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The Impact of Logistics Industrial Clusters on Manufacturing Total Factor Productivity and its Urban Heterogeneity

Yaozong Zhu[1], Kung-Don Ye[2], Cuilian Kong[3], Hsiu-Hua Hu[4]

[1]Nanjing Vocational Institute of Railway Technology, Nanjing, Jiangsu, China

[2]Department of Shipping and Transportation Management, National Taiwan Ocean University, Keelung, Taiwan, China

[3]Institute of Science Innovating and Culture, Rajamangala University of Technology Krungthep, Bangkok, Thailand

[4]Department of International Business, Ming Chuan University, Taipei, Taiwan, China

Abstract: The formation of a logistics industry cluster through the agglomeration of logistics enterprises within a specific area can enhance the overall factor productivity of urban manufacturing by facilitating regional factor circulation and optimizing resource allocation. Utilizing panel data from 284 cities at or above prefecture level in China between 2012 and 2019, we established a spatial econometric model to examine the impact of logistics industry clusters on manufacturing's total factor productivity. Our findings demonstrate that logistics industry clusters significantly enhance urban manufacturing's total factor productivity. Heterogeneity analysis reveals that such clusters have a notably positive effect on both megacities and small cities in eastern and western regions, while exhibiting an opposite effect in central cities. Furthermore, during the late stage of industrialization, logistics industry clusters play a significant role in promoting city development. Mechanism analysis results indicate that the development of logistics industry clusters positively influences manufacturing's total factor productivity by enhancing the specialization level and industrial collaboration within the logistics sector.

Keywords: Logistics; Logistics Industry Cluster; Manufacturing; Total Factor Productivity; Spatial Spillover Effect

1. Research Background

The Political Bureau of the Central Committee held a meeting on April 29, 2022 and proposed “adhere to the national chess game to ensure smooth transportation and logistics" to ensure the stability of the industrial chain and supply chain. In December of the same year, the General Office of the related departments of China issued the "14th Five-Year Plan" Notice on Modern Logistics Development Planning, which clearly stated that the deep integration of the logistics industry and manufacturing industry should be promoted. As a typical producer service industry, logistics industry runs through every link from manufacturing to circulation and consumption, and plays an important role in promoting the efficiency and upgrading of China's manufacturing industry.

Existing studies have predominantly focused on the positive impact of land, labor, knowledge innovation, and other factors on the total factor productivity of the manufacturing industry[1,2]. However, they have overlooked the significance of the logistics environment in facilitating factor circulation and optimizing resource allocation. In reality, as social division of labor becomes more specialized, many enterprises are outsourcing their logistics to third-party logistics providers. According to Sheffi (2010)[3], a logistics industrial cluster is characterized by three types of enterprises: those providing logistics services; those providing services for logistics enterprises; manufacturing and retail enterprises with extensive involvement in logistical activities. The presence of such clusters ties member companies more closely, leading to increased interaction and competition among them, while driving down costs and improving logistical efficiency, ultimately resulting in better services for end-users[4-6]. The deep integration between logistics and manufacturing industry has further bolstered overall total factor productivity[7,8].

The investigation not only offers insights for accurately understanding the developmental trends of logistics and manufacturing industries in different regions of China, but also facilitates a deeper interconnection between these two sectors. This study aims to utilize data from 284 prefecture-level cities in China spanning from 2012 to 2019, employing a spatial econometric model to explore the effects and mechanisms of logistics industry clusters on regional manufacturing industry total factor productivity, analyzing urban heterogeneity factors, and proposing policy recommendations.

2. Literature Review Theoretical Analysis

2.1 Literature Review

In recent years, the scale and quantity of China's logistics industry clusters have been improved. Many cities begin to attach importance to the construction of logistics industry clusters, and compete to develop and expand their own logistics industry clusters. Rivera et al. (2014)[9] based on the study of the logistics industry cluster in the United States, they found the logistics industry is now increasingly concentrated and is more closely related to economic development. Hylton & Ross (2018)[6] found that the existence of logistics industry cluster has a positive impact on the expansion of enterprises. With the expansion of the cluster, the number of related enterprises in the cluster shows a large proportion of growth trend, which promotes the rapid development of the logistics industry. The logistics industry cluster itself can significantly promote the performance of logistics enterprises[10] and bring about the economy and flexibility of logistics services[4]. At the same time, the external effects, network effects and resource sharing benefits generated by the agglomeration of logistics enterprises form their unique competitive advantages. For example, logistics industry clusters can make goods and services flow quickly and smooth the circulation of various factors, thus supporting the development of other industrial clusters in the same region[11,12]. Logistics industrial clusters also promote the sharing and cooperation of various resources among logistics enterprises, and guide them to provide more value-added services, so that their customers can obtain better experience[5]. Wang and Chen (2009)[13] systematically studied the positive effects of logistics industry clusters and pointed out that the clusters have four major advantages: promoting cooperation among logistics enterprises, providing value-added services to customers, enhancing the career mobility of employees and bringing more employment opportunities to the society. This series of studies has deepened the understanding of the role and significance of logistics industry cluster.

The logistics industry is intricately linked with the manufacturing industry, exerting a significant impact on its growth and expansion. Chinese scholars have conducted studies to examine the influence of the logistics industry on manufacturing based on empirical data. Wang and Chen (2009)[13] utilized provincial panel data from China to calculate the coordination degree in different regions, suggesting that each sub-industry within manufacturing should strive to enhance its relationship with the logistics industry in order to facilitate overall development. Xia and Xia (2009)[14] analyzed the symbiotic relationship between producer service clusters, highlighting positive effects such as external economic impacts, reduced transaction costs, and innovation advantages that contribute to manufacturing development. Furthermore, some scholars employed spatial econometric models of provincial panel data from China to examine the positive impact of the logistics industry on total factor productivity and labor efficiency within manufacturing. Their findings indicated that logistic industry agglomeration generates positive spatial spillover effects which promote regional manufacturing efficiency[8,15]. However, research by Wu Fuqing et al. (2015)[16] based on prefecture-level city panel data from Heilongjiang Province revealed that for resource-based cities, logistic industry clustering may have a negative impact on regional industrial structure.

Based on the above literature review, existing studies have verified the positive impact of logistics industry cluster on the efficiency of manufacturing industry, but there are still some shortcomings: First, these studies lack the mechanism of logistics industry cluster on the total factor productivity and its spatial spillover effect: Second, most of the research samples are provincial panel data, and the research on urban scale in China is relatively limited. Third, existing research rarely involves the correlation analysis of heterogeneity.

