Ecological Efficiency Evaluation and Spatiotemporal Characteristics Analysis of the Coupling Coordination of the Logistics Industry and Manufacturing Industry

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Ecological efficiency evaluation and spatiotemporal characteristics analysis of the coupling coordination of the logistics industry and manufacturing industry

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10 **Abstract**

11 The coupling coordination of the logistics industry and manufacturing industry conducive to the
12 sustainable development of logistics and manufacturing and the stability of sustainable supply chain.
13 The logistics and manufacturing industries are not only the basic industries that support social
14 development, but also the industries with high carbon emissions. Firstly, this paper classifies the
15 carbon emissions from the logistics industry and manufacturing industry as undesirable outputs,
16 evaluates the ecological efficiency of the logistics industry (LEE) and manufacturing industry (MEE)
17 in the Yangtze River Delta from 2006 to 2019 by using the unexpected slacks-based measure (SBM)
18 model. Secondly, the coupling coordination method is used to analyze the coupling coordination
19 scheduling of industrial ecological efficiency. Thirdly, the paper analyzes the spatial differences of
20 the coupling coordination ecological efficiency between logistics industry and manufacturing
21 industry (MLCC) by using the exploratory spatial data analysis method. Finally, the spatial
22 econometric model is used to analyze the driving factors of the MLCC. The results show: The
23 ecological efficiency of the manufacturing industry has steadily improved. The ecological efficiency
24 of the logistics industry presents the rising trend in fluctuation. The level of the coupling coordination
25 development between the logistics and manufacturing industries is high. The results of the spatial
26 heterogeneity analysis show that the spatial differentiation of high-high agglomeration and low-low
27 agglomeration is obvious. The spatial agglomeration characteristics are relatively stable, and the
28 spatial diffusion effect is strong; In space, the MLCC shows a trend of developing from multiple
29 agglomeration areas to one agglomeration area. The results of driving factor analysis show that
30 foreign direct investment(FDI), government intervention(GI) and human capital(HP) have positive
31 effects on the MLCC, while industrial structure(IS), environmental regulation(ER) and energy
32 intensity(EI) have negative effects on the MLCC.

33 **Keywords:** Ecological efficiency; Logistics industry; Manufacturing industry; Spatiotemporal
34 characteristics; Spatial econometric model.

1.INTRODUCTION

At present, with the rapid development of the social economy, China's logistics demand is increasing rapidly, and the scale of logistics is expanding rapidly. How to continuously improve the quality of the logistics industry while reducing energy consumption and carbon dioxide emissions is an urgent problem to be considered. Similarly, while China's manufacturing industry has made great achievements, it has also encountered various environmental problems in the process of industrialization similar to developed countries in recent centuries. The extensive economic growth mode of high input and high-energy consumption leads to the problems of low-resource utilization efficiency and the aggravation of environmental pollution (De Koster,2003).

The logistics and manufacturing industries have a naturally close relationship; they influence each other and develop interactively(W.L. Zheng et al., 2020). Under the background of a new round of technological innovation and industrial reform, logistics industry and manufacturing industry are undergoing the transformation from traditional industry to digital industry(Kaur et al., 2017). The coupling coordination of the logistics and manufacturing industries determines the sustainable development level of the "two industries" and the comprehensive competitiveness of the regional economy. It is conducive to the sustainable development of logistics and manufacturing and the stability of sustainable supply chain. In recent years, the development trend of coupling coordination and integration between China's logistics and manufacturing industries has increased, but the degree of integration is not high enough, the scope is not wide enough, and the degree is not deep enough, which does not meet the general requirements of promoting the formation of a strong domestic market, building a modern economic system, and adapting to the new pattern of "double cycle" development(Notice,2020).

According to the statistics of IEA database, the global power and heat production industry contributes 42% of carbon dioxide emissions, and the industry (including manufacturing, construction and non-fuel mining) and transportation industry contribute 18.4% and 24.6% respectively. In China, industry and transportation contributed 27.9% and 9.7% respectively. In 2020, China put forward the goal of striving to reach the peak of carbon dioxide emission by 2030 and achieving carbon neutralization by 2060(Hu,2021). At the same time, China's economy has entered the stage of high-quality development, and the cultivation of industrial clusters with international competitiveness has become a new power source to achieve high-quality economic development. In 2018, the integrated development of the Yangtze River Delta became a national strategy. The Yangtze River Delta is an important gathering area for China's advanced manufacturing industry. Through informatization, networking and the integration effect of modern logistics, the logistics cost of manufacturing enterprises can be effectively reduced, and more resources can be concentrated to develop the core competitiveness of the manufacturing industry. Therefore, it is of great practical significance to study the development of the coupling coordination between the logistics and manufacturing industries to promote the transformation and upgrading of the manufacturing industry in the Yangtze River Delta region, to achieve the goal of "made in China 2025" and to realize the high-quality development of the regional economy. It is further conducive to achieving the goal of reaching the carbon peak in 2030.

Since the concept of ecological benefit was first proposed by schartger and Sturm (1990), in recent years, many scholars have studied ecological efficiency (Zhou et al., 2015) (Watanabe and Tanaka, 2007: Wang Bing et al., 2010). The two directions related to this paper are logistics industry efficiency and manufacturing industry efficiency.

(1) In terms of the ecological efficiency of the logistics industry:

Long (2020) used carbon dioxide emissions as undesirable outputs to evaluate the logistics ecological efficiency. Zhang Linlin (2019) used SBM undesirable model to measure the efficiency of China's logistics industry under low-carbon constraints, and the panel Tobit model was used to empirically analyze its influencing factors. The results show that the overall efficiency of China's logistics industry is at the upper middle level, with obvious regional differences.

