PM_{2.5}$ in prefecture-level cities. Figure 5 shows a significant positive correlation between MI and its classified industries and $PM_{2.5}$ pollution. In addition, the logarithmic processing for each variable and their respective descriptive statistics are shown in Table 4.

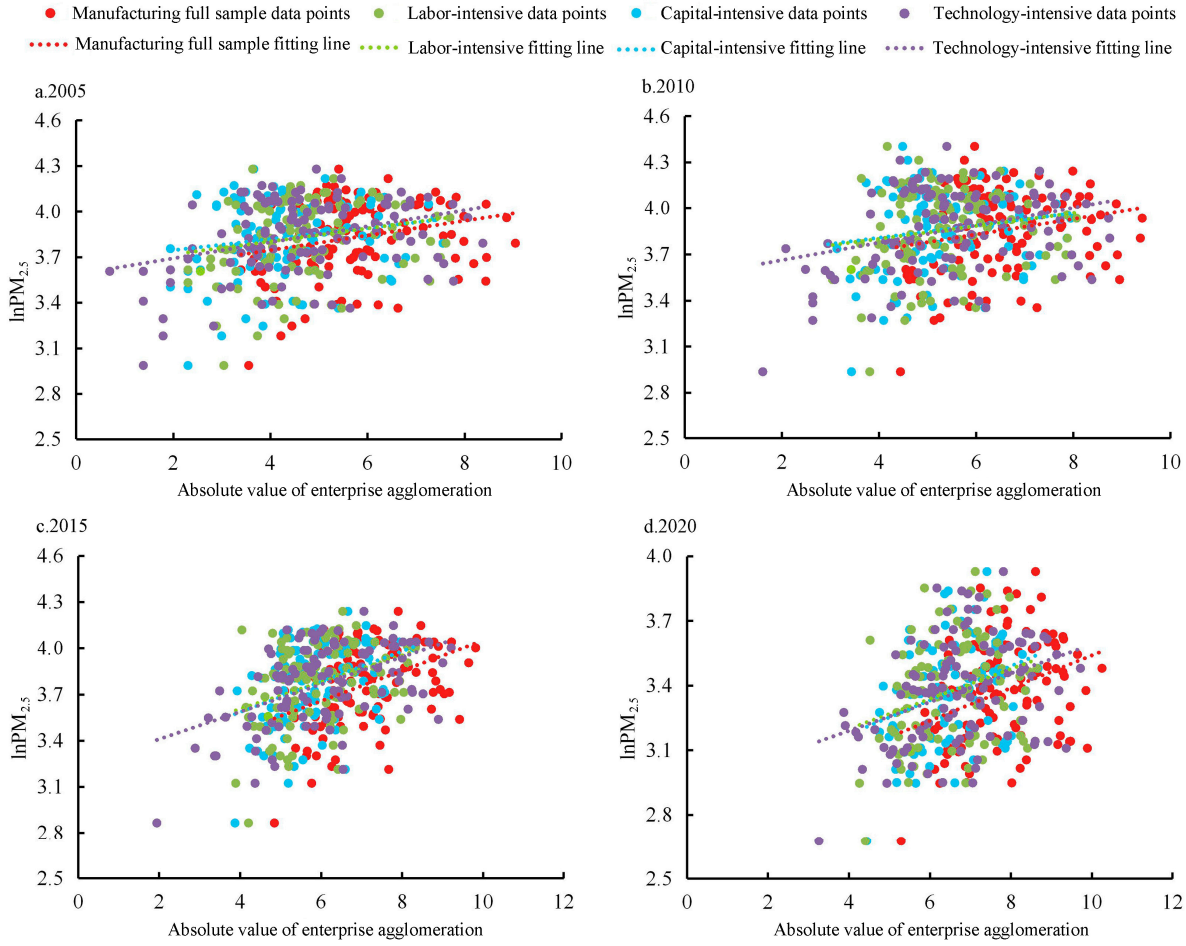

Figure 6. Distribution of nuclear density for different types of manufacturing industries.

Table 4. Descriptive statistics of variables.

Variable Name	Symbol	Mean Value	SD	Min	Max
Average annual $PM_{2.5}$ concentration ($\mu g/m^3$)	ln$PM_{2.5}$	3.765399	0.299881	2.633445	4.401156
Number of manufacturing enterprises	ln*Manu*	48.06142	17.84762	11.56814	105.2275
Average annual precipitation (millimeter)	ln*Rain*	7.100512	0.229435	6.457443	7.789269
Average annual temperature inversion	ln*Ainve*	0.333423	0.203969	0.00001	1.131231
Per capita GDP (CNY)	ln*Pgdp*	10.32373	0.816877	4.59512	12.20115
Environmental regulation	ln*Enr*	4.397535	0.355693	1.617406	6.654784
Tech spending (CNY ten thousand)	ln*Tech*	9.999481	1.84088	4.343805	15.26564
Level of opening-up (USD ten thousand)	ln*Open*	9.99823	1.963537	1.098612	14.48514

5.2. Model Correlation Test

The relevant measurement tests are shown in Table 5, which are used to find an appropriate measurement model for estimation. Based on the results, the Moran'*I* and LM tests, as they are significantly positive, are suitable for selection as the spatial measurement model for this study. The LR test significantly rejects the null hypothesis for which the model is applicable using the spatial econometric model for the estimation and cannot be degraded into SLM and SEM.