In comparison with existing studies, this paper makes several significant contributions. Firstly, on the research perspective, this paper explores from an urban circulation perspective, rather than the traditional approach of factor aggregation and innovation driving. Secondly, on the research data, this paper collects panel data at a national city level to depict the relationship between logistics industry clusters and manufacturing TFP in greater detail. Thirdly, on the research content, this paper analyzes the impact at both theoretical and empirical levels. So it can provide theoretical development policies within various cities to better promote industrial upgrading and improve efficiency within the manufacturing industry.

2.2 Analysis of Theoretical Mechanism

The external economic theory suggests that the formation of labor market, the connection with local large market and knowledge spillover are significant drivers of industrial agglomeration. As the economy and society develop, population and resources concentrate in cities. Driven by the demand for manufacturing industry development and government support, logistics industry clusters form in cities[17]. The development of logistics industrial clusters contributes to reducing transaction costs, improving transaction efficiency, and expanding economies of scale[13]. Simultaneously, manufacturing enterprises can leverage the logistics enterprises to access better services at lower costs of time and capital. This ultimately improves the overall level of total factor productivity in urban manufacturing industry.

The impact of logistics industry clusters on the total factor productivity of the manufacturing industry exhibits heterogeneity in several aspects. Firstly, different industries and their logistics activities generate varying linkage and synergistic effects[18]. Moreover, the development stage and situation of the manufacturing industry differ across cities, leading to heterogeneous impacts of logistics industry clusters. Secondly, the characteristics and scale of logistics industry agglomeration vary among cities due to factors such as market conditions, infrastructure, system development, and openness[19], which are closely linked to urban economic development levels and scales. Based on the above analysis, this paper proposes the first research hypothesis.

H1: The development of logistics industry clusters contributes to the improvement of the total factor productivity of the manufacturing industry, but with the change of urban location, scale and industrial stage, the impact is heterogeneous.

The formation of industrial clusters stems from a specialized division of labor, and the ongoing development of these clusters further promotes specialization within them[20]. The logistics industry cluster plays a crucial role in promoting specialization within the logistics industry for three main reasons: Firstly, to meet diverse needs of manufacturing enterprises, companies within the logistics industry cluster must enhance their level of specialization to encourage manufacturing enterprises to favor logistics outsourcing services. Secondly, businesses within the industrial cluster benefit from a favorable business environment and access to excellent infrastructure, allowing them to focus on improving their operational capabilities and service levels, thereby promoting sustainable development of specialized division of labor. Thirdly, industrial clusters facilitate the convergence of relevant talents and resources, making full use of manpower, material resources and advanced technologies to promote their specialized logistics service[21].

After the logistics cluster promotes specialized division of labor, the logistics enterprises within the cluster will offer more refined and high-quality services, thereby enhancing the total factor productivity of the manufacturing industry from multiple aspects. Firstly, it drives the upgrading of the manufacturing industry[22]. The additional and personalized services provided by the logistics industry will incentivize manufacturing enterprises to upgrade in order to fully utilize these services, compelling them to enhance product value and innovation levels. Secondly, there is a spillover effect[23]. As a producer service industry, the logistics sector can improve the flow of goods among enterprises; its specialized development will promote spillover effects for manufacturing enterprises. By sharing advantages such as information, knowledge, input factors, enterprises can learn from each other and improve their production and manufacturing efficiency. Thirdly, there are cost reductions and quality improvements in services. Specialization of logistics services will bring about scale effects leading to reduced average costs for logistics services; allowing manufacturing enterprises to benefit from better services at lower costs. Consequently, the overall operational efficiency within the manufacturing industry can be greatly promoted.

Based on the above analysis, the logistics industry cluster has the potential to cultivate a more favorable business environment for logistics enterprises, attract a greater pool of talents and resources, thereby enhancing the overall specialization level of the cluster. The enhanced specialization division of labor will in turn elevate the total factor productivity of the manufacturing industry through mechanisms such as backward forcing, spillover effects, and service optimization. Building upon this premise, we propose the second research hypothesis.

H2: The development of logistics industry cluster can improve the total factor productivity of urban manufacturing industry by improving the level of logistics specialization.

In the process of gathering and developing the logistics industry, the logistics industry will integrate with the manufacturing industry, and then realize the synergy. Khan et al. (2016)[24] discussed issues related to the integration of logistics industry and manufacturing industry in Pakistan and found that the deep integration between these two sectors can better create value. The reason why logistics enterprises choose to deeply integrate with manufacturing enterprises is that, on the one hand, the communication cost between logistics enterprises and manufacturing enterprises will be reduced, and then provide high-quality and efficient logistics services to increase customer stickiness. On the other hand, the synergy between logistics and manufacturing enables logistics companies to gain deeper insight into the actual needs of customers, provide more personalized services, and grow together with manufacturing companies in the process. With the deepening collaboration between the logistics and manufacturing industries, there will be a positive promotion of total factor productivity for three main reasons. Firstly, the logistics industry is better equipped to support the development, transformation, and upgrading of the manufacturing industry. Secondly, industrial collaboration enables logistics enterprises to quickly meet individual needs of manufacturing enterprises while promoting circulation of goods, greatly enhancing overall production efficiency[25]. Lastly, industrial cooperation facilitates comprehensive resource utilization; both logistics and manufacturing enterprises can achieve greater output with limited input resources[26].

In the process of the development of logistics industry cluster, logistics enterprises coordinate and integrate with manufacturing enterprises for the purpose of reducing communication costs and improving customer demand responsiveness. With the improvement of industrial synergy, the transformation and upgrading of manufacturing industry, the efficiency of goods circulation and the comprehensive utilization of resources will be improved, and the total factor productivity of manufacturing industry will be improved eventually. Therefore, the third research hypothesis of this paper is proposed.

H3: The cluster of the logistics industry facilitates the coordination and integration between logistics and manufacturing, thereby enhancing the total factor productivity of the manufacturing sector.