(2) In terms of the ecological efficiency of the manufacturing industry:

Zhang Feng (2019) constructs a three-stage efficiency measurement model of advanced manufacturing green technology innovation by using nonmandatory range adjustment and stochastic frontier functions and measures its green technology innovation efficiency based on manufacturing panel data. The results show that the overall efficiency of green technology innovation in the national advanced manufacturing industry is still low, and the capital intensity and industry profit rate have a significantly positive effect on the efficiency of green technology innovation in the advanced manufacturing industry. Han Jing (2014) Using the directional distance function, the ecological efficiency level of the manufacturing industry is calculated under the condition of considering the energy input and undesirable outputs. The research shows that the ecological efficiency of China's manufacturing industry is on the rise, but it is significantly lower than that without considering resource input and negative environmental output. The ecological efficiency level of the manufacturing industry shows obvious industry heterogeneity.

Recently, various studies have focused on production sector for estimation of resources, climatic and institutional barriers in the land use (Elahi et al., 2021ab; Elahi et al., 2019abcd; Elahi et al., 2018). Some studies for instance (Peng et al., 2020ab; Peng et al., 2019ab; Peng et al., 2018; Huang Q et al., 2020; Wang Y et al., 2019) have focused on ecological security, ecological footprint, ecological carrying capacity and ecological environmental vulnerability. However, ecological efficiency evaluation and spatiotemporal characteristics analysis of the coupling coordination development of the logistics industry and manufacturing industry has not been explored yet. Therefore, the current article aims to determine the ecological efficiency of the coupling coordination development of logistics industry and manufacturing industry considering environmental effects, as well as the spatial model (spatial heterogeneity, spatial agglomeration and driver analysis) and trend dynamic evolution of the coupling coordination development efficiency of the two industries.

The potential academic contributions of this paper are as follows: (1) The coupling coordination measurement system of logistics industry and manufacturing industry considering carbon emission is established. (2) This paper analyzes the spatial effect of the coupling coordination degree between logistics industry and manufacturing industry by using spatial correlation model, and discusses the influencing factors of coupling coordination by using spatial econometric model. The analysis has certain policy guidance and theoretical significance. The rest of this study is as follows. The second part presents introduces the relevant models. The third part explains the indicators and unexpected data. The fourth part presents the empirical analysis. Finally, this paper summarizes the conclusions and discusses relevant suggestions.

2.MODEL INTRODUCTION

2.1 Coupling coordination model of logistics industry and manufacturing industry

The coupling coordination Coupling degree indicates the degree of mutual influence between two or more systems or elements due to interaction. Coupling coordination degree is the horizontal embodiment of mutual promotion and benign interaction between systems. In recent years, the theory of coupling coordination has been widely used in many fields of transportation, such as control operation strategy, planning strategy, predictive control and so on. In the composite system composed of logistics industry and manufacturing industry, the coordinated development of two industries refers to the evolution of two subsystems and their components towards a harmonious and consistent direction, and the coupling of two industries refers to the mutual influence and interaction between two subsystems and their components. The order parameters in the two-industry complex system are the fundamental variables that determine the evolution trend of the system. The key to the evolution of the two-industry complex system is the synergy between the internal order parameters, and the coupling coordination degree is the measure reflecting the synergy.

$$C = 2 \left\{ (U_1 g U_2) / (U_1 + U_2)^2 \right\}^{1/2} \quad (3)$$

Where, C represents the coupling degree; U_1 and U_2 represent the comprehensive order parameters of logistics and manufacturing respectively, expressed by logistics efficiency and manufacturing efficiency under low-carbon constraints.

The coupling degree C cannot reflect the overall level of logistics efficiency and manufacturing efficiency and the synergy between them. For example, when the logistics efficiency and manufacturing efficiency are very low, the coupling degree will be very high. Therefore, based on relevant research results, a coupling coordination degree model is constructed:

$$D = \sqrt{CT}, T = \alpha U_1 + \beta U_2 \quad (4)$$

Where, D represents coupling coordination degree; C represents coupling degree; T represents the comprehensive coordination index of logistics efficiency and manufacturing efficiency under low-carbon constraints; α and β are undetermined parameters, and are assigned 0.5 respectively according to the practices of most scholars. The coupling coordination degree is between 0 and 1, and the median segmentation method is adopted to divide the coupling coordination degree into five grades (Table 1).

TABLE 1 | Hierarchical division of coupling coordination degree

Severe disorder	Moderate disorder	Slight coordination	Good coordination	Highly coordination
$0 < \gamma_{ij} \leq 0.2$	$0.2 < \gamma_{ij} \leq 0.4$	$0.4 < \gamma_{ij} \leq 0.6$	$0.6 < \gamma_{ij} \leq 0.8$	$0.8 < \gamma_{ij} \leq 1$

2.2 Measurement method of ecological efficiency

In order to give consideration to the generality and rationality of the index system, this paper selects the comprehensive technical efficiency as the decision-making basis for evaluating the comprehensive order parameters of logistics industry and manufacturing industry.

In view of the heterogeneity of production technology in the Yangtze River Delta, this paper uses the common frontier model based on SBM method to measure the comprehensive technical efficiency of manufacturing and logistics industry. The calculation is realized with MaxDEA ultra7.0 software.