Table 5. Correlation test.

Test	Statistic	*p*-Value
Moran'*I*	32.088 ***	0.000
LM(lag) test	223.297 ***	0.001
Robust LM(lag) test	212.955 ***	0.000
LM(error) test	51.54 ***	0.001
Robust LM(error) test	41.200 ***	0.000
Wald(SLM)	138.92 ***	0.000
Wald(SEM)	155.30 ***	0.001
LR_spatial_lag	48.03 ***	0.000
LR_spatial_error	63.50 ***	0.001

Note: ***, which respectively represent significancet at the level of 1%.

5.3. Baseline Regression Result

The baseline regression results in Table 6 indicate the significant positivity of the spatial regression coefficient rho, which demonstrates that $PM_{2.5}$ in each city has a significant positive correlation spatial effect, and neighboring cities will interact with each other. Additionally, as the lnMI and ln$PM_{2.5}$ have a significant positive correlation and show consistency across different models, there is a significant positive effect of the spatial agglomeration in the MI on $PM_{2.5}$ air pollution, thus verifying Hypothesis 1 of this paper. Considering that many pollution-intensive industries are involved in the MI, the increasing manufacturing enterprises may lead to the geographical concentration of polluting industries, thus resulting in a congestion effect and further aggravating regional air pollution. Nevertheless, the influence coefficient for the second term of lnMI on $PM_{2.5}$ is not significant, which is inconsistent with Hypothesis 2 of this paper and suggests that the influence of lnMI on $PM_{2.5}$ is linear and does not cross the inflection point [47]. These results indicate that the geographical agglomeration of manufacturing enterprises is dominated by the crowding effect, making it essential to improve the development level and resource allocation efficiency of the MI and strengthen the infrastructure construction and intensive pollution emission management.

Table 6. Baseline regression result.

Variable	(1)	(2)	(3)	(4)
	SLM	**SEM**	**SDM**	**SDM**
lnMI	0.0111 *	0.0342 ***	0.0413 ***	0.0371 **
	(1.87)	(4.11)	(4.92)	(2.22)
$lnMI^2$				0.0006
				(0.49)
ln*Rain*	−0.0090	−0.0090	−0.0118	−0.0128
	(−0.98)	(−0.60)	(−0.77)	(−0.84)
ln*Ainve*	0.0353 **	0.0601 **	0.0514 *	0.0508 *
	(2.21)	(2.26)	(1.92)	(1.90)
ln*Pgdp*	0.0105 *	0.0197 ***	0.0220 ***	0.0231 ***
	(1.72)	(2.60)	(2.92)	(3.03)
ln*Tech*	−0.0064 ***	−0.0107 ***	−0.0109 ***	−0.0116 ***
	(−3.32)	(−3.42)	(−3.48)	(−3.61)
ln*Enr*	−0.0057	−0.0039	−0.0075	−0.0058
	(−0.99)	(−0.70)	(−1.33)	(−1.02)
ln*Open*	−0.0068 ***	−0.0072 ***	−0.0060 ***	−0.0058 ***
	(−3.84)	(−3.76)	(−3.12)	(−3.0)
$w \times$ ln*Manu*			−0.0977 ***	−0.2184 ***
			(−4.84)	(−2.87)
rho	0.9794 ***		0.9740 ***	0.9746 ***
	(204.68)		(154.78)	(157.85)
lambda		0.9786 ***		
		(233.43)		
Observations	1760	1760	1760	1760
Hausman	Fe	Fe	Fe	Fe
Number of ID	110	110	110	110

Note: The z values in brackets are, *, **, ***, which represent significance at the level of 10%, 5%, and 1%, respectively.

Of all the control variables, a significant positive correlation is presented between ln*Ainve* and ln$PM_{2.5}$, which is consistent with the research results of Wang et al. (2014) for the hindering effect of temperature inversion on the diffusion of medium and fine particles in the air [48]. Meanwhile, between ln*Tech* and ln$PM_{2.5}$, there is a significant negative correlation, which unveils the advantages of increasing ln*Tech* for improving air pollution. On the one hand, increasing investment in science and technology helps to innovate highly polluting and energy-consuming industries, promote the application of clean technologies, and enhance the ecological process of industries. On the other hand, increasing investment in science and technology can promote technological progress and the development and utilization of new energy in the production process, achieve high efficiency and low emissions in the production process, and reduce air pollution. The ln*Pgdp* has a significant positive impact on $PM_{2.5}$, which is probably because economic development leads to the expansion of the industrial production scale, while the scale effect of production activities leads to an increase in raw material consumption and pollution emissions. Although A can significantly reduce B, it shows that YREB further plays the role of a gateway to the outside world, developing an export-oriented economy, and attracting foreign investment into the industrial field, which is conducive to promoting the local green transformation.