3. Construction of Research Model and Research Data

3.1 Research Model

Based on existing relevant studies, this paper will use spatial econometric models and apply spatial autoregressive model (SAR), spatial error model (SEM) and spatial Dubin model (SDM) for regression, and combine LMERR, LMLAG, R-LMERR, R-LMLAG and other indicators to select the final model. With reference to the model settings of Rivera et al. (2014)[9] and Shu et al. (2014)[15], this paper sets the model as follows:

$$\ln MTFP_{it} = \alpha + \beta_1 WnMTFP_{it} + \beta_2 lnLQ_{it} + \beta_3 WlnLQ_{it} + \beta_4 \ln X_{it} + \varepsilon_{it} \quad (1)$$

$$\varepsilon_{it} = \beta_5 WE_{it} + \upsilon_{it} \quad (2)$$

In this model, the subscript i denotes an individual city; t represents time, and W is a spatial weight matrix of the inverse distance space (which is assumed to be the same in the following text). MTFP represents the total factor productivity of the manufacturing industry, LQ represents the degree of agglomeration of the logistics industry, X represents other control variables that affect the total factor productivity of the manufacturing industry, α represents the individual effect, ε_{it} and υ_{it} are both random error terms that follow a normal distribution. When $\beta_3=\beta_5=0$, it is the SAR model, which features a spatial lag of the total factor productivity of the manufacturing industry; when $\beta_1=\beta_3=0$, it is the SEM model, which features a spatial lag of the error term; when $\beta_5=0$, it is the SDM model, which features spatial lags of both the total factor productivity of the manufacturing industry and the degree of agglomeration of the logistics industry.

3.2 Acquisition of Research Data and Variables

The data samples for this study are from 284 cities at the prefecture level and above in China from the year 2012 to 2019. (Due to insufficient data and inconsistent statistical standards, the data from the regions referred to as the two sides of the Strait and the three areas, as well as Lhasa, Xigaze, Lyüdü, Nyingchi, Shannan, Haidong, Turpan, Hami, Sansha, Danzhou, Laiwu, Bijie, and Tongren, were excluded.)

The panel data starts from year 2012, as in 2011, The related departments raised the threshold for industrial enterprises from an annual main business income of 5 million yuan to 20 million yuan. This paper utilizes data from industrial enterprises above a certain scale, and to ensure consistency in data quality, the starting point is set at 2012. The original data sources come from China Urban Statistical Yearbook, China Statistical Yearbook, and National Economic and Social Development Bulletin of each city from 2013 to 2020. Missing values are interpolated with averaging methods; when the average data is not applicable, the previous year's data is used directly.

3.2.1 Explained variable

The Malmquist index method, based on data envelopment analysis (DEA), was employed to compute the total factor productivity of the urban manufacturing industry as the explained variable.

The input factor consists of fixed capital investment and labor population, while the output factor is represented by the total industrial output value. The calculation of fixed capital input is based on the perpetual inventory method, with total fixed assets and the increase in fixed assets adjusted to the 2010 base period using the fixed assets investment price index. The labor force population is measured by the number of urban unit manufacturing employees in the city at year-end. The total industrial output value is indicated by the total industrial output value above a designated size for the city, with the industrial producer price index standardized to 2010 as the base period. Due to data availability, these deflators are substituted with those from the province where the city is located.

3.2.2 Explaining variable

In this study, we utilize location entropy *LQ* to quantify the level of agglomeration of explanatory variables in the logistics industry [27], as depicted in equation (3). Here, *Elg* denotes the employment count in transportation, warehousing, and postal services within urban units of city *g*, while *Etg* represents the total employment count within urban units of city *g*. Furthermore, *E* signifies the number of employees in transportation, warehousing, and postal industries across urban units nationwide, with *Et* representing the total national employment count. A higher location entropy indicates a greater concentration of the logistics industry within a specific city.

$$LQ = \frac{\frac{E_{lg}}{E_{tg}}}{\frac{E_l}{E_t}} \quad (3)$$

3.2.3 Control variable

In order to improve the overall interpretability of the model and alleviate the endogenous problems caused by missing variables, this paper introduces seven control variables: economic development level, human resources, scientific research level, financial expenditure, infrastructure level, public service level and market competition degree.

(1) Economic development level (*gdp*), the gross domestic product of each city is divided

by the urban area as the proxy variable;

(2) Human resources (*human*), taking the percentage of the number of students in ordinary colleges and universities in the city to the total population of the region as a proxy variable;

(3) Scientific research level(*science*), may be related to the efficiency of its manufacturing industry. Referring to the study of Yu et al. (2016)[28], the percentage of employees in scientific research, technical services and geological exploration in urban units in the total population of the region is taken as a proxy variable;

(4) Financial expenditure (*pubfinance*), expressed as a percentage of a city's public financial expenditure to its gross regional product;

(5) Infrastructure level *(infra*), taking the road area of the urban district as a proxy variable;

(6) Public service (*pubservice)*, expressed by the number of beds in urban hospitals and health centers;

(7) Market competition degree (*compete*), referring to the study of Wang et al. (2021)[29], uses the ratio of the number of urban industrial enterprises to the gross industrial product as a proxy variable.

The descriptive statistics of variables are shown in Table 1

Table 1. The Descriptive Statistics of Variables

variable	observed value	mean value	standard deviation	minimum value	maximum value
MTFP	2272	1.084	0.164	0.288	2.905
LQ	2272	0.757	0.456	0.062	4.719
gdp	2227	0.190	0.092	0.015	0.691
human	2272	1.897	2.462	0.000	13.110
sciencc	2272	0.250	0.418	0.013	5.243
pubfinance	2272	0.204	0.103	0.044	0.916
infra	2272	0.208	0.263	0.007	2.216
pubserice	2272	21000	18000	1478	180000
compete	2272	0.417	0.213	0.050	1.588

4. Empirical Findings

4.1 Spatial Autocorrelation Analysis of Regional Manufacturing Total Factor Productivity

As the dependent variable in the model, it is necessary to assess the spatial correlation of total factor productivity in the manufacturing industry. If there is a strong spatial correlation, traditional econometric models may overlook spatial effects and result in estimation deviations, thus select a spatial econometric model. The Moran index is a crucial measure of spatial correlation, with its basic definition shown in equation (4), where $S^2=\frac{1}{n}\sum_{i=0}^{n}(Y_i-\overline{Y})^2$ $\overline{Y}=\frac{1}{n}\sum_{i=1}^{a}Y_i$, Y represents the observed value of space unit *i*, and W_{ij} represents the spatial weight matrix. The Moran index ranges from -1 to 1; a value greater than 0 indicates positive spatial correlation between variables while a value less than 0 indicates negative spatial correlation. The larger absolute value of Moran index, the stronger of spatial correlation.

$$Moran's\ I = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n}W_{ij}(Y_i-\overline{Y})}{S^2\sum_{i=1}^{n}\sum_{j=1}^{n}W_{ij}} \quad (4)$$