2.3 Spatial diffusion effect model

1) Global spatial correlation

Global spatial correlation is used to analyze the spatial association and spatial difference of the research object and to determine whether there is spatial diffusion. It is generally measured by the global Moran index (Moran,1953).

$$I = \frac{\sum_{i=1}^n \sum_{j=1}^n W_{ij} (x_i - \bar{x})(x_j - \bar{x})}{s^2 \sum_{i=1}^n \sum_{j=1}^n W_{ij}} \quad (5)$$

where I is the Moran index and, $s^2 = \frac{1}{n} \sum_{i=1}^n (Y_i - \bar{Y})^2$, $\bar{Y} = \frac{1}{n} \sum_{i=1}^n Y_i$, X_i and X_j are the coupling coordination efficiency values of the logistics industry and manufacturing industry of cities I and j, respectively. According to the calculation results of Moran's I statistics, the normal distribution hypothesis can be used for testing. Finally, the significance level of spatial autocorrelation is tested by using the standardized statistic Z:

$$Z(d) = \frac{\text{moran's } I - E(I)}{\sqrt{\text{VAR}(I)}} \quad (6)$$

According to the spatial distribution, the expected value of standardized Moran's I was calculated

$$E(I) = -\frac{1}{n-1} \quad (7)$$

The variance of normal distribution is as follows:

$$\text{VAR}(I) = \frac{n^2 w_1 + n w_2 + 3 w_0^2}{w_0^2 (n^2 - 1)} - E^2(I) \quad (8)$$

where E(I) is the expectation of autocorrelation of observation variables, and VAR (I) is the variance. W_i and W_j refer to the sum of columns I and j in the spatial weight matrix, respectively, indicating the proximity of spatial positions I and J. When I and j are adjacent, $W_{ij} = 1$, and vice versa. The value range of Moran index is [-1,1]. When $I > 0$, it means that there is a positive correlation in each region; when $I = 0$, it means that there is no spatial correlation in each region; and when $I < 0$, it indicates that there is a negative correlation in each city (completed by ArcGIS 10.2, used to analyze the diffusion characteristics of logistics industrial efficiency, manufacturing industrial efficiency and coupling coordination efficiency of the two industries).

181 2) Local spatial autocorrelation

182 Local spatial autocorrelation is the local expression of Moran index, which is the test form of
183 agglomeration and dispersion effect of local area. It reflects the correlation degree between the
184 attribute value of a region and the attribute value of adjacent region.

$$185 \quad I_i = \frac{(x_i - \bar{x})}{s^2} \sum_{j=1}^n w_{ij} (x_j - \bar{x}) \quad (9)$$

186 Where: I_i is the local Moran index of area I , and other parameters are the same as above.

187 If I_i is greater than 0, it means that the local area and the surrounding area present similar spatial
188 agglomeration (high high or low low agglomeration). If I_i is less than 0, it shows different spatial
189 agglomeration (high low or low high agglomeration). The cluster of regions can be directly analyzed
190 by Moran scatter diagram, and the local Moran index is still tested by Z statistic.

191 2.4 Spatial econometric model

192 Common spatial measurement models include: spatial lag model (SLM), spatial error model (SEM)
193 and spatial Durbin model (SDM) (Elhorst, 2014; Liu et al., 2017). When spatial correlation exists in
194 the error terms of the model, then using the SEM, which can be expressed as follows:

$$195 \quad Z = X_\alpha + \delta W_\mu + \varepsilon, \quad \varepsilon \in N(0, \delta^2) \quad (10)$$

196 Z indicates explained variables and is the vector of $(n \times 1)$; X indicates explanatory variables, α
197 indicates the regression coefficient, and is the vector of $(k \times 1)$; μ indicates the random error vector; δ
198 is the coefficient of spatial correlation between regression residuals; W indicates the spatial weight
199 matrix $(n \times n)$; and ε indicates distributed random terms independently. If the model has significant
200 dependence between explained variables and would affect its results, using SLM model, which can
201 be expressed as follows:

$$202 \quad Z = \rho WY + X_\alpha + \varepsilon, \quad \varepsilon \in N(0, \delta^2) \quad (11)$$

203 ρ indicates the coefficient of endogenous interaction effects (WY), with its size representing the
204 degree of spatial diffusion and spatial dependence. A significant value shows that definite spatial
205 dependence exists in explained variables. If the model considers both the endogenous interaction
206 effect of the error term and the endogenous interaction effect of explained variables, then using SDM,
207 which can be expressed as follows:

$$208 \quad Z = \rho WY + X_\alpha + WX\theta + \varepsilon, \quad \varepsilon \in N(0, \delta^2) \quad (12)$$

209 θ is the spillover coefficient, others are as the same with SLM model.

211 3. INDICATORS AND UNDESIRABLE OUTPUTS DATA

212 3.1 Selection of indicators

213 With reference to most very weak research on the coupling coordination efficiency of these two
214 industries, combined with some selection principles (significance, practicability, data availability,
215 isotropy, etc.) of the indicator system, the manufacturing-and-logistics-industry, coupling
216 coordination-development, efficiency-evaluation, index system is constructed from the perspective of
217 input and output (Ji Xiaoli et al., 2018; Liang Hongyan et al., 2015; Chen Chunming et al., 2020). The

218 data used in this study mainly come from the China Statistical Yearbook, the statistical yearbooks of
 219 the provinces, the National Bureau of Statistics, the China Industrial Statistical Yearbook, the China
 220 Environmental Statistical Yearbook, the China Energy Statistical Yearbook and the school library.
 221 Due to the availability of data, the transportation industry and warehousing, postal and
 222 telecommunications industrial data are generally used as logistics industrial data (since China has not
 223 yet established a relatively complete statistical system for the logistics industry, and the statistical
 224 caliber of the logistics industry in each country is not the same, the model and index selection in this
 225 paper are only applicable to a single country or region with unified logistics industrial data statistics).
 226 The specific selection indicators are as follows.