5.4. Robustness Test

Given that regional economic activities, in addition to geographical distance, are also important factors affecting the spatial diffusion of regional $PM_{2.5}$, the robustness of the results is verified using an economic distance matrix rather than an geographic distance matrix in this study (Table 7). The results in Table 7 show that the effect of MI on $PM_{2.5}$ is significantly positive, which is consistent with the baseline regression results. The sign

and significance of the remaining control variables also fit with the benchmark regression results, validating the robustness of the empirical results in this paper.

Table 7. Robustness test.

Variable	(1)	(2)	(3)	(4)
	SLM	SEM	SDM	SDM
lnMI	0.0079 *	0.0223 ***	0.0246 ***	0.0167 **
	(1.89)	(3.62)	(3.88)	(2.40)
$lnMI^2$				0.0010
				(1.15)
ln*Rain*	−0.0005	0.0190	0.0209	0.0179
	(−0.08)	(1.39)	(−1.54)	(1.28)
ln*Ainve*	0.0305 ***	0.0672 ***	0.0789 ***	0.0948 ***
	(2.74)	(2.83)	(3.36)	(3.93)
ln*Pgdp*	0.0066	0.0096 *	0.0117 **	0.0124 **
	(1.56)	(1.83)	(2.28)	(2.38)
ln*Tech*	−0.0062 ***	−0.0049 **	−0.0050 **	−0.0059 **
	(−4.53)	(−2.18)	(−2.47)	(−2.54)
ln*Enr*	−0.0005	0.0002	0.0050	0.0012
	(−0.13)	(0.06)	(0.15)	(0.32)
ln*Open*	−0.0001	−0.0004	−0.0008	−0.0006
	(−0.05)	(−0.30)	(−0.67)	(−0.47)
$w \times$ ln*Manu*			0.0206	0.0345 **
			(1.82)	(2.30)
rho	0.9749 ***		1.0708 ***	1.0706 ***
	(217.88)		(175.12)	(175.56)
lambda		0.9767 ***		
		(281.97)		
Observations	1760	1760	1760	1760
Hausman	Fe	Fe	Fe	Fe
Number of ID	110	110	110	110

Note: The z values in brackets are, *, **, ***, which respectively represent significancet at the level of 10%, 5%, and 1%, respectively.

5.5. Analysis of the Spatial Spillover Effect

To obtain the direct and indirect influences of lnMI on $PM_{2.5}$ (Table 8), the regression results are further decomposed. The results indicate that the direct and indirect effects of lnMI on $PM_{2.5}$ are significantly positive at the 1% confidence level, suggesting that the environmental benefits of ln*Manu* may be felt in neighboring cities. This further verifies that the environmental effect of lnMI is not limited to the local area.

Table 8. Spatial spillover effect.

Variables	LR_Direct	LR_Indirect	LR_Total
lnMI	0.1376 ***	12.6630 ***	12.8010 ***
	(3.74)	(3.10)	(3.11)
ln*Rain*	−0.0014	−0.8008	−0.8023
	(−0.09)	(−0.48)	(−0.48)
ln*Ainve*	0.0736 ***	1.1009	1.1745
	(2.81)	(0.38)	(0.41)
ln*Pgdp*	0.0314 *	1.7433	1.7748
	(1.88)	(1.05)	(1.06)
ln*Tech*	−0.0342 ***	−2.6501 ***	−2.6843 ***
	(−3.81)	(−2.78)	(−2.79)
ln*Enr*	−0.1051 ***	−10.2570 ***	−10.3620 ***
	(−2.78)	(−2.61)	(−2.61)
ln*Open*	−0.0395 ***	−3.7144 ***	−3.7540 ***
	(−3.77)	(−3.24)	(−3.24)

Note: The z values in brackets are, *, ***, which respectively represent significancet at the level of 10% and 1%, respectively.

5.6. Heterogeneity Analysis

In view of the obvious differences in subdivided industries within the MI and the huge differences in the industrial structure and economic environmental conditions within the study area, the industrial classification method proposed by Lin and Teng is used in this study to classify each sub-sector within the MI into labor-intensive, capital-intensive, capital-intensive, and technology-intensive types. To analyze the industry and regional heterogeneity [41], the studied area is divided into the upper and middle reaches and the lower reaches (Table 9). As can be seen from Table 8, the MI regression coefficients for the three different industries in the upper and middle regions are significantly positive, consistent with the regression coefficients for the total samples, indicating that different factors have significant positive effects on air pollution. Among them, capital-intensive and labor-intensive MIs cover a large number of low-technology and high-pollution industries, and their participation in updating and iteration of production equipment and production process and pollution control is weak. An increase in the number of such industries will dominate the crowding effect in developing the MI, which may become an important factor in exacerbating regional air pollution. In addition, developing technology-intensive MI will lead producers to further start production and expand the production scale, resulting in a "rebound effect" and aggravating local air pollution. However, the influence coefficients for different types of MIs on $PM_{2.5}$ in downstream areas are not significant, which may be because the study area has been driven by policy and production technology progress in recent years. On the one hand, the industrial structure of the studied area has been upgraded, with backward production capacity eliminated and highly polluting industries treated or transferred to other areas. On the other hand, the improvement in operational efficiency in the manufacturing industry is positively related to economic and social development, which will force the transformation and upgrading of the polluting manufacturing industry.