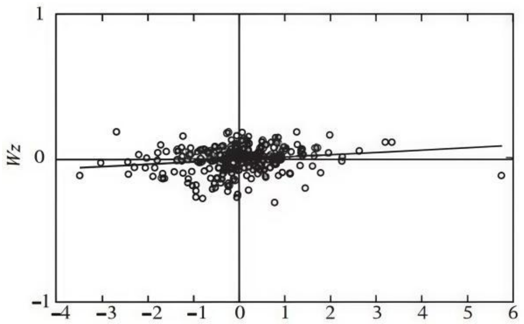
Based on the cross-sectional data of manufacturing total factor productivity from 2012 to 2019, we obtained the corresponding Moran index, and the results are presented in Table 2. The Moreland index of MTFP from 2012 to 2019 exhibited a positive trend, with the index and its corresponding *Z(d)* gradually increasing from 2012, reaching a peak in 2016, and then gradually declining. Most of the years passed the significance test at a level of 1%, indicating a significant spatial positive correlation between total factor productivity in the manufacturing industry. These findings are applicable to spatial metrology models.

Table 2. *MTFP* Moran Index from the Year 2012 to 2019

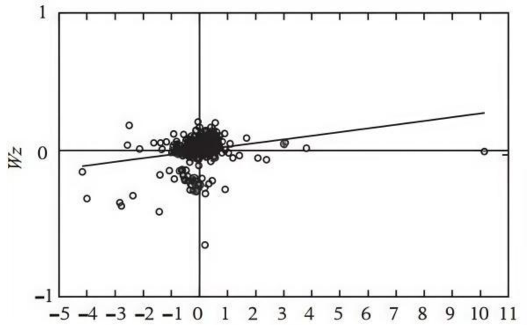
variable	2012	2013	2014	2015	2016	2017	2018	2019
Moran's I	0.016***	0.021***	0.026***	0.066***	0.085***	0.018***	0.016***	0.06***
Z(d)	3.907	4.768	6.230	13.657	17.622	4.310	4.051	1.983
P	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.047

Note: "and *** represent 1% and 5% significance levels, as shown Table 2.

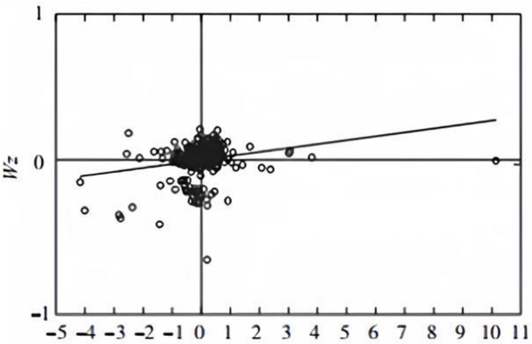
Reanalyze the data to generate a Moran index scatter plot, with the spatial variable *z* as the horizontal axis and its corresponding spatial lag term *Wz* as the vertical axis, where *W* represents the spatial weight matrix. If the scatter plot falls in the first quadrant (HH quadrant), it indicates high levels of both the variable and its neighboring variables; if it falls in the second quadrant (LH quadrant), it suggests a low level for the variable but high levels for its neighboring variables; if it falls in the third quadrant (LL quadrant), it signifies low levels for both the variable and its neighboring variables; if it falls in the fourth quadrant (HL quadrant), it implies a high level for the variable but low levels for its neighboring variables. Figure 1 demonstrates that manufacturing TFA's scattered points from 2012 to 2019 across 284 cities form an evenly distributed fitting line in both first and third quadrants, indicating significant spatial aggregation effects among cities.



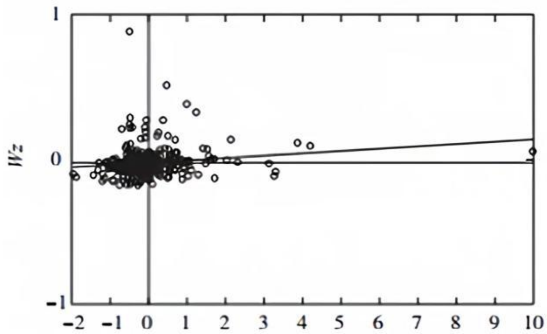
(a) In 2012
Note: Moran Index is 0.016



(b) In 2014
Note: Moran Index is 0.026



(c) In 2016
Note: Moran Index is 0.085



(d) In 2018
Note: Moran Index is 0.016

Figure 1. Moran Scatter Distribution

4.2 Benchmark Regression

This paper employs the Hausman test and the effect model for regression analysis. Additionally, the spatial panel model is selected for analysis based on the results of spatial autocorrelation analysis. A Durbin degradation test was conducted to examine the potential nested relationship between SDM and SAR model or SEM. The test result supports the null hypothesis that SDM can degenerate into SAR model or SEM, indicating that SDM should not be used. Based on the significance level of LMERR, LMLAG, R-LMERR, R-LMLAG and other indicators, regression results from the SAR model were ultimately chosen for further analysis using panel data from 284 cities in China from 2012-2019 as shown in Table 3.

The coefficient of *W* x ln*MTFP* is significantly positive, indicating that cities with high manufacturing TFP will have a positive impact on neighboring cities, with a significant positive spatial spillover effect. The In*LQ* coefficient is positive and passes the significance test at the 5% level, indicating that logistics industry clustering can significantly improve the total factor productivity of the manufacturing industry in the city. The regression results of the control variables show that: (1) The ln*gdp* coefficient is positive, suggesting that higher economic development levels in cities significantly enhance total factor productivity in urban manufacturing industries; (2) The In*human* coefficient is also positive, indicating that human resource levels benefit total factor productivity in urban manufacturing industries. Increasing proportions of individuals with higher education and an adequate labor force as well as improving labor quality can positively impact input and output efficiency within the manufacturing industry and promote overall improvement in total factor productivity. (3) The In*science* coefficient is negative, signifying that an increase in researchers may negatively impact total factor productivity within a city's manufacturing industry. The reason for this is that cities transform from traditional industrial centers to knowledge city, in which research and technology innovation is highly focused and traditional industries are abandoned[30]. (4) ln*pubfinance* coefficient is positive; thus increased government fiscal expenditure for urban development leads to improved total factor productivity within the manufacturing industry. (5) The ln*infra* coefficient is positive, that is, the improvement of regional infrastructure level is beneficial to the development of manufacturing industry and the improvement of manufacturing efficiency. Infrastructure is not only the foundation of industrial development, but also the key to promote the flow of goods and people. Perfect infrastructure will improve the total factor productivity of the manufacturing industry. (6) In*pubservice* coefficient is positive, which means the improvement of public service quality can attract the inflow of labor. The increase of labor population can enhance the vitality and competitiveness of the city, guide the aggregation of various factors, and thus promote the improvement of the total factor productivity of the manufacturing industry[2]. (7) ln*compete* coefficient is negative, indicating that competition among manufacturing enterprises will lead to the decrease of total factor productivity of manufacturing industry. Under the constraint of limited resources, in order to obtain sufficient supply of raw materials and huge consumer groups, there will be non- benign competition behavior among manufacturing enterprises, which will reduce the total factor productivity of manufacturing industry.