227 **TABLE 2 |** Index System of Manufacturing Industry Ecological Efficiency

Evaluation system	Index type	Name of index	Unit
Manufacturing system	Input indicators	The number of employees on the job in the manufacturing industry	Ten thousand people
		Total assets of industrial enterprises above designated size	100 million
	Output indicators	industrial added value	100 million
		Main business income of industrial enterprises above designated size	100 million
	Undesirable outputs	Carbon Emissions from Manufacturing	Tons

228

229 **TABLE 3 |** Index System of Logistics Industry Ecological efficiency

Evaluation system	Index type	Name of index	Unit
	Input indicators	Number of employees in the logistics industry	Ten thousand people
		Fixed capital investment	100 million
		energy consumption	Ten thousand tons of standard coal

Logistics system	Output	highway freight volume	Tons
	indicators		
		GDP of logistics industry	100 million
		Cargo turnover	Million ton-km
	Undesirable outputs	Carbon Emissions from Transportation	tons

230 The coupling coordination efficiency of logistics industry and manufacturing industry is the
231 comparative relationship between input and output or between cost and income in the process of
232 business activities of the whole system formed by logistics industry and manufacturing industry.
233 Therefore, the ecological efficiency of the coupling coordination between the manufacturing industry
234 and the logistics industry means that the ecological efficiency of the logistics industry and the
235 manufacturing industry are input factors to each other, which has an impact on the system. Therefore,
236 refer to the research methods of Wang Zhenzhen (2017), on the basis of **Table 2 and table 3**, after
237 considering the impact of both sides on each other, the index system as shown in **Table 4** is
238 constructed (Wang Zhenzhen et al.,2017).

239 **TABLE 4 |** The Ecological efficiency Index of the Coupling Coordination Between Logistics
240 Industry and Manufacturing Industry

Evaluation system	Index type	Name of index	Unit
System of Logistics Industry and Manufacturing Industry coupling coordination efficiency	Input indicators	Number of employees in the logistics industry	Ten thousand people
		Fixed capital investment	100 million
		energy consumption	Ten thousand tons of standard coal
		The number of employees on the job in the manufacturing industry	Ten thousand people
		Total assets of industrial enterprises above designated size	100 million

	Output indicators	highway freight volume	Tons
		GDP of logistics industry	100 million
		Cargo turnover	Million ton-km
		industrial added value	100 million
		Main business income of industrial enterprises above designated size	100 million
	Undesirable outputs	Carbon Emissions from Transportation	Tons
		Carbon Emissions from Manufacturing	Tons

241 **TABLE 5** | Variable Description for Spatial Econometric Model.

Variable	Description	Unit
Logistics eco-efficiency (LE)	Logistics ecological efficiency (The results are obtained by SBM model and table 1)	ratio
Manufacturing eco-efficiency (ME)	Manufacturing eco-efficiency (The results are obtained by SBM model and table 2)	ratio
Manufacturing and Logistics Coupling coordination eco-efficiency (MLCC)	Coupling coordination eco-efficiency (The results are obtained by SBM model and table 3)	ratio
Industrial Structure (IS)	The added value of the secondary industry as the proportion of the regional GDP	%
Government Intervention (GI)	The proportion of public finance expenditure to regional GDP	%

Foreign Direct Investment (FDI))	Total import and export trade as a percentage of GDP	%
Energy Intensity (EI)	The ratio of the logistics total energy consumption of the total turnover of freight	ratio
Human Capital (HC)	The average number of years of education in each city	thousand
Environmental Regulation (ER)	The ratio of total investment in industrial pollutants to GDP	ratio

242 3.2 Undesirable outputs data

243 (1) the concept of desirable Outputs and undesirable Outputs

244 In the production process of general economic system, we always hope that the smaller the input is,
245 the better the output is. That is to say, we can produce as many outputs as possible with the smallest
246 input, and the relative efficiency of production unit is also higher. The core idea of traditional DEA
247 model in dealing with input-output in efficiency evaluation is also based on this. The output
248 mentioned here is the expected output, which is the main purpose of economic production, and refers
249 to the output with benefit. However, the production process will inevitably produce some negative
250 effects on economic development, people do not want to produce output. The output mentioned here
251 is undesirable outputs, that is, the output that people do not expect. It is a subsidiary product of
252 economic production, which means the output that is not beneficial or even harmful. For example,
253 the paper products industry, while producing, emits industrial wastewater, waste gas, waste and other
254 pollutants. The paper or paper products here are called expected output, and industrial wastewater,
255 waste gas, waste and other pollutants are called undesirable outputs. Considering environmental
256 variables and paying attention to undesirable outputs will have important theoretical and practical
257 significance for transforming the mode of economic development, strengthening environmental
258 protection, promoting sustainable development, and establishing a saving and efficient industry.

259 (2) the undesirable Outputs data of manufacturing industry and logistics industry

260 This paper takes the CO₂ emissions of logistics industry and manufacturing industry as the
261 unexpected output index. Refer to Xu (2019), Zhang Shiqing (2017), Zheng WL (2018) and other
262 relevant scholars' research on carbon emissions from logistics and manufacturing. Firstly, the primary
263 energy consumption of 21 fuels mainly consumed by logistics and manufacturing industries such as
264 raw coal, diesel, kerosene, gasoline, fuel oil, liquefied petroleum and natural gas is selected and
265 converted into standard coal as the total energy source consumption of the two industries. Then, the
266 above seven energy consumption are converted according to the carbon emission coefficient in the
267 guidelines for national greenhouse gas emission inventories of the climate change Commission
268 (IPCC), and the CO₂ emissions of logistics industry and manufacturing industry are obtained
269 respectively. The calculation formula is:

$$CO_2 = \sum_{i=1}^n E_i \times CF_i \times CC_i \times COF_i \times \frac{44}{12} \quad (13)$$

Where i is the type of fuel, E_i is the consumption of i fuels, CF_i is the calorific value of i fuels, CC_i is the carbon content of i fuels, and COF_i is the oxidation factor of the fuel.