Table 9. Heterogeneity analysis.

	Classification of Industry	**LR_Direct**	**LR_Indirect**	**LR_Total**
Downstream area	Labor intensive	−0.0209	0.2415	0.2205
		(−0.83)	(0.57)	(0.51)
	Capital intensive	−0.0072	−0.0708	−0.0780
		(−0.29)	(−0.17)	(−0.18)
	Technology intensive	0.0059	0.3856	0.3915
		(0.23)	(0.88)	(0.87)
	Control variable	Yes	Yes	Yes
Middle reaches	Labor intensive	0.1439 ***	6.1157 ***	6.2596 ***
		(3.59)	(3.02)	(3.03)
	Capital intensive	0.1118 ***	5.4365 ***	5.5484 ***
		(3.09)	(2.96)	(2.97)
	Technology intensive	0.1673 ***	7.1666 ***	7.3339 ***
		(3.86)	(3.26)	(3.28)
	Control variable	Yes	Yes	Yes
Upstream region	Labor intensive	0.0961 ***	1.6969 **	1.7930 **
		(3.72)	(2.15)	(2.21)
	Capital intensive	0.1191 ***	2.5157 **	2.6349 **
		(3.37)	(2.26)	(2.30)
	Technology intensive	0.1317 ***	3.3819 ***	3.5137 ***
		(3.92)	(3.21)	(3.24)
	Control variable	Yes	Yes	Yes

Note: The z values in brackets are, **, ***, which respectively represent significancet at the level of 5%, and 1%, respectively.

6. Conclusions and Discussion

6.1. Discussion and Policy Recommendations

In this paper, in addition to the impact of the MI on $PM_{2.5}$ based on perspective space overflow, the spatial pattern characteristics in the MI in the YERB are probed from multiple perspectives. This not only serves as a useful supplement to the study on the environmental effect of industrial agglomeration but also an empirical test to explore the development pattern in the MI in the YREB and its environmental effect with certain theoretical and empirical value. According to our research conclusions, during the development of the MI in the YREB, an industrial pattern of "the lower reaches are higher than the middle and upper reaches, and the central cities are higher than the surrounding areas" was formed with significant agglomeration characteristics presented in the spatial distribution. The research results in this paper are consistent with the research conclusions of related scholars on Greece [49], Spain, and China's Pearl River Delta [50,51]. This paper comes to certain scientific and universal conclusions. On the one hand, the reasons for this result may be related to the regional characteristics of the Yangtze River Economic Belt. There are significant differences in the economic and social development of the Yangtze River Economic Belt. The development foundation of the central cities in the lower reaches and the middle and upper reaches of the Yangtze River Economic Belt is significantly higher than that in other regions, and they are more attractive to the manufacturing industry. On the other hand, the results may be related to the industrial characteristics of the manufacturing industry, which develops with the development of the industrial division of labor, while the central cities or core areas of the Yangtze River Economic Belt can communicate easier with the surrounding cities and form scale effects with the division of labor and cooperation with the surrounding cities, thus forming the spatial agglomeration and distribution pattern of the MI. The exchanges among various R&D institutions and different researchers will also be facilitated by the spatial proximity and agglomeration of the MI, forming a learning effect. The spatial agglomeration distribution is also characteristic of other industries such as the digital industry [52], logistics industry [53], aviation industry, etc., in addition to the MI, whose geographical pattern has a certain economic and social orientation [54]. Renewable energy and other industries also show agglomeration distribution characteristics but in close relation to spatial distribution patterns with the natural environment, resource endowment, and other factors, varying from the MI [55].

Based on empirical analysis, we determined that the environmental effects of air pollution exerted by the manufacturing agglomeration verify the research conclusion of Jones [56] and were basically consistent with the research results of Cheng et al. (2016) [57], indicating that the research conclusion of this study is scientific to some extent while reflecting the complexity and urgency of transforming industries into ecological, green, and high-end industries in the YREB. On the one hand, the spatial agglomeration of the MI is usually accompanied by the spatial agglomeration of population and economic production, increasing regional energy consumption and pollutant emission as well as environmental pressure. On the other hand, the MI is the main sector for consumption of production factors such as resources and energy. which covers many energy-intensive and pollution-intensive industries. Along with the development of the MI, the expanding industrial scale will reduce the cost of pollution control by leveraging the strengths of infrastructure utilization and developing a circular economy [58]. Moreover, the empirical analysis results of this paper are different from the conclusions of previous studies on the nonlinear relationship between the agglomeration of the MI and air pollution, that is, the agglomeration of MI can indirectly reduce regional air pollution with technological innovation and other paths [37]. On the one hand, the reasons for this phenomenon may be related to the regional characteristics of the YREB. Compared with other regions, the Yangtze River Economic Belt enjoys a more concentrated population and industries, although the region is facing a typical problem, namely, the environmental pollution caused by industrial development. On the other hand, although the YREB, especially the Yangtze River Delta region, is a relatively active area of technological innovation in China, it is still haunted by problems

such as imperfect environmental supervision and insufficient transformation mechanisms underlying innovation achievements. Improving the technological innovation level may also expand the production scale, produce rebound effect, and increase the emission of regional pollutants.