Table 3. Benchmark Regression Results

VAR	SAR	SEM	SDM
W x InMTFP	0.817**	0.817**	0.817**
	(0.059)		(0.059)
ln *L*Q	0.028**	0.0127*	0.027**
	(0.014)	(0.014)	(0.014)
W x In*LQ*			(0.146)
In*gdp*	0.096***	0.092***	0.099***
	(0.026)	(0.027)	(0.026)
In*human*	0.114***	0.116***	0.115***
	(0.032)	(0.032)	(0.032)
In*science*	-0.040***	-0.040***	-0.041***
	(0.013)	(0.014)	(0.013)
In*pubfinance*	0.120***	0.110***	0.121 ***
	(0.030)	(0.032)	(0.030)
In*infra*	0.027***	0.027***	0.028***
	(0.015)	(0.015)	(0.015)
ln*pubsertice*	0.112***	0.106***	0.111***
	(0.034)	(0.035)	(0.034)
Incompete	-0.158***	-0.158***	-0.158***
	(0.018)	(0.019)	(0.018)
Individual effect	Contral	Contral	Contral
Time effect	Contral	Contral	Contral
Sample size	2272	2272	2272
R^2	0.102	0.095	0.102

4.3 Robustness Test and Endogeneity Discussion

The benchmark regression results demonstrate that the logistics industry cluster significantly contributes to the enhancement of total factor productivity in the manufacturing industry, and this productivity can generate positive spillover effects on neighboring cities. To further validate the robustness of our findings and assess the explanatory power of our model, a robustness test is conducted by substituting variables and transforming the spatial weight matrix. The endogeneity issue is addressed using the difference-in-differences method.

4.3.1 Substitution variables

Table 4. Robustness Test Results of Replacement Variables

Variables	InlaboreJ	Inefch
Wx Inlstoref	0.851-	
	(0.050)	
Wxlffch		0.862**
		(0.046)
In*LQ*	0.105***	0.024*
	(0.023)	(0.014)
Control variable	Contral	Contral
Individual effect	Contral	Contral
Time effect	Contral	Contral
Sample size	2272	2272
R^2	0.467	0.150

The dependent variable of total factor productivity in manufacturing has been replaced by the rates of labor output and technology change in manufacturing, respectively. Labor productivity in manufacturing (*laboreff*) is defined as the ratio of total industrial output to the number of manufacturing employees in urban units, reflecting the average output level of the urban labor force. Technical efficiency change (*effch*) measures changes in technical efficiency levels within manufacturing. The regression results from the Spatial Autoregressive (SAR) model are presented in Table 4. These results indicate that all coefficients for *InLQ* are positive, suggesting that a strong logistics industry cluster has a consistent positive impact on manufacturing efficiency. Additionally, both spatial lag coefficients for *laboreff* and *effch* are positive, indicating a positive spatial spillover effect where high manufacturing efficiency in one city helps improve neighboring cities' efficiencies. When using labor productivity as the dependent variable, *InLQ* passes significance tests at the 1% level and both spatial lag terms also pass at this level. When using technical efficiency change as the dependent variable, *InLQ* passes significance tests at the 10% level. Overall, robustness testing after variable replacement aligns with expectations.

4.3.2 Transform the space weight matrix

In this section, the spatial weights are replaced by 0-1 matrix and economic weight matrix respectively. The regression results of SAR model, SEM and SDM under different matrix forms are presented in Table 5. The 0-1 matrix indicates adjacency between two cities, with a corresponding element of 1 if they are adjacent, and 0 otherwise. The economic weight matrix is based on the research of Wang and Wu (2020)[31], as shown in equation (5), where X represents the average value of actual per capita GDP for the region from 2012 to 2019 (adjusted to 2010). A smaller gap in per capita GDP between two regions leads to a greater weight for economic distance; conversely, a larger gap results in a smaller weight for economic distance.

$$W_{ij} = \begin{cases} \frac{1}{|X_i - X_j|}, i \neq j \\ 0, \ i = j \end{cases} \quad (5)$$

After controlling for individual and time effects, the regression results indicate that the coefficients of *W x* ln*MTFP* and In*LQ* are both positive following the transformation of the spatial weight matrix. This is consistent with the benchmark model, whether using a 0-1 matrix or an economic distance matrix, suggesting that the logistics industry cluster can enhance total factor productivity in urban manufacturing. Furthermore, there is evidence of positive spatial spillover effects on manufacturing total factor productivity. The coefficient for *W* x ln*MTFP* is significant at the 1% level, while In*LQ* has passed significance testing at the 5% level, aligning with expectations. Therefore, it can be concluded that both the promotion effect of logistics industry clusters on manufacturing total factor productivity and its spatial spillover effects are robust.

Table 5. Robustness Test Results of Transformation Space Matrix

Variables	0-1 Matrix			Economic Distance Matrix		
	SAR	SEM	SDM	SAR	SEM	SDM
W x In*MTFP*	0.252***		0.251***	0.030***		0.029***
	(0.027)		(0.027)	(0.039)		(0.039)
ln*LQ*	0.029***	0.027***	0.029***	0.029***	0.029***	0.029***
	(0.013)	(0.013)	(0.014)	(0.014)	(0.014)	(0.014)
W x In*LQ*			0.018			0.015
			(0.028)			(0.041)
Control variable	Contral	Contral	Contral	Contral	Contral	Contral
Individual effect	Contral	Contral	Contral	Contral	Contral	Contral
Time effect	Contral	Contral	Contral	Contral	Contral	Contral
Sample Size	2272	2272	2272	2272	2272	2272
R^2	0.106	0.102	0.107	0.102	0.102	0.102