4. EMPIRICAL ANALYSIS

4.1 Evaluate the overall efficiency value

FIGURE 1 | The efficiency changing trend of the logistics industry, manufacturing industry and Manufacturing and Logistics Coupling coordination Efficiency

The calculation results of the LEE, MEE and MLEE are shown in **Figure 1**. (1) From 2006 to 2019, the efficiency of the manufacturing industry in the Yangtze River Delta was stable. From 2006 to 2011, it increased slightly; it decreased slightly in 2012; from 2012 to 2019, it began to rise steadily and reached the highest value in 2019. (2) From 2006 to 2019, the efficiency of the logistics industry in the Yangtze River Delta increased slightly. It increased slightly from 2006 to 2010 and decreased significantly from 2011 to 2014. The reason may be that carbon emissions are included in the 12th Five Year Plan (2011-2015) as a binding indicator, and 2013 is the year of mid-term assessment of the 12th Five Year Plan for national environmental protection. However, the completion of carbon emission indicators in 2013 lags behind the requirements of time progress, so the situation is very serious. In response to this situation, the State Council issued the notice of 《The action plan for energy conservation, emission reduction and low carbon development for 2014-2015》, which requires to strengthen energy conservation and carbon reduction in transportation (Xuan,2015). Therefore, Lee is constrained by mandatory carbon emissions, resulting in a significant decline in Lee. After efficiency reached the lowest value in 2014, it rapidly increased to the highest value in 2019. The reason may be that during the 13th Five Year Plan period (2016-2020), China accelerated its support for the new energy vehicle industry, significantly increased the proportion of electric trucks, and gradually improved the carbon emission efficiency of the logistics industry, resulting in a significant increase in Lee.

4.2 Empirical analysis of spatial diffusion effect

1) Empirical analysis of global spatial autocorrelation

Utilizing ArcGIS 10.2 software, the data of the logistics and manufacturing industries in 25 cities in the Yangtze River Delta from 2006 to 2019 are calculated, and Moran's I value and its standardized Z value are obtained (see **Table 6**). The results show that the index of the logistics and manufacturing industries of 25 cities in the Yangtze River Delta is positively correlated. The Z value for each year is positive, and the p-value is less than α (0.05), which indicates that the spatial autocorrelation is significant. This indicates that the regions with similar development levels (high or low) of the logistics and manufacturing industries in the Yangtze River Delta are concentrated in space; that is, the cities with higher coupling coordination levels of the two industries have higher coupling coordination levels of the two industries in their peripheral cities, and vice versa. From 2006 to 2019, the Moran index of the logistics and manufacturing industry in the Yangtze River Delta showed a trend of first rising and then declining, but the Z value of the coupling coordination efficiency of the two industries was greater than 5, indicating that the spatial distribution of the logistics and manufacturing industries in the Yangtze River Delta during this period showed a globally significant similar level of agglomeration characteristics.

TABLE 6 | Global autocorrelation analysis of coupling coordination efficiency between logistics industry and manufacturing industry in Yangtze River Delta

Name	Year	Moran's Index	Z Score	P-value	Agglomeration
Coupling coordination efficiency of logistics industry and manufacturing industry	2006	0.5457	5.2465	0.01	Yes
	2013	0.5867	6.5684	0.01	Yes
	2019	0.5921	6.9635	0.02	Yes

2) Empirical analysis of local spatial autocorrelation

In order to reflect the spatial structure changes of logistics industry and manufacturing industry in the Yangtze River Delta region from 2006 to 2019, according to the local spatial autocorrelation analysis method, this paper selects the coupling coordination efficiency of logistics industry and manufacturing industry in 2006, 2013 and 2019 as the research data, and analyzes the spatial characteristics and changes of the coupling coordination efficiency between each city and adjacent cities in the Yangtze River Delta region. The results (**Table 7**) show that there is an obvious spatial distribution pattern of logistics and manufacturing industry in the Yangtze River Delta.

TABLE 7 | The results of Lisa analysis on the coupling coordination efficiency of logistics industry and manufacturing industry in the Yangtze River Delta in 2006, 2013 and 2019

Features	2006	2013	2019

High-High(HH)	Nanjing, Shanghai	Nanjing, Shanghai	Nanjing, Shanghai, Hangzhou
High-Low(HL)	Wenzhou	Wenzhou	Wenzhou
Low-High (LH)	Jiaxing, Taizhou	Jiaxing, Taizhou	Jiaxing
Low-Low(LL)	Lishui, Suqian	Lishui, Suqian	Lishui, Suqian

According to the results of Lisa, each city is divided into four quadrants according to its nature. As shown in **Table 7**, this paper selects several representative cities for analysis.