The results of this paper are also significant in the aspect of policy. Based on the empirical analysis, the policy proposals are as follows:

(1) Construct a green manufacturing cluster and improve the quality of industrial agglomeration. On the one hand, with reasonable planning and active guidance, similar industries and pollution-intensive manufacturing industries associated with the previous and the following items are promoted for gathering in the same industrial park. The production costs, transaction costs, and energy consumption of pollution-intensive manufacturing industries are reduced by the external effects of industrial agglomeration, such as economies of scale, factor resource sharing, knowledge spillover, and infrastructure sharing. On the other hand, different taxes, such as carbon tax, energy tax, and environmental tax, are set for different types of MI to optimize the interest balance mechanism between different industries, enterprises, and interest subjects, and incorporate market-oriented operation mechanisms, economic incentive mechanisms, and public supervision mechanisms into the pollution industry management system, thus promote the ecological level of the industry. In addition, for the key ecological functional areas of the YREB, a negative list system must be established for industrial access, prohibiting the entry of industries with high pollution, high energy consumption, and high emissions, and guiding the green development of industries. For the central cities in the lower reaches of the YREB and the middle and upper reaches of the YREB, we suggest building influential high-tech industrial parks and cultivating green and low-carbon, high-tech industrial clusters on the basis of industrial development, giving full play to the advantages of science and education resources. For the middle and upper reaches of the YREB, we recommend speeding up the transformation of traditional industries such as steel, nonferrous metals, and textiles, eliminating backward production capacity, and promoting the development of clean industries.

(2) Construct an industrial "service-manufacturing" integrated development platform and strengthen the degree of industrial synergy. On the one hand, for downstream areas with relatively complete industrial development systems, we recommend improving market-supporting facilities, improving the development level of producer services such as commercial leasing services, information and communication industries, and modern logistics industries, improving service quality, and promoting the further integration of producer services and manufacturing industries. For the middle and upper reaches of the YREB, we recommend developing advanced manufacturing industries, such as new energy and new materials, and developing supporting services based on local industrial advantages. On the other hand, taking the large gap in the development of the MI within the studied area into account, it is necessary to actively plan and guide regions to coordinated development and the linkage mechanism. The "service-manufacturing" integrated development platform for local industries is supposed to comprehensively develop the integrated development platform of the industry with several neighboring regions as the main body. Meanwhile, promoting the free flow of production factors in different regions along with the changes in market demand, breaking the regional barriers between different industries, and driving the industrial upgrading process in neighboring areas through the development of MI in central cities are also on the proposal list.

(3) Actively foster open industries based on regional advantages and scientific and technological potential. On the one hand, attention should be paid to investing in talent, capital, and technology, attracting experts and scholars in the field of ecological civilization construction, carrying out regular personnel exchange activities, cultivating professional environmental talents, further propelling the cooperation between industries and optimizing the functions of the industry, and driving the intelligent transformation of industrial parks. On the other hand, for the coastal areas in the lower reaches of the YREB, we suggest actively developing the export-oriented economy, strengthening internal and external

cooperation, actively investing in the scientific research costs in the development process for the export-oriented economy, achieving self-breakthrough, promoting the application of low-carbon and circular technologies using the sharing mechanism of industrial agglomeration and technology spillover effect, and optimizing the process flow. For the middle and upper reaches of the YREB, we recommend actively learning from the development experience of the downstream coastal areas, vigorously developing modern information technologies such as the digital economy and artificial intelligence, building innovation platforms, adjusting backward production capacity with core energy-saving technologies, and improving industrial production efficiency.

However, some shortcomings also exist in this research. Firstly, the mediation effect model is not used to discuss the influence path of the MI on $PM_{2.5}$. Secondly, producer services play an important role in the geographic pattern of industrial development, providing intermediate products and services for the manufacturing industry and promoting efficient production. The collaborative agglomeration of two industries is more conducive to identifying the scale effect of industrial agglomeration. Therefore, in future studies, the focus will be on the spatial pattern of collaborative agglomeration, as well as its economic and environmental effects.

6.2. Main Conclusions

To explore the environmental effects of the manufacturing industry on $PM_{2.5}$, an econometric model was established based on describing the characteristics of the spatial agglomeration pattern, spatial agglomeration level, and spatial agglomeration difference in the MI for the data on micro-enterprises, with research conclusions drawn as follows:

(1) The kernel density in the MI increases gradually, showing a geographically centralized distribution in space. The kernel density in the downstream region is higher than that in the middle and upper reaches, and that in the central city is higher than that in the surrounding cities. In the periphery of the central city, the kernel density values show a trend of distance attenuation based on the distance from the central city.

(2) The MI presents a significant spatial agglomeration feature, and its subdivision industry has a significant spatial agglomeration that is gradually increasing. Different industries vary in concentration levels, and the concentration level of technology-intensive MIs is higher than that of capital-intensive and labor-intensive MIs. The Gini coefficient for the whole basin area and its sub-regions is declining, and the regional differences gradually decrease, which indicates that the coordinated development in the basin has been in certain progress in recent years. In addition, there are still large differences between the upper, middle, and lower reaches in the MI, and coordinated development needs to be further promoted.