4.3.3 Discussion of endogeneity

In reference to the research conducted by Wang and Tan (2019)[32], and Yang et al. (2022)[33], which utilized the DID method to investigate the impact of logistics policy pilots on enterprise investment and manufacturing efficiency, this paper employs a multi-period spatial DID model to address endogeneity issues. The measurement model is presented in equations (6) and (7). The objective of piloting logistics service standardization is to enhance the standardized operation and service level of urban logistics hubs, facilities, and equipment[32], thereby fostering coordinated development within regional logistics industries and enhancing their capacity to serve the manufacturing sector. The policy consists of three trials: the first pilot was initiated in October 2014 in Beijing, Shanghai, and Guangzhou; the second pilot was launched in July 2015 across 11 cities including Tianjin, Shijiazhuang, and Nanjing; while the third pilot commenced in July 2016 spanning 19 cities such as Wuhan, Xiamen, and Hefei - encompassing a total of 33 prefecture-level or higher cities. Given its exogeneity, it is suitable for application within a DID model framework. Treating the pilot city as an experimental group while non-pilot city serves as control group; if city *i* implements logistic service standardization pilot policy in year *t* then assign a value of 1 for current year onwards; otherwise assign a value of 0. Other variable definitions remain consistent with those outlined in our benchmark model.

$$\ln MTFP_{it}=\alpha+\beta_1 W\ln MTFP_{it}+\beta_2 treat_{it}+\beta_3 Wtreat_{it}+\beta_4\ln X_{it}+\varepsilon_{it} \quad (6)$$

$$\varepsilon_{it}=\beta_5 W\varepsilon_{it}+v_{it} \quad (7)$$

Following the parallel trend test, the empirical findings are presented in Table 6. The *treat* coefficient exhibits a positive value, indicating that the standardization pilot of logistics services has enhanced the total factor productivity of urban manufacturing industry. This coefficient has demonstrated statistical significance at the 10% level under SAR model and SEM. The empirical results indicate that the influence of the logistics industry on the total factor productivity of manufacturing industry is exogenous to some extent, thereby mitigating endogeneity issues stemming from reverse causality.

Table 6. Results of Endogeneity Discussion

Variables	SAR	SEM	SDM
W x In*MTFP*	0854***		0854***
	(0.049)		(0.049)
treat	0.035*	0.032*	0.029*
W x *treat*	(0.019)	(0.019)	(0.019)
Control variable			0.315 (0.202)
Individual effect	Contral Contral	Contral Contral	Contral Contral
Time effect	Contral	Contral	Contral
Sample size	2272	2272	2272
R^2	0.070	0.071	0.071

4.3.4 Heterogeneity analysis

The impact of logistics industry clusters on the total factor productivity of the manufacturing industry may vary based on the level of urban development in different types of cities.

4.3.4.1 Empirical analysis of different regional distribution

The available data from 284 cities at the prefecture level and above were categorized into three regions: eastern, central, and western. The SAR panel model was employed for regression analysis, with the results presented in Table 7.

By comparing the regression results of the eastern region with the benchmark model, it is evident that the ln*LQ* coefficient of the core explanatory variable is significantly larger at the 1% level. This indicates a stronger promoting effect of logistics industry clusters on the total factor productivity of the manufacturing industry in the eastern region compared to the national average. The high level of economic development and robust infrastructure in the eastern region facilitate an enhanced impact of logistics industry clusters on total factor productivity within the manufacturing industry. To further advance total factor productivity in urban manufacturing, cities in this region should focus on enhancing competitiveness within their logistics industry clusters, leveraging their role in facilitating efficient flow of manufactured goods, attracting additional logistics enterprises into these clusters, and ultimately improving overall efficiency within their manufacturing industries.

In western China, we observe a positive ln*LQ* *c*oefficient which has passed significance testing at a 5% level. This suggests that logistics industry clusters have a positive influence on total factor productivity within western China's manufacturing industry. However, this effect is not as pronounced as observed in eastern China due to several factors: Firstly, while logistic cluster levels are not low in western China based on our measurement using location entropy for proportion of employed population engaged in logistics activities; however, given its smaller overall population size relative to eastern China, there may be limitations related to scale effects impacting logistical cluster performance. Secondly, the current level of manufacturing in the western region remains relatively low, with a significant disparity between quantity and quality. Consequently, there is an insufficient demand for high-quality logistics services. As manufacturing enterprises in the western

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region continue to develop, the role of the logistics industry in enhancing the total factor productivity of the manufacturing sector will gradually become more prominent.

The regression results for the central region indicate that the ln*LQ* coefficient of the core variable is statistically significant at the 10% level, showing a negative impact of logistics industry clustering on the total factor productivity of the manufacturing industry. This can be attributed to several factors: Firstly, resource-rich provinces such as Shanxi and Henan in the central region are currently undergoing a period of transformation and upgrading in their traditional manufacturing industries, leading to short-term efficiency losses[16]. However, in the long term, it is expected that the impact of logistics industry clustering in central China on the total factor productivity of the manufacturing industry will exhibit a positive trend. Secondly, the overall level of logistics industry clusters in the central region is relatively low, with fewer regional logistics center cities. Due to this low degree of logistics industry clustering, logistics services lack economies of scale, making it difficult to provide cost-effective and high-quality services. This also limits the impact on manufacturing efficiency. However, the industrial foundation of cities in the central region is strong and has significant development potential under national strategies such as "Rise of Central China" and "Revitalization of Northeast China". To enhance total factor productivity in manufacturing industries, cities in the central region should focus on developing their own logistics industry clusters, enabling logistic enterprises to expand and achieve economies of scale while providing crucial support for urban manufacturing.

Table 7. Results of Urban Regression in Different Regions

Variables	Eastern Regions	Central Regions	Western Regions
W x In*MTFP*	0.816***	0.435***	0.199***
	(0.056)	(0.127)	(0.184)
lnLQ	0.118***	-0.036***	0.058***
	(0.027)	(0.020)	(0.025)
Control variable	Contral	Contral	Contral
Individual effect	Contral		
Time effect	Contral	Contral	Contral
Sample size	800	800	672
R_2	0.176	0.130	0.134

4.3.4.2 Empirical analysis of different population size of a city

The population size of a city is indicative of the level of development to some extent. Different levels of urban development result in varying impacts of logistics industry clusters on the total factor productivity of the manufacturing industry. In accordance with the 2014 Notice from The related departments regarding adjustments to city size classification standards (Guofa [2014) No. 51), cities are categorized into five groups: small cities, medium cities, large cities, mega cities and super cities. The regression results for these categories are presented in Table 8.