The first quadrant is the HH agglomeration type of logistics and manufacturing coupling coordination ecological efficiency. The cities in this quadrant have relatively large local Moran values, and the local Moran values of the surrounding cities are also relatively large. That is to say, the logistics and manufacturing coupling coordination efficiency of this city is relatively high, and it has a significant positive impact on the logistics and manufacturing coupling coordination efficiency of neighboring cities. The high value area of industry coupling coordination efficiency is surrounded by the same high value area, and the diffusion effect is obvious. It can be seen that the high agglomeration areas of logistics and manufacturing coupling coordination efficiency in the Yangtze River Delta are mainly concentrated in Shanghai, Hangzhou and Nanjing. By comparing 2006 and 2019, it can be found that in 2006, they were mainly distributed in Shanghai, the provincial capital and municipality directly under the central government, and in 2019, Wuxi, Suzhou, Changzhou and other surrounding cities were added. The coupling coordination efficiency of the two industries in these cities presents a development trend from multiple agglomeration areas to one agglomeration area in space, which indicates that the coupling coordination of logistics industry and manufacturing industry in the research area has entered a relatively centralized development stage(Li Z et al.,2020).

The second quadrant is the LH agglomeration type. The local Moran value of cities in this quadrant is relatively small, and the local Moran value of surrounding cities is relatively large, that is, the cities with low coupling coordination efficiency of logistics and manufacturing industry are surrounded by high value cities. It can be seen that the low and high efficiency agglomeration areas of logistics and manufacturing in the Yangtze River Delta are mainly concentrated in Jiaxing, Taizhou and other cities. By comparing 2006 and 2016, it can be found that in 2006, they were mainly distributed in Jiaxing, a city close to Shanghai, and Taizhou, a city close to Suzhou Wuxi Changzhou economic zone. By 2016, they were reduced to only Jiaxing, and the surrounding areas of Jiaxing were developed by Shanghai, Hangzhou, Ningbo and other cities. It's surrounded by the city.

The third quadrant is LL agglomeration type. The local Moran value of cities in this quadrant is relatively small, and the local Moran value of surrounding cities is also relatively small. That is to say, the coupling coordination efficiency of logistics and manufacturing in this city is low, and it has a significant negative impact on the coupling coordination efficiency of logistics and manufacturing in neighboring cities. The low value area of industry coupling coordination efficiency is surrounded by the same low value area. It can be seen that the low efficiency of the coupling coordination between logistics industry and manufacturing industry in the Yangtze River Delta is mainly concentrated in the northern and southern mountainous areas, such as Suqian, Lishui, Quzhou and other cities. By comparing 2006 and 2019, we can find that the low and low concentration areas are all the cities in Northern Jiangsu and southern Zhejiang. The coupling coordination efficiency of the

two industries in these cities presents a negative externality agglomeration in space, and these cities will easily cause a vicious circle between cities and form a marginal area through the spatial spillover effect(Hackius et al.,2020; Kant K et al.,2017; Zhang Y et al.,2018; Chen J et al.,2020; J. Li et al.,2018;).

The fourth quadrant is the HL agglomeration type. The cities in this quadrant have relatively large local Moran values, and the local Moran values of the surrounding cities are relatively small, that is, the logistics and manufacturing coupling coordination efficiency of the city is higher, and the local Moran values of the surrounding cities are relatively low, that is, the cities with high logistics and manufacturing coupling coordination efficiency are ignored Surrounded by low value cities, it has spatial spillover effect on the surrounding cities. It can be seen from **Table 7** that the agglomeration areas of logistics and manufacturing coupling coordination efficiency in Yangtze River Delta are mainly concentrated in Wenzhou and other cities. By comparing 2006 and 2019, it can be found that these cities are concentrated in southern Jiangsu. There are too many low value cities around, which indicates that Wenzhou, as a big city around, has limited power to drive the efficiency of the two industries coupling coordination(Chen J et al.,2020; J.J Wang et al.,2020; Choi T M et al.,2016; Shi Y et al.,2016).

To sum up, the spatial agglomeration attribute of logistics and manufacturing coupling coordination efficiency in Yangtze River Delta is relatively stable, and the spatial diffusion effect is strong. In recent years, the rise of Suzhou, Wuxi and Changzhou makes the Yangtze River delta form a development trend from multiple agglomeration areas to relatively concentrated agglomeration areas. Jiaxing and Taizhou are the typical cities in the Low-High agglomeration type. These cities are in the transition zone of Shanghai, Nanjing and Hangzhou megalopolis, surrounded by these developed cities, and are the transition zone of the study area megalopolis for factor flow. Lishui and Suqian are typical cities in Low-Low cluster type. The development level of logistics industry in these cities is backward, the foundation of manufacturing industry is poor, and the coupling coordination efficiency of the two industries in the surrounding areas is also low, which is easy to form marginal areas. The typical city in High-Low agglomeration type is Wenzhou, where the export-oriented economy is developed and the manufacturing industry has a good foundation, resulting in spatial spillover effect(Jiang P et al.,2018; He D et al.,2020; John E et al.,2018).

4.3 Empirical analysis of spatial econometrics

According to the previous analysis, the spatial autocorrelation test of coupling coordination efficiency of logistics industry and manufacturing industry indicates that it exists a spatial agglomeration. To find a proper spatial econometric model, this paper use (robust) lagrange multipliers (LM) test, the likelihood ratio (LR) test, the Wald test and Hausman test (**Table 8**).

TABLE 8 | Estimation results without spatial interactive effects

	Mixed OLS estimator	Spatial fixed effect	Temporal fixed effect	Temporal and spatial double fixed effect
LM_lag	3.98**	37.81***	8.84	11.61*

R_LM_lag	2.34	14.32***	14.3	2.26*
LM_error	3.12**	29.63***	6.23	3.84*
R_LM_error	1.48	12.14	1.98	1.77
Wald_spatial_lag		15.506**	18.632**	
LR_spatial_lag		13.454**	17.563**	
Wald_spatial_error		18.647**	19.457***	
LR_spatial_error		18.345**	17.864**	
Hausman test			39.497,15,0.001	
LR spatial fixed effects			614.303,30,0.000	
LR time fixed effects			289.531,12,0.000	

395 Note: the data are from the model regression, and the results are sorted out by the author, *, **, ***,
396 respectively, indicating the significance level of 0.1, 0.05 and 0.01.