(3) There is a significant positive correlation between the MI and $PM_{2.5}$ pollution. An increase in the number of manufacturing enterprises may lead to the geographic concentration of polluting industries, resulting in the congestion effect and further aggravating regional air pollution. In addition, the influence of lnMI on $PM_{2.5}$ is not limited to local areas, and $PM_{2.5}$ pollution in a local city may be influenced by neighboring cities. From the perspective of the heterogeneity analysis, the influence of MI on $PM_{2.5}$ in the downstream region is not significant, reflecting gradual improvement in the development level and resource allocation efficiency of the MI in the region in recent years, as well as the continuous enhancement in intensive pollution emission control ability. The conclusions of this study in the upper and middle reaches are consistent with the overall study area.

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References

1. Zhai, X.Q.; An, Y.F. Analyzing influencing factors of green transformation in China's manufacturing industry under environmental regulation: A structural equation model. *J. Clean. Prod.* **2020**, *251*, 119760. [CrossRef]
2. Guo, J.; Sun, Z.X. How does manufacturing agglomeration affect high-quality economic development in China? *Econ. Anal. Policy* **2023**, *78*, 673–691. [CrossRef]
3. Marcello, R. The chip manufacturing industry: Environmental impacts and eco-efficiency analysis. *Sci. Total Environ.* **2022**, *858*, 159873. [CrossRef]
4. Hang, Y.; Wang, Q.W.; Zhou, D.Q.; Zhang, L. Factors influencing the progress in decoupling economic growth from carbon dioxide emissions in China's manufacturing industry. *Resour. Conserv. Recycl.* **2019**, *146*, 77–88. [CrossRef]
5. Yang, T.; Zhou, K.L.; Ding, T. Air pollution impacts on public health: Evidence from 110 cities in Yangtze River Economic Belt of China. *Sci. Total Environ.* **2022**, *851*, 158125. [CrossRef]
6. Marshall, A. Element of Economics of Industry. James Mavor? *Ethics* **1892**, *3*, 266.
7. Ohlin, B. Equilibrium in International Trade. *Q. J. Econ.* **1928**, *43*, 184–188. [CrossRef]
8. Krugman, P. Scale Economies, Product Differentiation, and the Pattern of TradeScale Economies, Product Differentiation, and the Pattern of Trade. *Am. Econ. Rev.* **1980**, *70*, 950–959.
9. He, W.J.; Chen, C.Y.; Liu, Z.Y. Can anti-corruption help realize the "strong" Porter Hypothesis in China? Evidence from Chinese manufacturing enterprises. *J. Asian Econ.* **2022**, *80*, 101473. [CrossRef]
10. Li, L.S.; Ma, Y.J. Spatial-temporal pattern evolution of manufacturing geographical agglomeration and influencing factors of old industrial base: A case of Jilin Province, China. *Chin. Geogr. Sci.* **2015**, *25*, 486–497. [CrossRef]
11. Hassan, M.M.; Alenezi, M.; Good, R. Spatial pattern analysis of manufacturing industries in Keraniganj, Dhaka, Bangladesh. *GeoJournal* **2020**, *85*, 269–283. [CrossRef]
12. Duranton, G.; Overman, H.G. Exploring the detailed location patterns of UK manufacturing industries using microgeographic data. *J. Reg. Sci.* **2008**, *48*, 213–243. [CrossRef]
13. Kristian, O.B.; Fredrik, P.; Clara, B.; Keyvan, A.; Sigrid, R.; Nina, B.; Tom, T.; Fredrik, G.; Sigmund, G.; Jan, H. High-Intensity Shoulder Abduction Exercise in Subacromial Pain Syndrome. *Med. Sci. Sport. Exerc.* **2021**, *53*, 1–9. [CrossRef]
14. Zhou, M.; Yuan, M.; Huang, Y.; Lin, K. Effects of institutions on spatial patterns of manufacturing industries and policy implications in metropolitan areas: A case study of Wuhan, China. *Land* **2021**, *10*, 710. [CrossRef]
15. Tiwari, P.; Syamwil, I.B.; Doi, M. Spatial pattern of Japanese manufacturing industry in four ASEAN countries. *Pap. Reg. Sci.* **2003**, *82*, 403–415. [CrossRef]
16. Li, J.; Li, L.Y.; Liu, S.M. Attenuation of agglomeration economies: Evidence from the universe of Chinese manufacturing firms. *J. Urban Econ.* **2022**, *130*, 103458. [CrossRef]
17. Bi, K.X.; Huang, P.; Wang, X.X. Innovation performance and influencing factors of low-carbon technological innovation under the global value chain: A case of Chinese manufacturing industry. *Technol. Forecast. Soc. Chang.* **2016**, *111*, 275–284. [CrossRef]
18. Turka, S.K. Factors influencing the Choice of Manufacturing Location: A Study of Selecting Industries. *Financ. India* **2013**, *27*, 187–190.
19. He, X.H.; Ping, Q.Y.; Hu, W.F. Does digital technology promote the sustainable development of the marine equipment manufacturing industry in China? *Mar. Policy* **2022**, *136*, 104868. [CrossRef]
20. Zhou, J.Z.; Wen, X. Research on influencing factors and multiple driving paths of intelligent transformation in China's manufacturing industry. *J. Comput. Methods Sci. Eng.* **2021**, *21*, 1561–1573. [CrossRef]
21. Yu, H.Q.; Chen, Y.K. Manufacturing Industry Agglomeration in Guizhou Province Based on Regression Analysis of Influencing Factors. *Manag. Sci. Eng.* **2020**, *9*, 25–33. [CrossRef]
22. Corinne, B.; Nicolas, P. Market access and the other determinants of North-South manufacturing location choice: An application to the Euro-Mediterranean area. *Econ. Syst.* **2011**, *35*, 537–561. [CrossRef]
23. Li, D.; Zhao, Y.; Wu, R.; Dong, J. Spatiotemporal Features and Socioeconomic Drivers of $PM_{2.5}$ Concentrations in China. *Sustainability* **2019**, *11*, 1201. [CrossRef]
24. Han, S.S.; Sun, B.D. Impact of Population Density on $PM_{2.5}$ Concentrations: A Case Study in Shanghai, China. *Sustainability* **2019**, *11*, 1968. [CrossRef]
25. Alli, A.; Clark, S.; Hughes, A.; Nimo, J.; Bedford-Moses, J.; Baah, S.; Wang, J.; Vallarino, J.; Agyemang, E.; Barratt, B.; et al. Spatial-temporal patterns of ambient fine particulate matter ($PM_{2.5}$) and black carbon (BC) pollution in Accra. *Environ. Res. Lett.* **2021**, *16*, 074013. [CrossRef] [PubMed]
26. Amador-Muñoz, O.; Villalobos-Pietrini, R.; Miranda, J.; Vera-Avila, L. Organic compounds of $PM_{2.5}$ in Mexico Valley: Spatial and temporal patterns, behavior and sources. *Sci. Total Environ.* **2011**, *409*, 1453–1465. [CrossRef]