Table 8. Regression Results of Cities of Different Sizes

Variables	Super cities	Mega cities	Large cities	Medium cities	Small cities
W x ln*MTFP*	-0.134	-0.523*	0.649***	0.577***	0.094
	(0.254)	(0.279)	(0.103)	(0.113)	(0160)
In*LQ*	0.405	0.275****	-0.003	0.030	0.121**
	(0.301)	(0.063)	(0.016)	(0.027)	(0.051)
Contral variables	Contral	Contral	Contral	Contral	Contral
Individual effect	Contral	Contral	Contral	Contral	Contral
Time effect	Contral	Contral	Contral	Contral	Contral
Samples	32	88	1160	696	296
R^2	0.535	0.422	0.125	0.123	0.191

The ln*LQ* coefficients are predominantly positive, with the exception of large cities. This suggests that the development of logistics industry clusters in both megacities and small cities can significantly enhance the total factor productivity of the manufacturing industry in their respective locations. However, this impact is not significant for megacities, big cities, and medium-sized cities. The concentration of logistics enterprises in large cities can create a stronger pull for high-quality manufacturing enterprises at an urban level, thereby promoting improvements in the total factor productivity of urban manufacturing industries. On the other hand, industrial development in small-scale cities is constrained by factors such as transportation and logistics; however, government-guided agglomeration of logistics enterprises can notably boost the total factor productivity of their manufacturing industries. These findings indicate that the clustering of producer services like the logistics industry is influenced by both enterprise demand and government initiatives.[17] The coefficient of *W* x ln*MTFP* is negative in megacities and positive in medium-sized and small cities. However, the spatial spillover effect is not significant due to the small number and scattered distribution of megacities and small cities. The negative spatial spillover effect among megacities has been found to be statistically significant at the 10% level, possibly attributed to their competition for high-quality enterprise resources rather than cooperation[34]. Conversely, a positive spillover effect exists between large and medium-sized cities, contributing to the improvement of manufacturing TFP levels in neighboring cities.

4.3.4.3 Empirical analysis of different industrial stages

According to Jia Baijun et al. (2011) [35], during the early stage of industrialization, the primary industry accounted for over 20% of the GDP, while the secondary industry experienced rapid growth and the tertiary industry grew at a slower pace. In the middle stage of industrialization, the primary industry's share dropped to less than 20%, with the secondary industry becoming the largest contributor to GDP structure. As industrialization progressed further, the primary industry's share decreased to less than 10%, and the secondary industry reached its peak in contribution to GDP. This study categorizes 284 cities into three stages—early industrialization, middle industrialization, and late industrialization, based on each city's GDP composition across industries in 2019. The findings are presented in Table 9.

According to the core explanatory variable 1n*LQ*, in the early stage of industrialization, the degree of logistics industry cluster has a negative impact on the total factor productivity of manufacturing industry, while in the middle and later stages of industrialization, the influence of logistics industry cluster on the total factor productivity of manufacturing industry changes from negative to positive. Moreover, the positive impact of logistics industry clusters in cities in the late industrialization period on the total factor productivity of manufacturing industry has passed the significance test at the 5% level. The empirical results show that with the change of urban industrial structure, the proportion of manufacturing industry has gradually increased, and the logistics industry agglomeration can better promote the improvement of the total factor productivity of manufacturing industry. The main reasons are as follows:

First, in the later stage of industrialization, the number of manufacturing enterprises in the city increases, and the enterprises in the logistics cluster can serve a larger number of manufacturing enterprises. This trend will bring scale effect, which is convenient for logistics enterprises to provide more efficient services. Second, industrialization is accompanied by the improvement of urban infrastructure, business environment and urban vitality [36]. Under the influence of multiple factors, logistics industry clusters can better promote the total factor productivity of manufacturing industry. Third, in the process of industrialization, the proportion of the tertiary industry in GDP is constantly increasing. As a major part of the service industry, the logistics industry itself is also constantly developing and expanding. The logistics industry can make full use of advanced information technology, good transportation equipment and professional talents to promote the total factor productivity of the manufacturing industry.

Table 9. Regression Results of Cities with Different Industrial Stages

Variables	early industrialization	middle industrialization	late industrialization
W x ln*MTFP*	0.022	0.078	0.742***
	(0155)	(0.198)	(0.077)
ln*LQ*	-0.007	0037	0.029***
	(0.068)	(0.025)	(0.016)
Contral variables	Contral	Contral	Contral
Individual effect	Contral	Contral	Contral
Time effect	Contral	Contral	Contral
Samples	184	812	1160
R^2	0.217	0.090	0.147

4.3.5 Mechanism test

Based on the theoretical mechanism analysis above, this part will test the impact mechanism of logistics industry cluster on the total factor productivity of manufacturing industry from the two dimensions of specialized division of labor and industrial collaboration. According to the testing method of intermediary mechanism proposed by Baron & Kenny (1986)[37], this paper is divided into two parts on the basis of benchmark regression. The first step is to test the impact of logistics industry clusters on the specialization of logistics and the synergy of logistics manufacturing industry. The second step is to examine the effects of logistics specialization and logistics manufacturing industry collaboration on the total factor productivity of the manufacturing industry. The model is shown in formula (8) and (9), MV is the intermediary mechanism variable, and the meanings of other variables are consistent with the benchmark model.

$$\ln MV_{it}=\alpha+\beta_1 lnLQ_{it}+\beta_2 lnXit+\varepsilon_{it} \quad (8)$$

$$\ln MTFP_{it}=\alpha+\beta_1 W\ln MTFP_{it}+\beta_2\ln LQ_{it}+\beta_3 WInLQ_{it}+\beta_4 lnMV_{it}+\beta_5 lnX_{it}+\varepsilon_{it} \quad (9)$$

Based on the research by Zhang Wenxi et al. (2019)[38], the specialization of the logistics industry is quantified as $ELQ_i = S_{ij} - S_j$, where S_{ij} represents the proportion of the employed population in producer services such as transportation, storage, and postal industries in city *i,* and *S* represents the proportion of employed population in these producer services at a national level. Following Gu Naihua's definition of producer services (2010)[39], this category includes transportation, warehousing and postal industry; information transmission, software and information technology service industry; financial industry; real estate industry; leasing and business service industry; as well as scientific research and technology service industry.