397 LM test results show that the spatial lag effect is more significant than the spatial error effect.
398 Therefore, it is more suitable to use spatial Durbin model.

399 It is noteworthy that the coefficients of the SDM model do not directly reflect the marginal effects of
400 the corresponding explanatory variables on the dependent variable (LeSage and Pace, 2010), so it
401 needs to verify spatial effects from the total effect, the direct effects and indirect effect (**Table 9**).

402 **TABLE 9** | Estimation and test results based on Spatial Durbin model (SDM) for the driving factor

Spatial Durbin model (SDM) for the driving factor				
	Coefficient	Direct	Indirect	Total
LnIS	-0.051**	-0.019***	-0.056	-0.075***

	(-1.904)	(-0.154)	(-0.322)	(-0.323)
LnFDI	0.046*** (5.172)	0.116 (0.564)	0.057 (0.261)	0.173 (0.844)
LnER	-0.031*** (-2.943)	-0.027** (-0.278)	-0.005 (-0.685)	-0.032 (-0.844)
LnGI	0.046*** (5.172)	0.046*** (1.214)	0.337*** (0.475)	0.383*** (0.527)
LnEI	-0.009*** (-2.543)	-0.028*** (-1.141)	-0.124*** (-0.439)	-0.152*** (-0.549)
LnHC	0.032*** (2.743)	0.193*** (1.233)	0.421*** (1.242)	0.614*** (1.267)
W*LnIS	-0.006 (-0.324)			
W*LnFDI	0.098** (1.889)			
W*LnER	0.097*** (9.979)			
W*LnGI	-0.002*** (-2.834)			
W*LnEI	0.065*** (4.645)			
W*LnHC	-0.001**			

	(-1.086)
W*LnLE	0.019*** (1.998)
W*LnME	0.034*** (1.443)
W*LnMLCC	0.325*** (4.033)

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403 ***Significance level at 1%. **Significance level at 5%. *Significance level at 10%.

404 The regression results show in Table 8, the industrial structure (IS) has a negative impact on the
405 coupling coordination ecological efficiency, it fully shows that the increase in the proportion of
406 China's logistics industry and manufacturing industry has a negative effect on ecological efficiency.
407 With the acceleration of industrialization, the secondary industry drives economic growth will not
408 change in a short period of time.

409 Foreign direct investment (FDI) is the invisible driving force of the logistics industry and
410 manufacturing industry development. Foreign direct investment increases 1%, coupling coordination
411 ecological efficiency will increase 0.116%, the hypothesis of "polluting heaven" is not established.
412 This is mainly because in the process of logistics and manufacturing transformation, China gives
413 priority to the development of green logistics and advocates green production. Relevant documents
414 have been formulated and very strict measures have been taken for pollution prevention and
415 ecological protection. In addition, we should pay more attention to the introduction of high-quality
416 foreign investment and strengthen the examination and approval of foreign investment. The spillover
417 effect of high-quality foreign capital is conducive to improving the coupling coordination ecological
418 efficiency of logistics industry and manufacturing industry in the Yangtze River Delta.

419 Environmental regulation (ER) has a negative impact on the improvement of logistics ecological
420 efficiency, the higher the intensity of environmental regulation, the lower the logistics ecological
421 efficiency. The in efficiency of environmental regulation is caused by the decentralized governance
422 structure and the performance appraisal mechanism. This leads to the "race-to-the-bottom"
423 competition of local governments in the process of enacting and implementing environmental
424 regulations. Because environmental pollution is external and can be transmitted between regions,
425 even if strict environmental regulations are implemented in this region, it will not necessarily reduce
426 the damage caused by environmental pollution.

427 The government intervention (GI) direct coefficient is 0.046, indicating that the current government
428 intervention has a positive impact on the coupling coordination ecological efficiency. The problems
429 existing in the coupling coordination development of logistics industry and manufacturing industry
430 are that the degree of marketization is not enough, the direct information asymmetry of the two
431 industries, and the willingness of active cooperation is still not high. Therefore, government
432 intervention can play a positive role in standardizing the market order, coordinating the operation of

433 logistics and manufacturing industries, continuously guiding the two industries to actively cooperate,
434 and improving the coupling coordination efficiency of the two industries.

435 The energy intensity (EI) direct coefficient is -0.028, indicating that the energy intensity has a
436 significant negative effect on the improvement of logistics ecological efficiency. The greater the
437 energy intensity, the stronger the dependence of logistics industry and manufacturing industry on
438 energy and also the greater the energy consumption. At the same time, the proportion of clean energy
439 used in China's logistics industry is small. Therefore, high energy consumption and high carbon
440 emission restrict the efficient and sustainable development of logistics industry.

441 Human capital (HC) direct coefficient is 0.193, indicating that the human capital has a positive
442 impact on coupling coordination ecological efficiency. The indirect coefficient of human capital is
443 0.421, indicating that human capital has a positive spillover effect. The result shows that the higher
444 the education level of the labor force in a certain city, the more propitious it is to promote the
445 progress of coupling coordination ecological efficiency in neighboring city. This is related to the
446 development stage of logistics and manufacturing in the Yangtze River Delta. At present, the
447 Yangtze River Delta is the most active region in China's economic development and the leading
448 region of high-tech development. The logistics industry and manufacturing industry have gradually
449 crossed the primary stage driven by material capital and labor input, and entered the growth stage
450 driven by human capital and core technology.