27. Diao, B.D.; Ding, L.; Cheng, J.H. Differences of $PM_{2.5}$ health risks and influencing factors in different types of cities. *China Popul. Resour. Environ.* **2021**, *31*, 90–100. [CrossRef]
28. Li, W.L.; Yang, G.F.; Qian, X.Y. The socioeconomic factors influencing the $PM_{2.5}$ levels of 160 cities in China. *Sustain. Cities Soc.* **2022**, *84*, 104023. [CrossRef]
29. Liu, J.; Zhao, Y.H.; Cheng, Z.H.; Zhang, H.M. The Effect of Manufacturing Agglomeration on Haze Pollution in China. *Int. J. Environ. Res. Public Health* **2018**, *15*, 2490. [CrossRef]
30. Wang, S.J.; Li, M.Y. Impact of spatial structure of urban agglomerations on $PM_{2.5}$ pollution; Based on resource misallocation. *Heliyon* **2023**, *9*, e14099. [CrossRef]
31. Wu, Q.; Guo, R.; Luo, J.; Chen, C. Spatiotemporal evolution and the driving factors of $PM_{2.5}$ in Chinese urban agglomerations between 2000 and 2017. *Ecol. Indic.* **2021**, *125*, 107491. [CrossRef]
32. Song, Y.; Zhu, J.; Yue, Q.; Zhang, M.; Wang, L. Industrial Agglomeration, Technological Innovation and Air Pollution: Empirical Evidence from 277 Prefecture-level Cities in China. *Struct. Chang. Econ. Dyn.* **2023**, *66*, 240–252. [CrossRef]
33. Wu, L.; Wan, X.; Jahanger, A.; Li, M.; Murshed, M.; Balsalobre-Lorente, D. Does the digital economy reduce air pollution in China? A perspective from industrial agglomeration. *Energy Rep.* **2023**, *9*, 3625–3641. [CrossRef]
34. Hao, Y.; Guo, Y.; Li, S.; Luo, S.; Jiang, X.; Shen, Z.; Wu, H. Towards achieving the sustainable development goal of industry: How does industrial agglomeration affect air pollution? *Innov. Green Dev.* **2022**, *1*, 100003. [CrossRef]
35. Zhang, H.R.; Zhang, J.W.; Song, J.F. Analysis of the threshold effect of agricultural industrial agglomeration and industrial structure upgrading on sustainable agricultural development in China. *J. Clean. Prod.* **2022**, *341*, 130818. [CrossRef]
36. Yang, R.; Hu, Z.G.; Hu, S.H. The failure of collaborative agglomeration: From the perspective of industrial pollution emission. *J. Clean. Prod.* **2023**, *387*, 135952. [CrossRef]
37. Yuan, H.X.; Zou, L.H.; Luo, X.Y.; Feng, Y.D. How Does Manufacturing Agglomeration Affect Green Development? A Spatial and Nonlinear Perspective. *Int. J. Environ. Res. Public Health* **2022**, *19*, 10404. [CrossRef] [PubMed]
38. Zhang, J.; Zhang, P.; Wang, R.; Liu, Y.; Lu, S. Identifying the coupling coordination relationship between urbanization and forest ecological security and its impact mechanism: Case study of the Yangtze River Economic Belt, China. *J. Environ. Manag.* **2023**, *342*, 118327. [CrossRef]
39. Luan, Q.Z.; Jiang, W.; Liu, S.; Guo, H.X. Impact of Urban 3D Morphology on Particulate Matter 2.5 ($PM_{2.5}$) Concentrations: Case Study of Beijing, China. *Chin. Geogr. Sci.* **2020**, *30*, 294–308. [CrossRef]
40. China National Standardization Administration. *Industrial Classification of National Economy: GB/T 4754-2017*; China National Standardization Administration: Beijing, China, 2017.
41. Lin, B.L.; Teng, Y.Q. Decoupling of economic and carbon emission linkages: Evidence from manufacturing industry chains. *J. Environ. Manag.* **2022**, *322*, 116081. [CrossRef]