To assess the level of collaborative development between the logistics and manufacturing industries, this study adopts the inter-industry collaborative aggregation degree formula from Zhang et al. (2017)[40], as shown in equation (10). Here, LQ_i represents the logistics industry aggregation index and LQ_j represents the manufacturing industry aggregation index, both derived from location entropy. COR_{ij} denotes the synergistic aggregation index of the logistics and manufacturing industries. A higher index indicates a greater degree of synergy between these two industries, while a lower index suggests a lesser degree of synergy.

$$COR_{ij}=\left(1-\frac{|LQ_i-LQ_j|}{LQ_i+LQ_j}\right)+|LQ_i-LQ_j| \quad (10)$$

The results presented in Table 10 demonstrate that the coefficient of ln*LQ* is 0.045, passing the significance test at the 1% level. This indicates that the agglomeration of urban logistics industry significantly enhances the specialization level of the logistics industry. Additionally, a significant coefficient of ln*ELQ* at the 1% level suggests that improved specialization within the logistics industry has contributed to enhanced operational efficiency for urban manufacturing enterprises and increased total factor productivity within the manufacturing industry. Furthermore, after introducing mediating variables, there is a notable decrease in significance levels of coefficients, providing further evidence for the existence of mediating effects.

The results of the industrial collaboration mechanism demonstrate that the coefficient of ln*LQ* is 0.278, which also passes the significance test at a 1% level, indicating that the development of logistics industry clusters significantly promotes the integration and collaborative development of both logistics and manufacturing industries. The positive coefficient of ln*COR* suggests that logistics industry clusters have notably enhanced the total factor productivity of the manufacturing industry, with a significant decrease in significance level for this coefficient. The intermediary mechanism tests industrial specialization and synergy, confirming hypotheses H2 and H3 proposed above: namely, that logistic enterprise agglomeration forms a foundation for industrial cluster specialization levels, guides deep integration between manufacturing and logistics industries, thereby promoting cost reduction and efficiency improvements in logistics services to better meet manufacturing enterprises' logistical needs. Ultimately, this enhances overall total factor productivity within manufacturing.

Table 10. Results of Mediation Mechanism Test

Variables	Specialized division of labor		Industrial collaboration	
	In*ELQ*	In*MTFP*	In*COR*	Im*MTFP*
W x InMTFP	0.861***			0.824***
		(0.041)		(0.057)
In*LQ*	0.045***	-0.002***	0.278***	-0.044***
	(0.002)	(0.016)	(0.005)	(0.032)
In*ELQ*		0.511***		

		(0.187)		
In*COR*				0.442***
				(0.058)
Contral Variables	Contral	Contral	Contral	Contral
Sample Size	2272	2272	2272	2272
R_2	0.426	0.013	0.605	0.122

5. Conclusion and Policy Recommendation

This study focuses on 284 Chinese cities and employs a spatial econometric model to examine the influence of logistics industry clusters on the total factor productivity of the manufacturing industry with heterogeneity analysis and mechanism testing method.

The conclusion is as follows: (1) The logistics industry cluster can significantly enhance the total factor productivity of the manufacturing industry in the city. The robustness test demonstrates that the conclusion aligns with expectations. (2) Heterogeneity analysis results indicate that for the eastern and western regions, the logistics industry cluster has a positive impact on the total factor productivity of the manufacturing industry, while cities located in the central region have a certain negative impact, mainly due to transformation and upgrading of the manufacturing industry in central cities and a low degree of logistics industry clustering; In megacities and small cities, logistics industry clusters can significantly promote total factor productivity in manufacturing industries, while in other cities, their effect is not significant. With urban industrial stage evolution, the impact of logistics industry clusters on manufacturing industries has changed from negative to positive. (3) Mechanism analysis results show that development of logistic clusters will improve total factor productivity of urban manufacturing industries by enhancing specialization levels within logistic industries and cooperation degrees within logistic-manufacturing industries.

Based on the above research conclusions, this paper puts forward the following policy suggestions for the development of urban logistics and manufacturing industry:

Firstly, develop logistics industry clusters and guide the aggregation of logistics enterprises based on local conditions. The development of logistics industrial clusters and the facilitation of logistics enterprises can enhance the overall factor productivity of the manufacturing industry in cities. However, due to variations in geographical location, scale, and developmental stage among cities, the impact of logistics industrial clusters on total factor productivity within the manufacturing industry is heterogeneous; therefore, it is essential to implement measures tailored to each city's specific circumstances. From a regional perspective, eastern and western cities' logistics industry clusters play a more significant role in enhancing total factor productivity within the manufacturing industry. Central region cities should transform and upgrade their manufacturing industries. In terms of city size, megacities and small cities gain substantial benefits from developing their own logistic clusters; however, for other scales of cities, the effect on improving total factor productivity within the manufacturing industry is not as pronounced. Regarding industrial stages, late-stage industrialization cities should actively promote quality and efficiency improvements in manufacturing through developing logistic industrial clusters. Early-stage industrialization cities need to focus on increasing secondary and tertiary industries' proportion while promoting industrial upgrading as their primary task. Middle-stage industrialization cities must enhance urban vitality and ensure market players' enthusiasm to effectively boost goods circulation efficiency.

Secondly, enhance the level of specialization in the logistics industry and drive the integrated development of the logistics manufacturing sector. The results of the mechanism test indicate that the development of logistics industrial clusters promotes an increase in specialization within these clusters and facilitates collaborative development within the manufacturing industry, thereby enhancing total factor productivity within urban manufacturing. Cities should not solely focus on expanding industrial scale or increasing the number of enterprises; rather, they should actively guide professional talent and specialized technologies to converge and form a hub for logistical industry development, which will have positive spillover effects on urban areas. Furthermore, heightened specialization in the logistics industry can compel upgrades within manufacturing sectors and leverage economies of scale to deliver

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high-quality services to manufacturing enterprises. Regarding industrial layout within cities, spatial connections between logistic and manufacturing industries must be strengthened to support improvements in total factor productivity for manufacturers.

Thirdly, establish a pattern of industrial complementarity and collaborative development and fully leverage the spillover effect of manufacturing total factor productivity. Cities should capitalize on the spatial spillover effect of neighboring cities with high manufacturing TFP to enhance their own manufacturing efficiency. To better utilize the spatial spillover effect of manufacturing total factor productivity, measures can be implemented from three aspects: Firstly, develop industries that can promote integration with neighboring cities. Secondly, make policies that can promote industrial coordination with neighboring cities. In this way, it can ensure comprehensive discussions on industrial development and build emerging industrial clusters; Lastly, improve intercity transportation infrastructure. It's necessary to facilitate smoother flow of people, vehicles and materials between cities, promoting factor mobility and thereby enhancing the quality of industrial development. For the satellite cities, they should take actions to better utilize the spillover effect among industrial transfer and personnel flow. In this way, they can cultivate their own unique industrial advantages and seize important opportunities for development in manufacturing.

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