451 **5.CONCLUSION**

452 In this paper, the ecological efficiency of logistics and manufacturing industry is evaluated by SBM
453 model; The coupling coordination method is used to analyze the MLCC. The spatial heterogeneity
454 and spatial aggregation of the MLCC are analyzed by the spatial correlation analysis; The driving
455 factors of the MLCC are analyzed by using the spatial measurement method. It provides theoretical
456 reference and decision support for improving the coupling coordination efficiency of logistics and
457 manufacturing industry in Yangtze River Delta. The results show that:

458 The calculation results of industrial coupling coordination ecological efficiency show that: the
459 ecological efficiency of the manufacturing industry in the study area has steadily improved; the
460 ecological efficiency of the logistics industry has fluctuated greatly, first rising, then falling, and
461 finally steadily improving; the deviation of the ecological efficiency curve between the logistics and
462 manufacturing industries shows that when considering the undesirable outputs, the logistics and
463 manufacturing industries cannot achieve an absolutely high level of coupling coordination
464 development during the research period, but the ecological efficiency of the logistics and
465 manufacturing industries is relatively stable. The coupling coordination development is at a high
466 level.

467 The results from spatial heterogeneity show that there is a positive spatial correlation between the
468 indexes of the logistics and manufacturing of 25 cities in the Yangtze River Delta. Areas with similar
469 development levels (high or low) of the logistics and manufacturing industries are concentrated in
470 space. From 2006 to 2019, the Moran index of the logistics and manufacturing industries in the
471 Yangtze River Delta region showed a trend of first rising and then declining, which indicates that the
472 spatial distribution of the logistics and manufacturing industries showed a significantly similar level
473 of agglomeration characteristics.

474 The results of the local spatial autocorrelation analysis show that: The coupling coordination
475 ecological efficiency of the two industries in the Yangtze River Delta presents a development trend

476 from multiple agglomeration areas to one agglomeration area in space, which indicates that the
477 coupling coordination of logistics industry and manufacturing industry in the Yangtze River Delta
478 has entered a relatively centralized development stage.

479 The results of empirical analysis of spatial econometrics show that FDI, GI and HC have positive
480 effects on the coupling coordination ecological efficiency of the two industries, while IS, ER and EI
481 have negative effects on the coupling coordination ecological efficiency of the two industries.

482 **6.SUGGESTIONS AND POLICY IMPLICATIONS**

483 According to the above research conclusion, this paper presents some suggestions for the coupling
484 coordination development of the logistics and manufacturing industries in the Yangtze River Delta
485 region.

486 First, although the efficiency of the regional logistics industry is at a high level, this still cannot meet
487 the needs of the manufacturing industry, and the coupling coordination ecological efficiency of the
488 two industries lags behind the efficiency of the manufacturing industry. Therefore, in order to
489 improve the level of coupling coordination development, it needs to continue to make greater effort
490 to develop high-end logistics dominated by high-tech; which can greatly improve the service level,
491 specialization level and economies of scale that are advantageous for logistics enterprises; and to help
492 the manufacturing industry to reduce costs and to improve efficiency.

493 Second, the transformation and upgrading of the local manufacturing industry needs to continue to be
494 promoted. Although the efficiency of the manufacturing industry in the research area is at a high
495 level, there is still room for development. In the future, the transformation and upgrading of China's
496 manufacturing industry should be promoted under the guidance of the Internet of Things,
497 Blockchain, artificial intelligence, big data, cloud computing and other advanced technologies to
498 achieve the goal of "made in China 2025".

499 Third, it is increasing concern to society about the environment impact of the development of the
500 logistics and manufacturing industries. The development policies of the logistics and manufacturing
501 industries formulated by relevant managers should not only consider the economic benefits but also
502 consider the impact on the environment.

503 Fourth, energy conservation and emission-reduction technology should be promoted. In order to
504 achieve the goal of reaching the carbon peak by 2030, the government should increase investment in
505 the development of energy-saving and emission-reduction technology, enhance the exchange of
506 advanced technology and the management experience of energy savings and environmental
507 protection, actively develop and promote energy savings and emission-reduction technology to
508 effectively improve the increasingly serious problem of environmental pollution.

509 Fifth, the government should actively develop the circular economy and realize the recycling of
510 resources and sustainable development of logistics and manufacturing. Government managers can
511 expand the scope of circular economy pilots to spread all over the country, formulate environmental
512 regulation policies reasonably, encourage industries with high-energy consumption and large
513 amounts of pollution to develop an internal circular economy, and reduce undesirable outputs.

514 The limitations of this paper include the following. Regarding research data acquisition: because the
515 logistics industry is a network industry involved in many other industries, currently, a systematic
516 evaluation index of the efficiency of the logistics industry is still missing; there are currently no

517 authoritative logistics statistical indicators in China; and compared to urban logistics and
518 manufacturing data, the availability of undesirable outputs data is poorer.

519 Regarding future research: with the development of informatization, big data and the Internet of
520 Things, more extensive research can be conducted on index selection and data acquisition in the
521 future. This study is limited to the Yangtze River Delta region. The interaction between 'the logistics
522 and manufacturing industries has a different development status in different regions in China. In the
523 future, the study area can be extended to the entire country.

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526 **Declarations**

527 No potential conflict of interest was reported by the author(s).

528 **Data availability**

529 The original contributions presented in the study are included in the article/Supplementary Material,
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531 **Author contributions**

532 Juan Su: designed the paper framework. Tong Shen: Writing - original draft. Shuxin Jin: Supervision.

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