42. Ye, X.Y.; Xu, X.; Lee, J.; Zhu, X.Y.; Wu, L. Space–time interaction of residential burglaries in Wuhan, China. *Appl. Geogr.* **2015**, *60*, 210–216. [CrossRef]
43. Shim, C.; Kim, W.; Heo, W.; Yi, S.; Chung, Y.D. Nearest close friend search in geo-social networks. *Inf. Sci.* **2018**, *423*, 235–256. [CrossRef]
44. Zheng, R.; Cheng, Y.; Liu, H.; Chen, W.; Chen, X.; Wang, Y. The Spatiotemporal Distribution and Drivers of Urban Carbon Emission Efficiency: The Role of Technological Innovation. *Int. J. Environ. Res. Public Health* **2022**, *19*, 9111. [CrossRef]
45. Tian, L.; Wang, H.H.; Chen, Y.J. Spatial externalities in China regional economic growth. *China Econ. Rev.* **2010**, *20*, S20–S31. [CrossRef]
46. Liu, X.P.; Zhang, X.L.; Sun, W. Does the agglomeration of urban producer services promote carbon efficiency of manufacturing industry? *Land Use Policy* **2022**, *120*, 106264. [CrossRef]
47. Wang, M.; Arshed, N.; Munir, M.; Rasool, S.F.; Lin, W. Investigation of the STIRPAT model of environmental quality: A case of nonlinear quantile panel data analysis. *Environ. Dev. Sustain.* **2021**, *23*, 12217–12232. [CrossRef]
48. Wang, L.L.; Zhang, N.; Liu, Z.R.; Sun, Y.; Ji, D.S.; Wang, Y.S. The Influence of Climate Factors, Meteorological Conditions, and Boundary-Layer Structure on Severe Haze Pollution in the Beijing-Tianjin-Hebei Region during January 2013. *Adv. Meteorol.* **2014**, *10*, 685971. [CrossRef]
49. Vogiatzoglou, K.; Tsekeris, T. Spatial Agglomeration of Manufacturing in Greece: Sectoral Patterns and Determinants. *Eur. Plan. Stud.* **2013**, *21*, 1853–1872. [CrossRef]
50. Albert, J.M.; Casanova, M.R.; Orts, V. Spatial location patterns of Spanish manufacturing firms. *Pap. Reg. Sci.* **2012**, *91*, 107–136. [CrossRef]
51. Li, X.W.; Tan, Y.M.; Xue, D.S. From World Factory to Global City-Region: The Dynamics of Manufacturing in the Pearl River Delta and Its Spatial Pattern in the 21st Century. *Land* **2022**, *11*, 625. [CrossRef]
52. Zhu, W.J.; Chen, J.J. The spatial analysis of digital economy and urban development: A case study in Hangzhou, China. *Cities* **2022**, *123*, 103563. [CrossRef]
53. Mu, N.Y.; Wang, Y.S.; Tian, P.L. Spatio-temporal Distribution Characteristics of the Cooperation Between Logistics Industry and Economy in Southwest China. *Int. J. Comput. Intell. Syst.* **2022**, *15*, 7. [CrossRef]
54. Wang, Y.Z.; Hao, C.Z.; Liu, D.W. The spatial and temporal dimensions of the interdependence between the airline industry and the Chinese economy. *J. Transp. Geogr.* **2019**, *74*, 201–210. [CrossRef]

55. Wang, Q.; Kwan, M.P.; Fan, J.; Zhou, K.; Wang, Y.F. A study on the spatial distribution of the renewable energy industries in China and their driving factors. *Renew. Energy Int. J.* **2019**, *139*, 161–175. [CrossRef]
56. Jones, D.W. How urbanization affects energy-use in developing countries. *Energy Policy* **1991**, *19*, 621–630. [CrossRef]
57. Cheng, Z.H. The spatial correlation and interaction between manufacturing agglomeration and environmental pollution. *Ecol. Indic.* **2016**, *61*, 1024–1032. [CrossRef]
58. Fang, J.Y.; Tang, X.; Xie, R.; Han, F. The effect of manufacturing agglomerations on smog pollution. *Struct. Chang. Econ. Dyn.* **2020**, *54*, 92–101. [CrossRef]

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